

UYGULAMA KONULARI

THE POTENTIAL OF USING SUNFLOWER OIL AS A FUEL FOR DIESEL ENGINES

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Abstract: The effect of sunflower oil fuel and sunflower oil/diesel fuel mixture, which are heated and over pressured before injection, to a turbulence chamber diesel engine performance was investigated in this paper. Results show those, from the performance viewpoint, both sunflower oil and sunflower oil/diesel fuel mixture are promising alternatives as diesel fuel turbulence chamber diesel engines. Because of its high viscosity, drying with time and thickening in cold conditions, sunflower oil still has problems such as flow and atomization.

(Key words: Alternative fuels, sunflower oil fuel, vegetable oil fuels)

AYÇİÇEĞİ YAĞININ DIESEL MOTORLARINDA YAKIT OLARAK KULLANILABİLME POTANSİYELİ

Özet: Bu araştırmada, pompa ve enjektör öncesinde ısıtılan ve enjeksiyon basıncı artırılan ayçiçek yağı ve ayçiçek yağı/diesel yakıtı karışımlarının, türbülans odalı bir diesel motorunun performansına etkileri incelenmiştir. Deney sonuçları, performans açısından, ayçiçek yağının ve ayçiçek yağı/diesel yakıtı karışımlarının, ön odalı diesel motor yakıtı olarak kullanılabilir olduğunu; ancak, ayçiçek yağının vizkozitesinin yüksek oluşu, zamanla kuruma ve düşük sıcaklıklarda katılaşma eğilimi nedeniyle, çözümlenmesi gereken, akış ve atomizasyon gibi problemleri bulunduğunu göstermektedir.

(Anahtar kelimeler: Alternatif yakıtlar, ayçiçek yağı yakıt, bitkisel yağ yakıtlar)

1. INTRODUCTION

The idea of using vegetable oils as fuel for diesel engines is not new. Rudolph Diesel used peanut oil to fuel one of his engines at the Paris Exposition of 1900. Recent petroleum crises, rapidly increasing prices and uncertainties concerning petroleum availability let the scientists work on alternative fuel sources so, vegetable fuel studies become current among various investigations. Results show that, if vegetable oils used as diesel engine fuel, it has the potential of supplying some of the energy needed by this area. The most important advantage of vegetable oils is that they are renewable energy sources compared to the limited resources of petroleum. Vegetable oils show promise of providing all the liquid fuel needed on a typical farm by diverting 10% or less of the total acreage to fuel production [14]. The extraction and procession of vegetable oil are a

simple low energy process that makes use of equipment not unlike that which farmers are already familiar.

Among the vegetable oil seeds that can be grown as domestic field crops, sunflower seed is the major production of Turkey, Table 1 [2]. Sunflower cultivation of Turkey has started to grow and production has increased rapidly since 1930. However, crop yield is inconsistent according to harvest area, climatic conditions, etc. Turkey is one of the major sunflower producer of the world. By the end of 1988, it had 6.18% of total world production areas [24]. As seen in Table 2, together with sunflower seed, refined sunflower oil production has also increased about 124%, from 1986 to 1992, [3].

The objectives of this study were to comparatively evaluate the performance and exhaust

Table 1. Harvest areas, yields and production levels of some oil seeds of Turkey in 1992 [2].

Crops	Area harvested, Ha	Yield, kg/ha	Production, ton
Sunflower	613,000	1,564	950,000
Rapeseed	500	2,000	1,000
Cottonseed	-	1,420	905,350
Soyabean	46,000	2,065	95,000
Sesame	83,000	411	34,000

Table 2. Annual production quantities and number of plants for some vegetable oils [3].

Vegetable oil	Years -->	1986	1987	1988	1989	1990	1991	1992
Sunflower oil	No of plants*	32	34	35	37	36	46	38
	Yield, ton	201,787	249,357	256,547	355,611	391,391	455,546	452,220
Olive oil	No of plants*	10	8	10	6	5	8	9
	Yield, ton	56,026	57,398	41,764	45,414	18,026	12,294	10,282
Cottonseed oil	No of plants*	9	10	10	10	9	9	8
	Yield, ton	31,389	24,715	27,244	28,657	26,997	22,470	12,640

* Number of plants that employ more than 50 persons.

emissions of a diesel engine using 100% refined sunflower oil and 50/50 v/v sunflower oil/diesel fuel mixture. Because of its warmer operation, a turbulence chamber diesel engine was selected for the tests and the injection pressures were increased to improve the atomization problem during injection. Because of its high viscosity, sunflower oil was heated before the fuel pump and before the injectors to minimize its resistance to flow.

2. CHEMICAL COMPOSITION AND COMBUSTION

Vegetable oils have different chemical structures than diesel fuel. Diesel fuel contains hydrocarbons and atoms are arranged in normal or branched-chain structures. The normal structure is preferred for better ignition quality. Diesel fuel can

contain both saturated and unsaturated hydrocarbons, but the latter are not present in large enough amounts to make fuel oxidation problem. Vegetable oils are esters of fatty acids ($R-COOH$), which linked with a three bonded alcohol glycerine ($C_3H_5(OH)_3$, 1,2,3 trihydroxypropan) and called *glicerids*. If the three bonds of glycerine were occupied by fatty acids, then its called *triglyceride* [10]. A structural formula of a typical sunflower oil and its component parts illustrated in Figure 1. The type and quantity of unsaturated fatty acids in triglyceride define the characteristics of vegetable oil. Table 3 shows mean mass ratio of fatty acids of sunflower oil.

