

CHEMISTRY EXTENDED ESSAY

“Investigation of the effect of experimental conditions on the composition of biodiesel obtained from waste cooking oil”

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ABSTRACT

As well as its known diesel is very essential in daily life. Most of the transports need fuel to operate because fuels give required energy to activate the motor system when they are burned. However, fuels (especially fossil fuels) are limited and they run out rapidly each day. So, this situation leads to a new problem: finding alternative sources instead of fossil fuels. Biodiesel is considered as the primary alternative way instead of fossil fuels for future's world. There are a lot of types of producing biodiesel from different sources such as vegetable oils and animal fats.

In this experiment, I have aimed to produce biodiesel from wasted vegetable cooking oil. To obtain biodiesel production methanol should be react with wasted oil. By changing the some reaction parameter such as oil/methanol ratio, reaction temperature, reaction time, the concentration of the catalyst I want to determine the most efficient conditions for the production of biodiesel. The results showed that biodiesel production is possible under moderate conditions. The triglycerides in vegetable oil react with methanol and alkyl esters are formed. These alkyl esters are known as biodiesel. My studies showed that NaOH catalyst has a little effect on the efficiency of the transesterification reactions under studied conditions. The compositions of esters were investigated with the method of Gas Chromatography and it is found that the major compounds of biodiesel are linoleic acid, elaidic acid, oleic acid and palmitic acid methyl esters. Among which, the relative content of linoleic acid methyl esters was the highest one, reaching 59 %. Moreover, the optimum temperature is found as 60°C and hence, all the other experiments have been conducted at this temperature changing other parameters. After that, it is found that the reaction time has not any remarkable effect on the yield of methyl esters and excessive methanol had no significant effect on the yield either.

(311)

INTRODUCTION

Each time that I eat lunch during the lunch breaks in my school, I am always curious about what would employees do to the waste oil after they cooked? When I was having my lunch one day, I thought that I could search it from my school's library or from the internet even if there are some alternative ways to evaluate this waste oil. From the web sites that I have search at the internet, it is said that waste vegetable oil could be turned into biodiesel with some techniques¹. Suddenly, I realized the presence of great amount of waste cooking oil in our school's kitchen. Then, I tried to find some alternative ways to evaluate this waste.

I want to test that if the waste cooking vegetable oil, could give the efficient amount of biodiesel. In my opinion, answer of this question is very important for the next generations as there are considerable (huge) numbers of fast-food restaurants in all over the world and most of them throw away their waste oils. If this technique works, it is going to be an alternative way for people's requirement of fuel in future world. According to the literature values, lots of countries should make a mixture of biodiesel with the petroleum diesel to reduce CO₂ emission from the motor vehicles². Emission of hydrocarbons, the destructive effects of toxic substances in air and CO and hydrocarbon emissions can be reduced by the help of biodiesel. Choosing biodiesel as a fuel makes great reduction in the emissions of greenhouse gases. Biodiesel contains virtually no sulphur or aromatics, and use of biodiesel in a conventional diesel engine results in substantial reduction of unburned hydrocarbons, carbon monoxide and particulate matter³.

¹ http://www.biodiesel.org/resources/reportsdatabase/reports/gen/20011101_gen-346.pdf

² <http://www.icis.com/Articles/2007/10/08/9067778/mandatory-blending-levels-for-biodiesel-in-europe-threatens-supplydemand-balance.html>

³ <http://www.keystonebiofuels.com/benefits.html>

Usage of extensive fossil fuels like petroleum, natural gas and coal - which plays an important role in 21st century world - raises the problems of pollution. There are a lot of problems related with the burning of fossil fuels such as increase in the amount of carbon dioxide (CO₂) and nitrous oxide (NO_x) and other greenhouse gases which cause the global warming. As a result of this, it is essential to develop renewable energy sources such as biodiesel (Karatay and Dönmez, 2010). Biodiesel signifies an alternative and renewable fuel from vegetable oils such as rapeseed oil, used cooking oil, sunflower oil for diesel engines.

Biodiesel's viscosity is similar to petro diesel. It has a colour of yellowish with the flash point of 150 °C, (the flash point is a characteristic of liquid fuel, and it is also used to help define the fire hazards of liquids) biodiesel is non-flammable and non-explosive, in contrast to the petroleum diesel, which has a flash point of 64 °C. Biodiesel is non-hazardous and ecological. It notably reduces hazard and some emissions caused when fuel is burned. Biodiesel is an alternative fuel for fuels containing petroleum. The urgency requires an alternative fuel. It should have the characteristics such as technically advantageous, easy to produce and environment-friendly. Biodiesel fuels defined as fatty acid methyl esters (FAME) derived from various renewable lipid resources and vegetable oils. However, producing biodiesel requires a huge capital and this is seen as the most obstructive problem for its commercialization. Using waste oils could be an alternative to lower its cost.

The method used in this work is transesterification of used cooking sunflower oil with a base catalysis (NaOH). Effect of experimental conditions such as methanol/oil ratio, catalyst amount, and reaction time on the composition of biodiesel was investigated.