Table 3. Mass ratio of fatty acids of sunflower oil.

	Palmitic, 16:0*	Stearic, 18:0	Oleic, 18:1	Linoleic, 18:2
Tahir	6	4	18.5	71
Goering	6.08	3.26	16.93	73.73
Köksal	7	4	25	63
Average	6.36	3.75	20.14	69.24

* Number of carbon and unsaturated bonds.

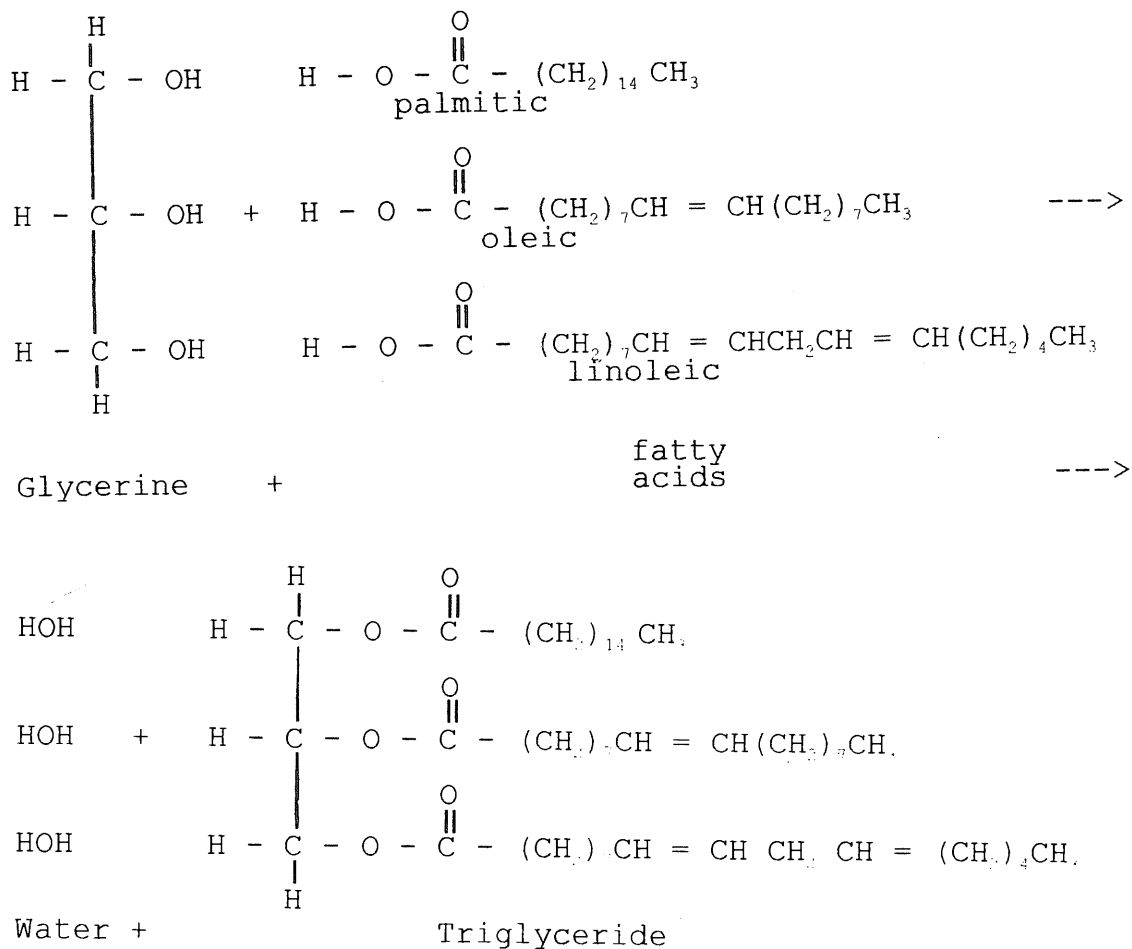
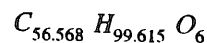


Figure 1. Structural formula of a typical sunflower oil.

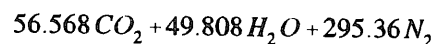
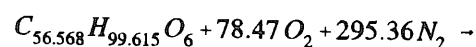
From the Table;				
fatty ratio	mass ratio	molecular mass	mole acid	
Palmitic	6.36	256	0.0248	$C_3H_5(OH)_3 + 0.208(C_{16}H_{32}O_2) + 0.111(C_{18}H_{36}O_2)$
Stearic	3.75	284	0.0132	$+ 0.601(C_{18}H_{34}O_2) + 2.079(C_{18}H_{32}O_2) \rightarrow$
Oleic	20.14	282	0.0715	$C_3H_5 + 0.208(C_{16}H_{31}O_2) + 0.111(C_{18}H_{35}O_2)$
Linoleic	69.24	280	0.2473	$+ 0.601(C_{18}H_{33}O_2) + 2.079(C_{18}H_{31}O_2) + 3H_2O$
Total			0.3568	