Transesterification takes place as a reaction of alcohols with triglycerides to produce glycerol and alkyl esters which is known as biodiesel. This reaction typically requires a base or acid catalyst. In diesel engines, FAME (fatty acid methyl esters) could be used straight. Furthermore, they are being marketed as a fuel called B100. On the one hand, B100 is a 100% pure biodiesel and could be burned exactly as a fuel in some diesel engines. On the other

hand, alkyl esters could be mixed with petro diesel up to 25% volume. In this case engine modification is not necessary. Biodiesel and petro diesel are mixed and sold as a fuel between ranges of B1 to B20 which means 1% to 20% volume of biodiesel.

Biodiesel has environmental benefits. Figure 1 shows a graph of the emissions of biodiesels compared to other liquid fuels⁴. According to Figure 1, it can be said that biodiesel energy is not harmful for the living beings by reducing the poisonous gases.

⁴ <http://biodiesel-expansion.com/biodiesel-ebook.htm>

Reduction of Harmful Materials by Using Biodiesel and Petroleum Diesel Blends

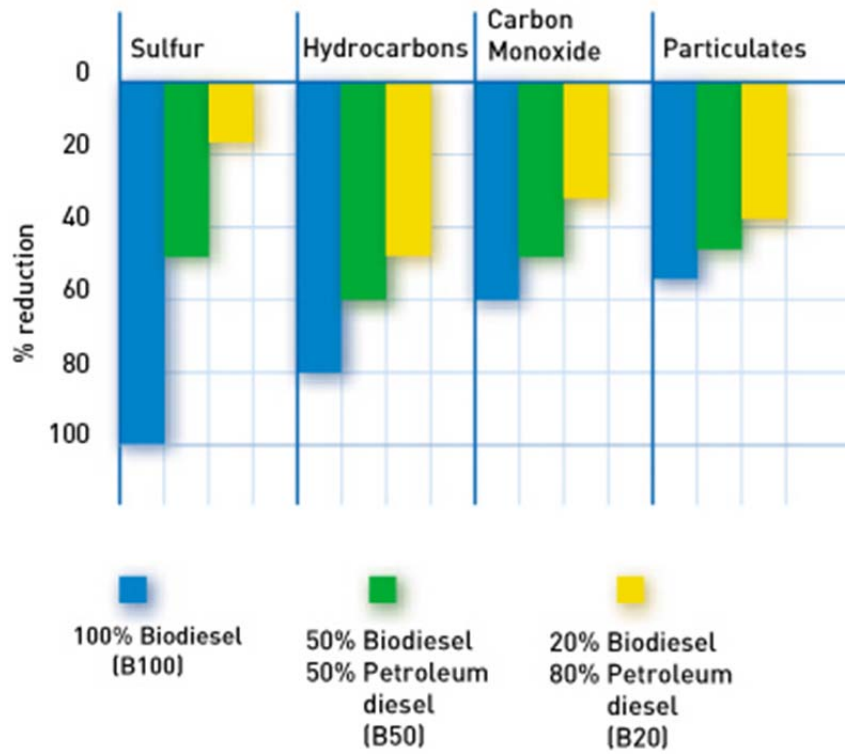


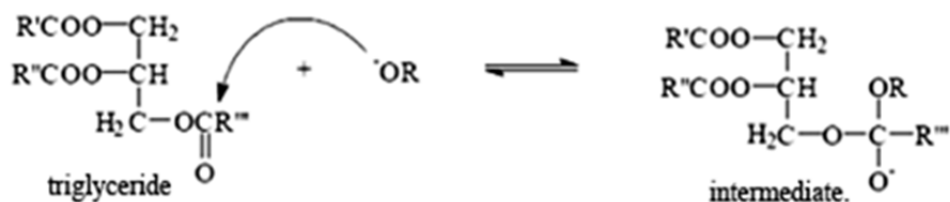
Figure 1: Reduction of hazardous materials by using biodiesel blends.

The base-catalysed transesterification of oils mechanism can be seen in Figure 2 (Schuchardt et al.,1998).

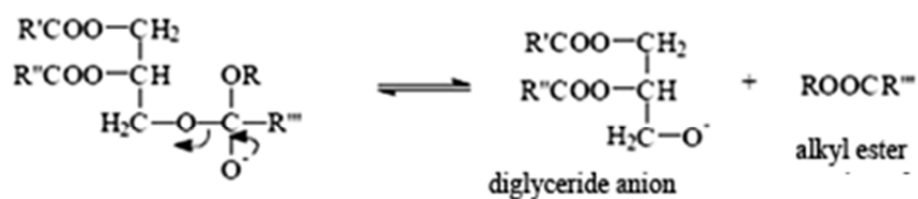
THE BASE-CATALYSED TRANSESTERIFICATION OF VEGETABLE OILS MECHANISM



The first step in the reaction mechanism for base-catalyzed transesterification involves reaction of the base with methanol to produce an alkoxide species



The alkoxide then reacts with the triglyceride to form a tetrahedral intermediate.



This intermediate then decomposes to form an alkyl ester and the corresponding anion of the diglyceride. This step is followed by the deprotonation of methanol by the diglyceride anion regenerating the alkoxide species.