It means that, 1 mole glycerine bonds with;
 0.208 mole palmitic,
 0.111 mole stearic,
 0.601 mole oleic, and
 0.079 mole linoleic fatty acids. Chemical equation then becomes;

from the equation above, number of total carbon, hydrogen and oxygen can be summed up and approximate sunflower equation becomes;



and chemically correct combustion equation can be written that;



and air/fuel mass ratio becomes;

$$A/F = \frac{373.83 \cdot 28.697}{56.568 \cdot 12.011 + 99.615 \cdot 1.008 + 6 \cdot 15.999}$$

$$= 12.36/1 \text{ kg air/kg fuel}$$

4. EXPERIMENT AND TEST PROCEDURE

Tests were conducted at the Automotive Laboratory of Gazi University, Technical Education Faculty. Diesel fuel (motorin), refined-winterized sunflower oil (brand: Biryag) and 50/50 v/v sunflower oil/diesel fuel mixture were used as test fuels. The fuels were purchased from commercial market.

Because of its warmer operation, a four cylinder BMC Leyland turbulence chamber tractor diesel engine were selected for the tests and the injection pressures were increased to improve the atomization problem during injection. Technical specifications of test engine are summarized in Table 4.

Table 4. Technical specifications of the test engine [5].

Type	15 T
Year	1975
Number of cylinders	4
Compression ratio	23:1
Cylinder diameter	73.012 - 73.05 mm
Stroke	88.9 mm
Clearance volume	1489 cm ³
Idle speed	600-650 1/min
Maximum speed	2750 1/min
Maximum loaded speed	2500 1/min
Torque	8.74 mkg at 1750 1/min
Fuel injection pump	CAV-DPA 3247E090 with hydraulic governor
Injectors	CAV-BDN.O.SPL.6389
Injector opening pressure	135 atm.

Because of its high viscosity, sunflower oil was heated before the fuel pump and before injectors to minimize its resistance to flow. Thermostatically controlled electrical heaters were used for this purpose. The temperatures were about 120°C - 110°C for both region. Because similar diesel fuel spray at 175 kg/cm² injection pressure were obtained at 250 kg/cm² with sunflower oil,

injector opening pressures were readjusted to the latter value.

Tests were held on a laboratory test bench which consisted of a hydraulic dynamometer (Go-Power), a cooling tower, an exhaust gas aspiration system and engine mounting elements, as shown in Figure 2. Engine fuel system was modified by adding two fuelmeters and one 3-way, hand operated control valve which allowed rapid switching between the standard diesel fuel and the test fuel. Fuel return line of the engine was connected back to the fuelmeter. Air consumptions were measured with Go-Power M-5000 flowmeter and exhaust emission values were measured with Gaco-Sn gas analyser.

The parameters obtained from full load and variable speed performance tests. The engine was operated on diesel fuel first and than on sunflower and diesel fuel/sunflower oil mixture with a 20 min running in period between each operation. After sunflower and diesel fuel/sunflower oil mixture tests, the engine was run about 20 min at idle speed to replace the test fuel in the system again with diesel fuel. The test matrix consisted of 7-8 speeds for each fuel operation. All engine performance data were corrected to the standard atmospheric conditions and calculations were made as the example given below (engine running with diesel fuel at 1275 1/min):

a) The power correction factor is (according to TS 1231):

$$K_d = f_a^{f_m}$$

where;

$$f_a = \left(\frac{99}{P_a} \right) \cdot \left(\frac{T_a}{298} \right)^{0.7}$$

$$f_m = 0.036 \cdot q_c - 1.14, \quad q_c = q/r$$

Since $q \approx 1$, $r = 1$, $q_c = 1$. Therefore,

$$f_m = 0.036 - 1.14 = -1.104$$

$$f_a = \left(\frac{99}{99.86} \right) \cdot \left(\frac{299.8}{298} \right)^{0.7} = 0.996$$

and

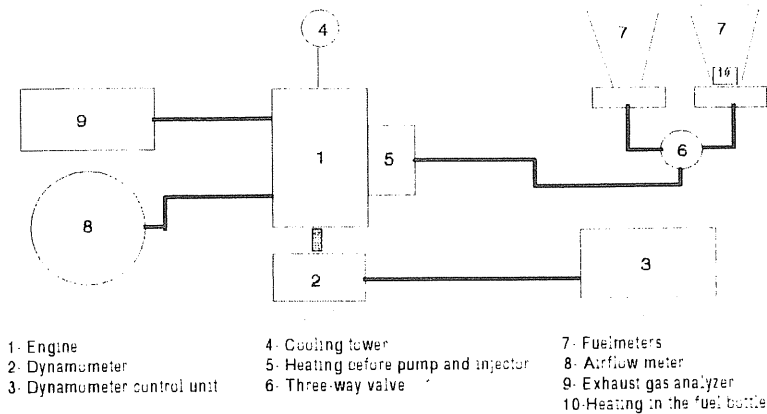


Figure 2. Schematic layout of the test system.

$$K_d = 0.996^{-1.104} = 1.0044$$

b) Corrected torque:

$$M_{el} = 53.96 \cdot 1.044 = 54.20 \text{ Nm}$$

c) Corrected power:

$$P_{el} = \frac{M_{el} \cdot n}{9549} = \frac{54.20 \cdot 1275}{9549} = 7.24 \text{ kW}$$

d) Specific fuel consumption:

$$f_{el} = \frac{F_{el}}{P_{el}} \cdot 10^3 = \frac{2.53}{7.24} \cdot 10^3 = 349.4 \text{ g/kWh}$$

5. RESULTS AND DISCUSSION

Performance

The variation of engine torque in relation with the engine speed for diesel fuel, sunflower oil

and diesel fuel/sunflower oil mixture are shown in Fig 3. Observed maximum torques were about 63-65 Nm at about 1800 1/min for each fuel. At lower speeds, effective torques with sunflower oil were slightly higher than with diesel fuel. However, at higher speeds, diesel fuel was more advantageous. At higher speeds than the maximum torque speed, torque with sunflower oil was decreased rapidly and become 4.91 Nm at 2160 1/min. This may be due to higher viscosity of sunflower oil. Because of its higher viscosity, back leak from transfer pump decreases and output pressure increases with engine speed. Increased feed pressure forces fuel control valve of hydraulic governor to the governor spring and fuel flow shot down starting in lower engine speeds. This result is supported by the actual condition that when the blades of transfer pumps worn, maximum speed of the engine increases. The observed torque values with the mixture were between the values with sunflower and with diesel fuel.

The variation of engine power in relation with the engine speed for diesel fuel, sunflower oil

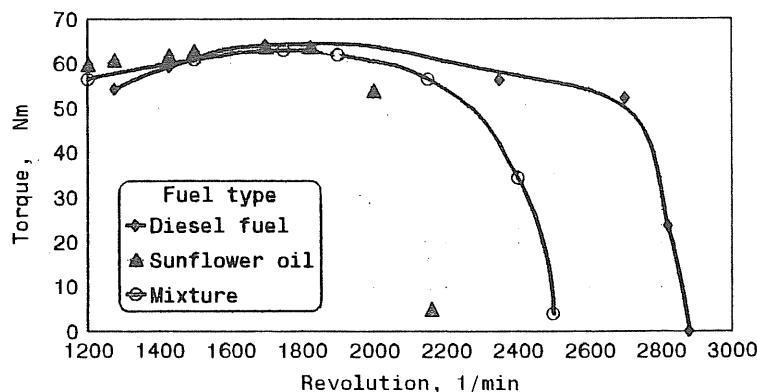


Figure 3. The variation of engine torque in relation with the engine speed.

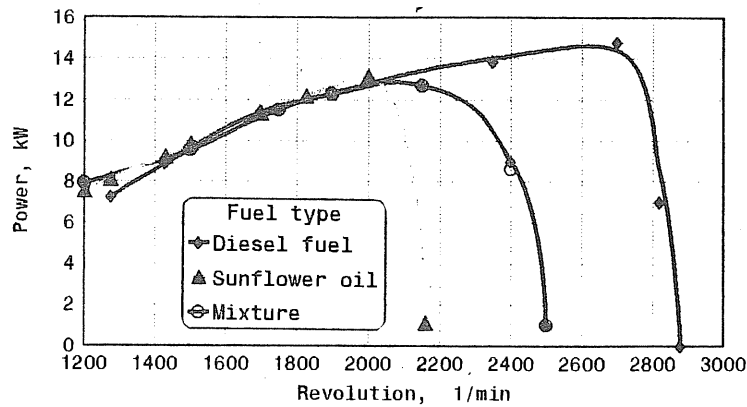


Figure 4. The variation of engine power in relation with the engine speed.

and diesel fuel/sunflower oil mixture are shown in Fig 4. At 1200-2000 1/min interval, the difference between power curves is negligible. However, above 2000 1/min, power with sunflower oil decreased more rapidly than with diesel fuel and became 1.1 kW at 2160 1/min. Like the torque curves, power curve with the mixture lay between sunflower oil and diesel fuel curves. Maximum measured power values were 13.14 kW at 2000 1/min with sunflower oil 14.77 kW at 2700 1/min with diesel fuel and 12.55 kW at 2150 1/min with diesel fuel/sunflower oil mixture. Up to 2000 1/min, power with sunflower oil was 1.8%-12% higher than with diesel fuel. This result is similar to the results of other researchers, [19, 6,16].

As shown in Figure 5, sunflower oil consumption values were greater than diesel fuel consumption in 1200-2000 1/min interval. At given injection pump settings, higher density of sunflower oil caused observed mass flow to increase. The higher viscosity of sunflower oil also contributed to increased fuel flows by reducing internal pump

leakage. Running with sunflower oil, the engine received more fuel, more energy, and operated at lower air/fuel ratios. At higher speeds than 2000 1/min, sunflower oil consumption was decreased rapidly and become 3.6 kg/h at 2160 1/min. This was because, the fuel system was not optimized for sunflower operation. As previously mentioned, owing to higher viscosity of sunflower oil, back leak from transfer pump decreases resulting output pressure increase. Increased feed pressure to the hydraulic governor, forces fuel control valve to the governor spring and the valve starts shooting down the flow in lower engine speeds. Maximum fuel consumption values were 5.14 kg/h at 2000 1/min with sunflower oil, 4.80 kg/h at 2350 1/min with diesel fuel and 4.80 kg/h at 2150 1/min with diesel fuel/sunflower oil mixture. As seen in Figure 5, fuel consumption curve with the mixture lay between sunflower oil and diesel fuel curves. Up to 2000 1/min, sunflower oil consumption was 11%-22% higher than with diesel fuel. This result is similar to the results of other researchers [19,6,16].