Diglycerides and monoglycerides are converted by this same mechanism into alkyl esters and glycerol

Figure 2: The base-catalysed transesterification of vegetable oils mechanism.

Presently, for the biodiesel production vegetable oils are being used by transesterification reaction. Sunflower and rapeseed are the most popular feed-stocks for biodiesel production in Europe. Palm oil is been preferred in tropical countries, and animal fats and soybean oils in the U.S. (Haas et al., 2004). To produce biodiesel from the plants, some pre-treatments are necessary. Firstly, the vegetable oils should be extracted from the plants (Erickson et al., 1980). There are two products produced within this processes. One of them is vegetable oil where another of it is dry solid residue known as meal. The meal contains a significant percentage of protein. Because of that, it is used as a protein supplement for fodder. Triglycerides decompose to its monomers which are three fatty acid molecules and one glycerol molecule. As shown in Table 7, each fatty acid has a different carbon chain length and number of double bonds as a result of its origin. In that table, it can be seen that plants have different saturated and unsaturated vegetable oils. If the fatty acid has no double bonds in its structure, it is called as “saturated”. Saturated fatty acids have maximum number of hydrogen atoms in each carbon. If the fatty acid has one or more double bonds, then it is called “unsaturated”. Location and number of double bonds plays an important role in fatty acids as they undermine the chain of fatty acid. Linoleic acid is an example to unsaturated fatty acids which has 18 carbon atoms and 2 double bonds and one of them is at the 6th carbon atom from the methyl end.

Since the inventor of the diesel engine Rudolph Diesel first tested peanut oil 100 years ago, the use of vegetable oils as alternative fuels has been around (Shay, 1993). However, cheap petroleum products were popular for a long time and that restricted biodiesel production to be in high demand.

RESEARCH QUESTION

By looking at this information given above I thought that whether I can produce biodiesel from waste cooking vegetable oils. That brings my research question: *Can biodiesel be produced from waste cooking vegetable oils in moderate conditions, and if yes how the composition of this biodiesel changes when the reaction conditions of biodiesel production changes?* In that assessment, I have aimed to determine the optimum conditions for biodiesel productions. For this, I am going to investigate the effect of the temperature of the reaction, the effect of the catalyst and efficiency of concentration of catalyst on the profit of biodiesel, reaction's duration and oil to methanol ratio.

CALCULATIONS

From the Gas Chromatogram, the total peak area of C14 - C24 methyl esters are determined and the methyl ester content of individual compounds is calculated from the relative peak areas. Every methyl ester compound has its own peak areas in Gas Chromatography.

According to EN 14103 Standard, the linoleic acid methyl ester content is calculated with the formula shown below and also expressed as a weight percent. Methyl heptadecanoate (C17) is used as the internal standard again.

$$L = \frac{A_L}{\Sigma A - A_{IS}} \times 100\%$$

Where:

ΣA = total peak area C14:0 – C24:1

A_{IS} = internal standard (methyl heptadecanoate) peak area

A_L = linoleic acid methyl ester peak area

RESULTS and DISCUSSION

Typical chromatogram of the products of transesterification reaction of used cooking oil at the lowest reaction temperature (30°C) presented in Figure 5. As seen in this figure, the chromatogram is characterized by a series of consecutive peaks, which correspond to fatty acid methyl esters, having different C-number. The major compounds in the products are seen on the chromatogram.