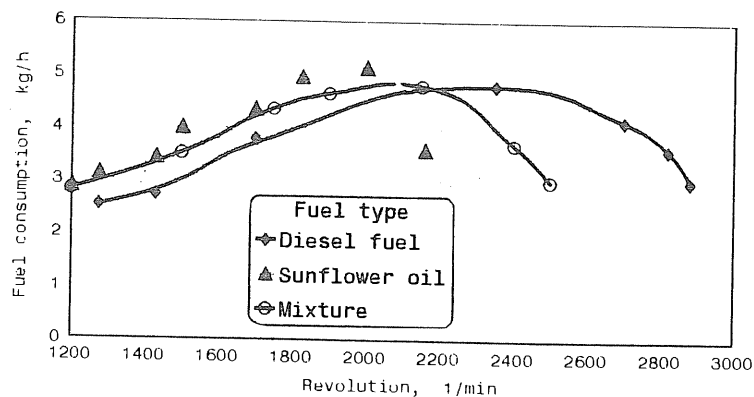


Figure 5. The variation of fuel consumption in relation with the engine speed.

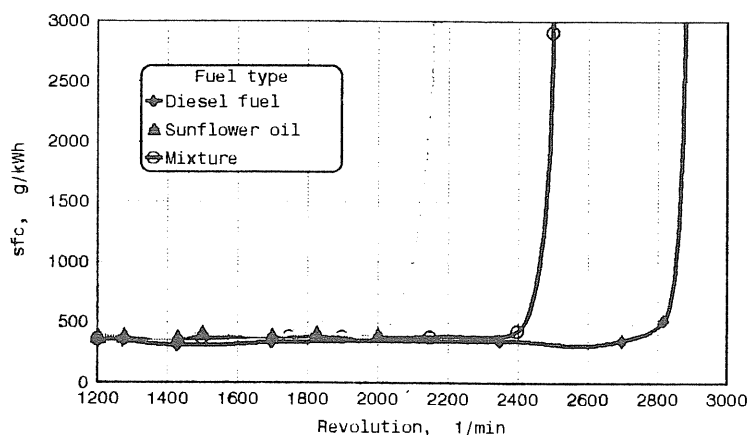


Figure 6. The variation of specific fuel consumption in relation with the engine speed.

Specific fuel consumption is one of the important parameters of the engine and defined as the consumption per unit of power in a unit of time. As shown in Figure 6, up to 2000 1/min, specific fuel consumption curves are similar to each other with the exception of very little higher values of sunflower oil. Minimum specific fuel consumption values were 370.4 g/kWh at 1430 1/min with sunflower oil, 307 g/kWh at 1430 1/min with diesel fuel and 357 g/kWh at 1200 1/min with diesel fuel/sunflower oil mixture. Up to 2000 1/min, specific sunflower oil consumption was 9%-15% higher than specific diesel fuel consumption and this result is similar to the results of other researchers [19,8,16]. Higher specific fuel consumption in the case of sunflower oil is due to its lower energy content.

The variation of exhaust gas temperature in relation with the engine speed for diesel fuel, sunflower oil and diesel fuel/sunflower oil mixture are shown in Figure 7. Maximum exhaust gas temperatures were 502°C at 1700 1/min with sunflower oil, 462°C at 2700 1/min with diesel fuel

and 527°C at 1750 1/min with diesel fuel/sunflower oil mixture. Up to 2000 1/min, exhaust gas temperatures with sunflower oil were 1.5%-15% higher than with diesel fuel. This may be due to delays in combustion periods with sunflower oil and resulting much of the fuel burned in expansion stroke.

Exhaust Emissions

The variation of O_2 emissions in relation with the engine speed for diesel fuel, sunflower oil and diesel fuel/sunflower oil mixture are shown in Figure 8. The most effective use of oxygen was about at 1800 1/min. Oxygen emissions were 2.4% with sunflower oil, 2.4% with the mixture and 5.6% with diesel fuel. Up to 2000 1/min, O_2 emissions values with sunflower oil were less than with diesel fuel. This may be due to greater amount sunflower oil consumption.

The variation of CO emissions in relation with the engine speed for diesel fuel, sunflower oil and diesel fuel/sunflower oil mixture are shown in

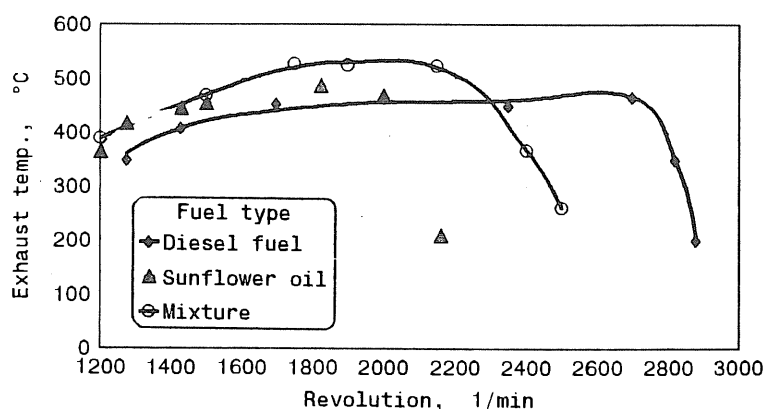


Figure 7. The variation of exhaust gas temperatures in relation with the engine speed.