Peaks of FAME's Obtained from the Transesterification at 30 °C

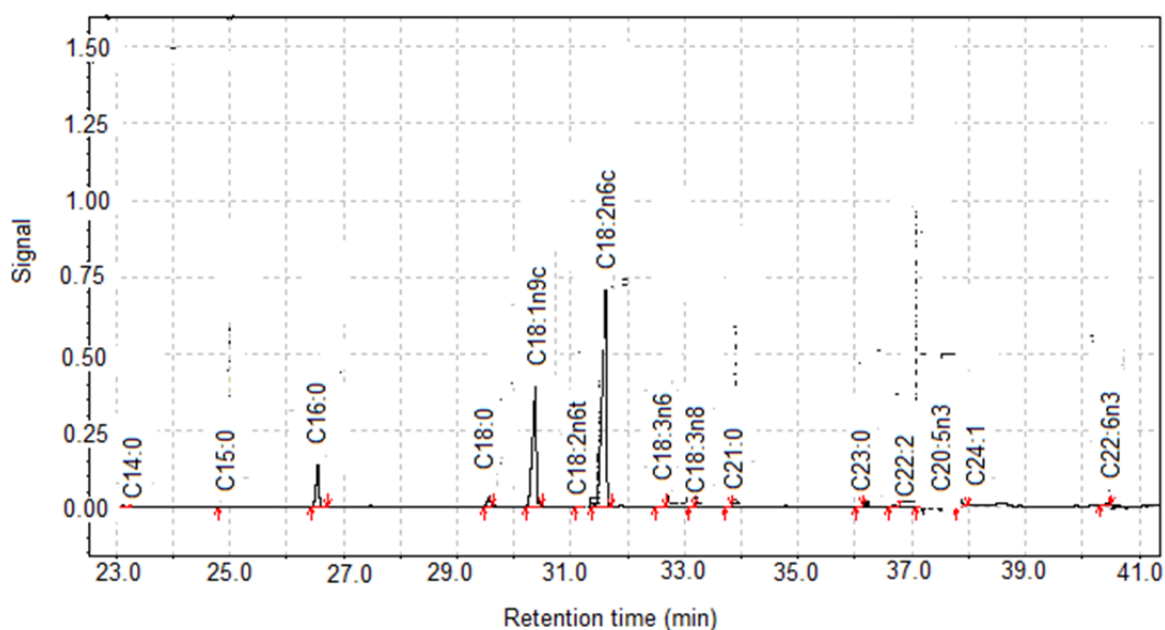


Figure 5: An example of the gas chromatogram of the transesterification products

The fatty acid methyl esters (FAME) obtained in this experiment is also given in Table 1. The wt % of individual fatty acid methyl esters is determined from the relative peak areas. The conditions of this experiment are:

Reaction time: 60 min \pm 1 min ,

Reaction temperature: 30°C \pm 1°C,

Oil/methanol ratio: 1/2 (vol./vol.)

Amount of catalyst (NaOH): 0.5 wt %

The Amount of Individual Fatty Acid Methyl Esters (wt %)

Fatty Acid Methyl Esters	wt %
Caprylic acid (C8:0)	0.149±0.02
Myristic acid (C14:0)	0.149±0.02
Pentadecanoic acid (C15:0)	0.023±0.02
Cis-10 pentadecanoic acid (C15:1)	0.168±0.02
Palmitic acid (C16:0)	6.548±0.02
Palmitoleic acid (C16:1)	0.173±0.02
Cis-10-Heptadecanoic acid (C17:1)	0.026±0.02
Stearic acid (C18:0)	1.609±0.02
Elaidic acid (C18:1n9t)	26.662±0.02
Oleic acid (C18:1n9c)	0.432±0.02
Linoleic acid(C18:2n6c)	62.913±0.02
Linolenic acid (C18:3n6)	0.010±0.02
Heneicosanoic acid (C21:0)	0.036±0.02
Cis-11,14-eikosadienoic acid (C20:2)	0.138±0.02
Behenic acid (C22:0)	0.074±0.02
Cis-8,11,14-eicosatrienoic acid (C20:3n6)	0.036±0.02
Tricosanoic acid (C23:0)	0.025±0.02
Cis-13,16-docosadienoic acid (C22:2)	0.037±0.02
Cis-5,8,11,14,17-eicosapentaenoic acid (C20:5n3)	0.023±0.02
Lignoseric acid (C24:0)	0.023±0.02
Nervonic acid (C24:1)	0.054±0.02
Cis-4,7,10,13,16,19-docosaheksaenoic acid (C22:6n3)	0.197±0.02

Table 1: The amount of fatty acid methyl esters (wt %)

In this experiment the major compounds of transesterification are linoleic acid, elaidic acid, palmitic acid and stearic acid esters with amount of 62.9%, 26.7%, 6.5% and 1.6% respectively. Elaidic acid methyl ester only occurs specifically at this temperature (30°C). In other experiments made at 60°C a little amount of elaidic acid ester is observed.

Figure 6 and Table 2 shows variation of the fatty acid ester yields with the different amount of catalyst. Transesterification reaction has been conducted at a temperature of 60°C for 60 minutes. According to the results, increasing catalyst addition leads to no significant variation on the profit of methyl esters. The possible reason of this ineffectiveness is deactivation of catalyst caused by formation of soaps that have markedly reduced catalytic activity and allows production of emulsions between the obtained biodiesel and the by-product glycerol, requiring a very long settling time for the separation (Di Serio et al. 2007). Di Serio has claimed that usage of homogeneous alkaline catalysts for accelerating the transesterification reaction requires refined oils containing not more than 0.5% of free fatty acids. Because of water causes the formation of free fatty acids by hydrolysis of triglycerides, the anhydrous conditions are necessary. Generally, the transesterification reaction should be affected by catalyst concentration (Deng et al. 2011). According to Deng et al, biodiesel production is affected by the composition and particle size of catalyst. However, in the present study, when catalyst amount was increased from 0.1 % to 5 %, the transesterification products have a possibility to turn into an emulsion and result in hard separation. So no remarkable variation of fatty acid esters was observed.

According to these experimental results, it can be concluded that the cost of biodiesel could be lowered by using a heterogeneous catalyst instead of a homogeneous one. It results in a high quality of esters and glycerol, which can be successfully separated. Under these conditions, glycerol does not need expensive refining processes (Bournay, et al, 2005).