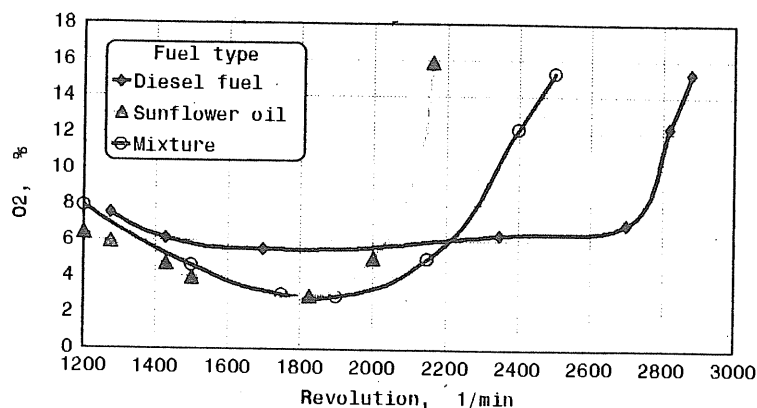


Figure 8. The variation of O_2 emissions in relation with the engine speed.

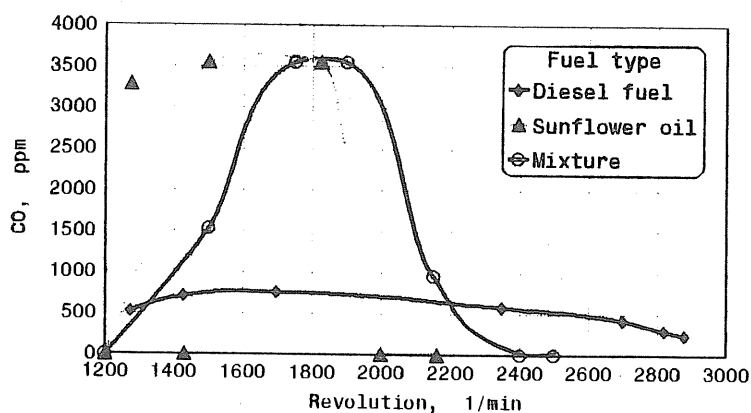


Figure 9. The variation of CO emissions in relation with the engine speed.

Figure 9. Maximum CO emissions were 3550 ppm at 1500 1/min and 1825 1/min with sunflower oil, 754 ppm at 1700 1/min with diesel fuel and 3550 ppm at 1750 1/min and 1900 1/min with diesel fuel/sunflower oil mixture. According to test data, CO emissions with sunflower oil were five times higher than with diesel fuel. This result is not surprising. Excessive CO emission with sunflower oil is a serious problem concerning with environ. Because, as mentioned in fuel consumption evaluation, fuel system was not optimized for sunflower oil operation.

in this working range.

The variation of SO_2 emissions in relation with the engine speed for diesel fuel, sunflower oil and diesel fuel/sunflower oil mixture are shown in Figure 11. Maximum SO_2 emissions were 53 ppm at 1825 1/min with sunflower oil, 73 ppm at 2700 1/min with diesel fuel and 67 ppm at 1900 1/min with diesel fuel/sunflower oil mixture. Since sulphur content of sunflower oil is less than diesel fuel, SO_2 emissions with sunflower oil are generally less than with diesel fuel.

The variation of CO_2 emissions in relation with the engine speed for diesel fuel, sunflower oil and diesel fuel/sunflower oil mixture are shown in Figure 10. Maximum CO_2 emissions were 13.2% at 1825 1/min with sunflower oil, 11.3% at 1700 1/min with diesel fuel and 13.2% at 1900 1/min with diesel fuel/sunflower oil mixture. Up to 2000 1/min, CO_2 emissions with sunflower oil were higher than with diesel fuel. This is an expected result of more sunflower oil consumption

The variations of NO_x (NO and NO_2) emissions in relation with the engine speed for diesel fuel, sunflower oil and diesel fuel/sunflower oil mixture are shown in Figure 12 and Figure 13. Maximum NO emissions were 15 ppm at 1825 1/min with sunflower oil, 281 ppm at 2700 1/min with diesel fuel and 89 ppm at 2400 1/min with diesel fuel/sunflower oil mixture. Maximum NO_2 emissions were 29 mg/m³ at 1825 1/min with sunflower oil, 928 mg/m³ at

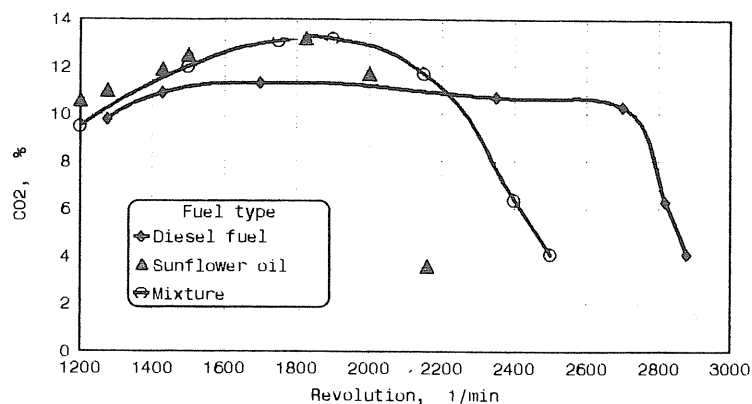


Figure 10. The variation of CO₂ emissions in relation with the engine speed.

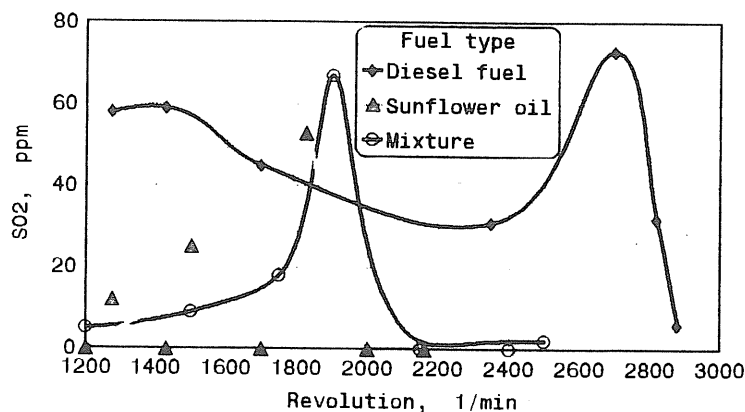


Figure 11. The variation of SO₂ emissions in relation with the engine speed.

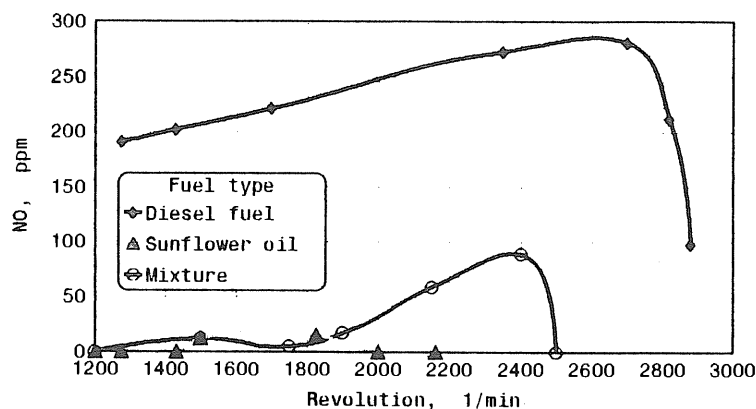


Figure 12. The variation of NO emissions in relation with the engine speed.

2700 1/min with diesel fuel and 385 mg/m³ at 2400 1/min with diesel fuel/sunflower oil mixture. As seen in the graphics NO_x emissions with sunflower oil were lower than with diesel fuel. The most significant factor that causes NO_x formations is the maximum combustion temperatures. Since maximum combustion temperatures with sunflower

oil are lower than with diesel fuel, NO_x emissions were less.

The variations of particulate emissions of the three fuels in relation with the engine speed are shown in Figure 14. Maximum smoke number values were, 9 at 1200 1/min with sunflower oil, 8

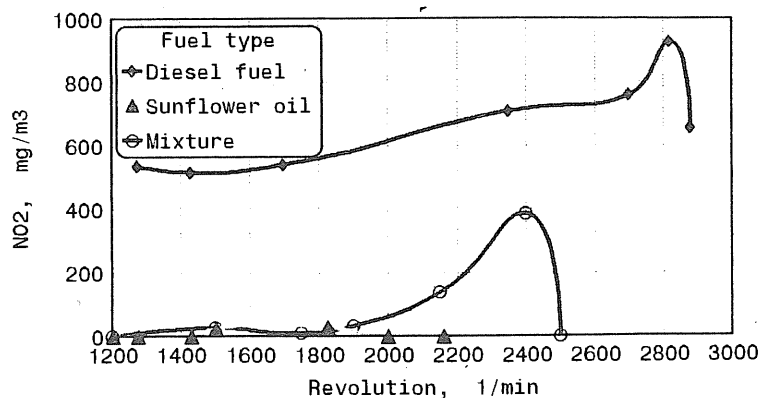


Figure 13. The variation of NO_2 emissions in relation with the engine speed.

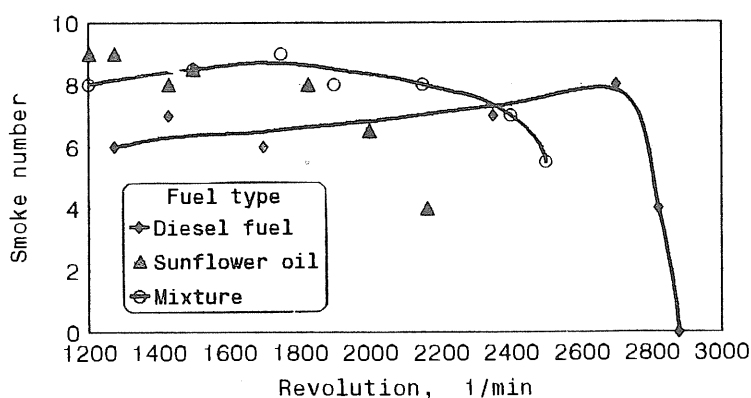


Figure 14. The variation of particulate emissions in relation with the engine speed.

at 2700 1/min, and 9 at 1750 1/min with the mixture.