Yield of methyl esters in the presence of different amount of catalyst

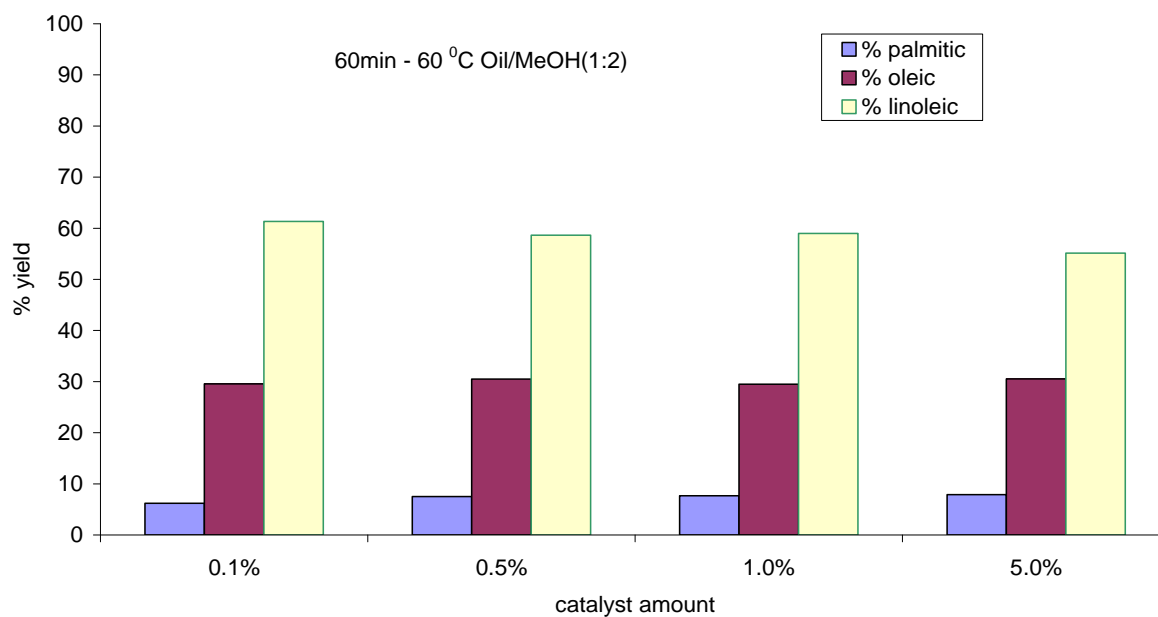


Figure 6: Effect of catalyst amount on the yield of methyl esters

Effect of Catalyst Amount on Yield Methyl Esters (60 min - 60°C - Oil/Methanol(1:2))

wt %	wt %			
Catalyst amount	palmitic	oleic	elaidic	linoleic
0.1	6.18±0.02	29.51±0.02	0	61.31±0.02
0.5	7.51±0.02	30.42±0.02	0	58.62±0.02
1.0	7.65±0.02	29.52±0.02	0	58.91±0.02
5.0	7.87±0.02	30.50±0.02	0	55.15±0.02

Table 2. Effect of catalyst amount on the yield of methyl esters with errors (60 min - 60°C - Oil/Methanol(1:2))

The effect of changing oil to methanol ratio on the yield of biodiesel was also investigated. As seen in Figures 7, 8 and 9 slight differences on fatty acid methyl ester yields were remarkable if the oil/methanol ratios were varied. In all figures linoleic acid contents of the biodiesel samples were the highest. Oleic acid amounts of the samples were also high.

The maximum yield of linoleic acid 59% was obtained when the oil/methanol ratio was approximately 1/2 at different reaction times changing from 30 minutes to 120 minutes (Figure 10). Generally, when the molar ratio is higher than the stoichiometric value leads a high rate of ester formation. After all, too much methanol doesn't make an important effect on the profit when the ratio of oil/methanol is above 1/2. As a result of their experiments Hossain et al. suggested that generally the biodiesel yields increased with increasing oil to methanol ratios (Hossain et al. 2010). In the literature, there are some contradictory results about the biodiesel yields. Math et al. have concluded that excess use of methanol had no significant effect on biodiesel yield and that complicate glycerol and ester separation (Math et al. 2010).