Up to 2000 1/min, smoke number values with sunflower oil were greater than with diesel fuel. Particulate emissions characteristics showed similar tendencies with CO emissions [6].

Before the sunflower oil and sunflower oil/diesel fuel mixture testings, cylinder head and the injectors of the engine was disassembled and the head, the tops of the pistons, and the tips of the injectors were cleaned. Upon the competition of the sunflower oil and sunflower oil/diesel fuel mixture testings, the former parts of the engine was disassembled again and subjected to inspection. It was seen that the surfaces of these parts were covered with a thin layer of soot and concluded that this amount of soot could not affect the operation of the engine seriously.

The variations of combustion efficiencies in relation with the engine speed are shown in Figure 15. As seen in the figure, up to 2000 1/min,

variations of combustion efficiencies were closer for the three fuels with an insignificant higher values with sunflower oil. Maximum combustion efficiencies were 81.6% at 1200 1/min with sunflower oil, 81.1% at 1275 1/min with diesel fuel and 77.9% at 1200 1/min with diesel fuel/sunflower oil mixture.

The variations of excess air factors (λ) for the three fuels in relation with the engine speed are shown in Figure 16. It can be seen that the most effective use of the air was near the maximum torque operations for each fuel and the curves showed similar characteristics as O_2 curves of Figure 8. Since sunflower oil consumption was more than diesel fuel, air consumption with this fuel was also more. Minimum excess air factor values were, 1.16 at 1825 1/min with sunflower oil, 1.36 at 1700 1/min with diesel fuel, and 1.16 at 1900 1/min with the mixture.

6. CONCLUSIONS

In this study, it was concluded that

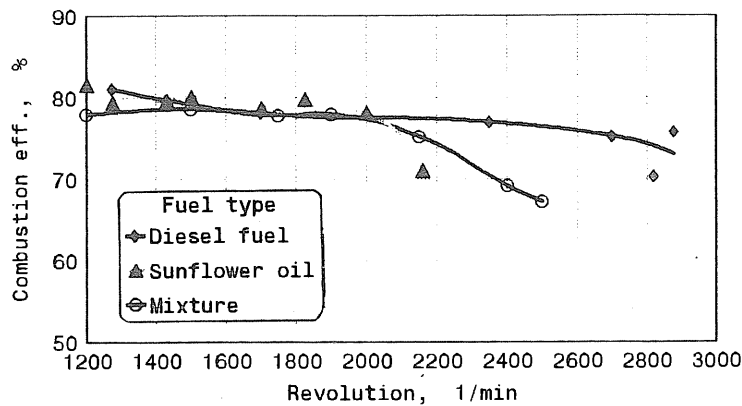


Figure 15. The variation of combustion efficiencies in relation with the engine speed.

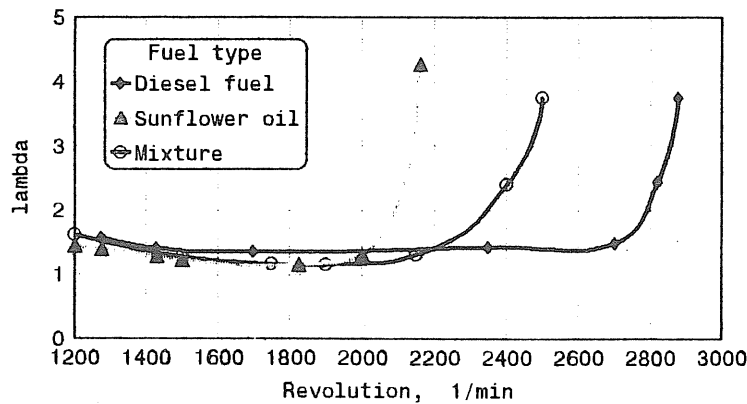


Figure 16. The variation of excess air coefficients in relation with the engine speed.

sunflower oil can be used as a fuel in diesel engines with minimum modifications. Before starting wide application, there are some improvements should be done such as:

- Fuel system should be optimized for sunflower oil operation.

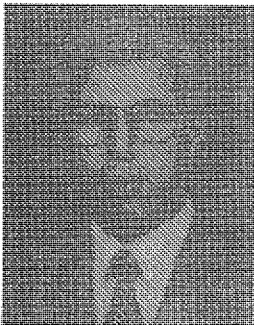
- Sunflower oil is mainly consumed on the food market. Therefore, it has some unfavourable properties as fuel, such as high density, drying with time and gumming, lower cetane number, etc. More tests need to be conducted to improve fuel characteristics of sunflower oil.

- At the present, sunflower oil is more expensive than diesel fuel and annual harvesting values of sunflower are inconsistent. Production yield can be increased and production cost can be decreased by evaluating of the residue for feeding up livestock.

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