Yield of methyl esters in the different oil/methanol ratios

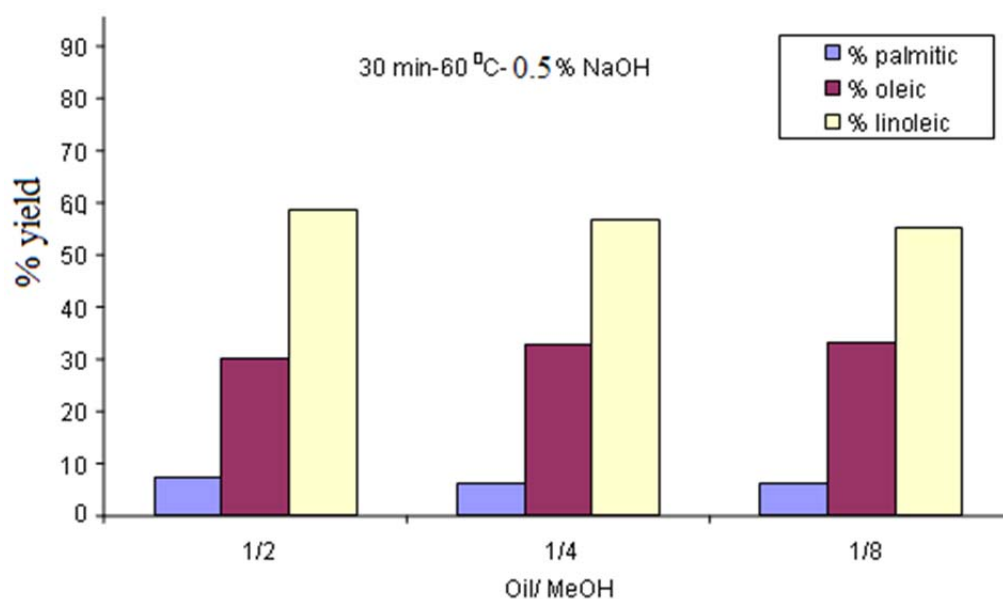
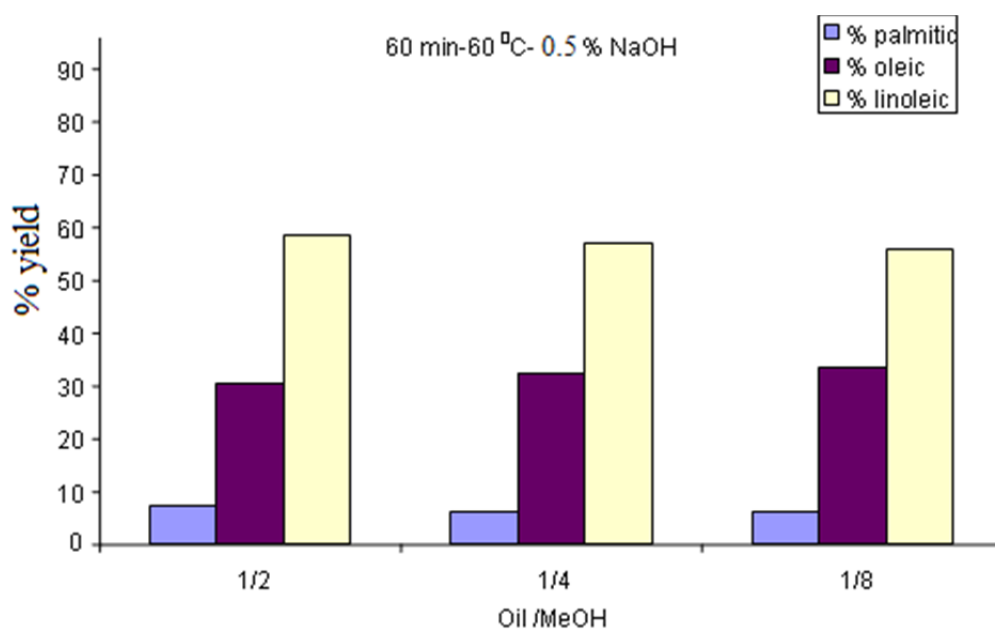


Figure 7: Effect of oil/methanol ratios on the yield of methyl esters (30 min, 60°C)

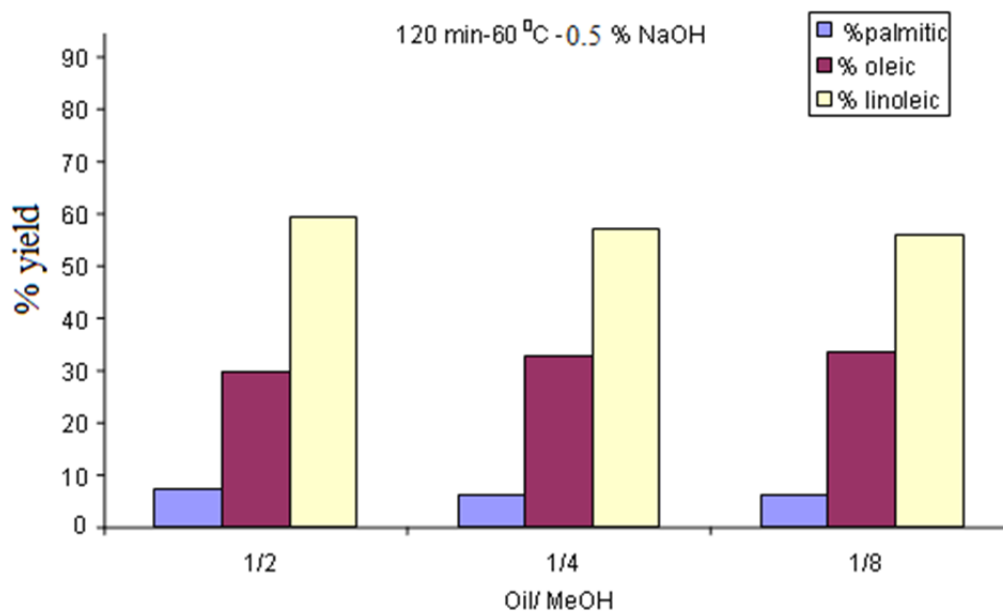
Effect of Oil/Methanol Ratios on Yield Methyl Esters (30 min. - 60°C)

Oil/Methanol	wt %			
	palmitic	oleic	elaidic	linoleic
1/2	7.48±0.02	30.24±0.02	0	58.75±0.02
1/4	6.32±0.02	32.82±0.02	0.03±0.02	56.55±0.02
1/8	6.28±0.02	33.31±0.02	0.05±0.02	55.31±0.02

Table 3: Effect of oil/methanol ratios on the yield of methyl esters with errors (30 min, 60°C)**Yield of methyl esters in the different oil/methanol ratios****Figure 8:** Effect of oil/methanol ratios on the yield of methyl esters (60 min, 60°C)

Effect of Oil/Methanol Ratios on Yield Methyl Esters (60 min. - 60°C)

Oil/Methanol	wt %			
	palmitic	oleic	elaidic	linoleic
1/2	7.51±0.02	30.49±0.02	0	58.62±0.02
1/4	6.36±0.02	32.53±0.02	0	57.03±0.02
1/8	6.26±0.02	33.66±0.02	0	55.73±0.02

Table 4: Effect of oil/methanol ratios on the yield of methyl esters with errors (60 min, 60°C)**Yield of methyl esters in the different oil/methanol ratios****Figure 9:** Effect of oil/methanol ratios on the yield of methyl esters (120 min, 60°C)

Effect of Oil/Methanol Ratios on Yield Methyl Esters (120 min. - 60°C)

Oil/Methanol	wt %			
	palmitic	oleic	elaidic	linoleic
1/2	7.13±0.25	29.89±0.25	0	59.21±0.25
1/4	6.23±0.25	32.78±0.25	0	57.01±0.25
1/8	6.19±0.25	33.33±0.25	0	55.74±0.25

Table 5: Effect of oil/methanol ratios on the yield of methyl esters with errors (120 min, 60°C)

Some esterification reactions are carried out at different time intervals from 30 minutes to 120 minutes to investigate the effect of the duration of reaction on the fatty acid esters yield. It is seen from Figure 10, that the reaction time has not any remarkable effect on the yield. From this observation, it can be concluded that the transesterification reaction is already completed in 30 min under studied conditions.

Yield of methyl esters in the different reaction times

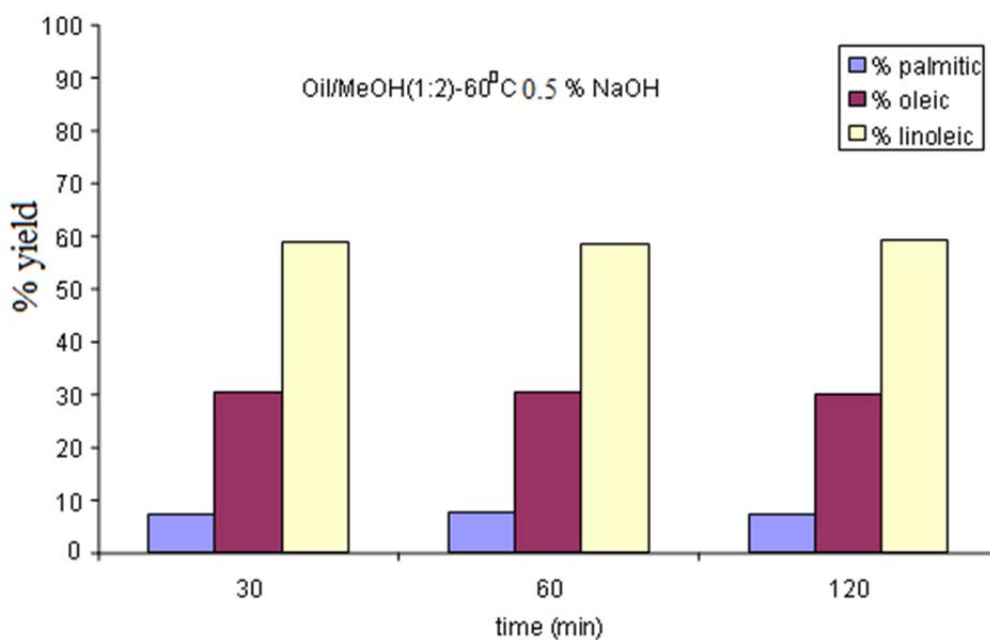


Figure 10: Effect of reaction time on the yield of methyl esters (60°C)

Effect of Reaction Time on Yield Methyl Esters (60°C – Oil/Methanol (1/2) – 0.5% Catalyst)

Time (min)	wt %			
	palmitic	oleic	elaidic	linoleic
30	7.42±0.02	30.28±0.02	0	58.76±0.02
60	7.53±0.02	30.43±0.02	0	58.62±0.02
120	7.11±0.02	29.80±0.02	0	59.22±0.02

Table 6: Effect of reaction time on the yield of methyl esters with errors (60°C, Oil/Methanol (1/2), 0.5 % catalyst)

COMPARISON OF THE RESULTS WITH THE LITERATURE

Table 7 shows that compositions of fatty acids in vegetable oils for the different plants. According to the results of this study, methyl esters yield of linoleic acid (18:2) and oleic acid (18:1) were found as the highest, approximately 60% and 30% respectively. This finding is comply with the fatty acid compositions of sunflower oil given in Table 7, which are 14 - 43 wt % for oleic acid (18:1) and 44 - 74 wt % for linoleic acid (18:2) respectively.

Compositions of Fatty Acids in Vegetable Oils For Different Plants

vegetable oil	fatty acid composition (wt %)										iodine value	sapon value
	(no. of carbons: C=C bonds)											
	8:0	10:0	12:0	14:0	16:0	18:0	18:1	18:2	18:3	22:1		
canola					1.2-6	1-2.5	52-66.9	16.1-31	6.4-14.1	1-2	110-126	188-193
coconut	4.6-9.5	4.5-9.7	44-51	13-20.6	7.5-10.5	1-3.5	5-8.2	1.0-2.6	0-0.2		6-12	248-265
corn				0-0.3	7-16.5	1-3.3	20-43	39-62.5	0.5-13.5		103-140	187-198
cotton-seed				0.6-1.5	21.4-26.4	2.1-5	14.7-21.7	46.7-58.2			90-119	189-198
olive			0-1.3	7-20	0.5-5.0	55-84.5	3.5-21				75-94	184-196
palm		0-0.4	0.5-2.4	32-47.5	3.5-6.3	36-53	6-12				35-61	186-209
peanut				0-0.5	6-14	1.9-6	36.4-67.1	13-43		0-0.3	80-106	187-196
rapeseed				0-1.5	1-6	0.5-3.5	8-60	9.5-23	1-13	5-56	94-120	168-187
soybean					2.3-13.3	2.4-6	17.7-30.8	49-57.1	2-10.5	0-0.3	117-143	189-195
sunflower					3.5-7.6	1.3-6.5	14-43	44-74			110-143	186-194
tallow (beef)				2.1-6.9	25-37	9.5-34.2	14-50	26-50			35-48	218-235

Table 7. Compositions of fatty acids in vegetable oils (Knothe et al. 2005)

In that table above, for example canola oil has an interval of 52%-66.9% elaidic acid (C18:1), 16.1%-31% linoleic acid (C18:2) and 6.4%-14.1% linolenic acid (C18:3).

CONCLUSION AND EVALUATION OF THE RESULTS

As an alternative fuel, biodiesel can be used safely in modern diesel engines. The most important advantages of using biodiesel for diesel engines instead of petro diesel are reducing the emissions and increasing the wear protection.

Based on the study of the alkaline transesterification of used cooking sunflower oil from a student cafeteria the following results were obtained:

The results showed that biodiesel can be produced under very moderate conditions from used cooking sunflower oil with high yields of linoleic and oleic acid. The small effectiveness of investigated parameters on the yield of fatty acid methyl esters can be attributed on the soap formation during the esterification. In this study, the raw material used for biodiesel production was used cooking oil, which generally contained large amount free fatty acids (Hossain et al. 2010). These free fatty acids react with the alkaline catalyst to form soap. High soap formation would lead to formation of gels, which subsequently traps a large of amount of esters within the glycerin layer and leads to the loss of biodiesel in studied conditions (Stavarache et all 2005).

Based on the results obtained, the usage of homogenous effective base catalyst NaOH doesn't make a significant effect on the production of biodiesel from waste oils containing fatty acids. Consequently, a heterogeneous solid catalyst was used. It can be seen that, heterogeneous solid catalyst provides a better decomposition. Moreover, the catalyst wasn't denaturated as quickly as homogenous catalyst.

One of the important fuel properties of biodiesel is fatty acid profile. Because of the influence of fatty acid profiles on fuel properties of biodiesel, the composition of the esters were investigated with GC. It was found that biodiesel from cooking sunflower oil was mainly consisted of linoleic acid, elaidic acid, oleic acid and palmitic acid methyl esters. Among which, the relative content of linoleic acid methyl esters was the highest one, reaching 59 %.

The compositions of oils produced in this work comply with the compositions given in the literature. Experimental conditions have no significant difference on the yields of fatty acid esters meaning that waste cooking oil can easily be transesterified to biodiesel conveniently under moderate conditions.

EVALUATION FOR THE METHOD OF THE EXPERIMENT

While doing this experiment, there could be some errors which cause uncertainties. For example, the homogeneity of the two samples of oils taken could have not been equal. When the samples were poured from glass tubes into beakers, some oil droplets were remained in the tubes. So, this makes small differences in the mass of the sample than expected. It is very possible for someone to miss the actual value. However, in this situation it is unacceptable. Because it could affect the peaks, which were resulted by Gas Chromatography, and the calculations. Nevertheless, when the results were compared with the literature, it is seen this mistake didn't have significant effect on the results.

Moreover, a small part of the catalyst (NaOH) was reacted with water vapour in the air while measuring it. The small amount of NaOH turned into a solution and remained on the paper which was put under of it. So, this situation leads to the uncertainty for the amount of the catalyst.

FURTHER INVESTIGATION

In addition, this study should be further developed for usage of biodiesel as a motor fuel. ASTM (American Society for Testing and Materials) has some standards for motor fuels to have in order to be released on the market. Biodiesel production would likely to be the most beneficial fuel source in tropical countries. Although it's not a tropical country, in Turkey %65 of the biodiesel production is made from the companies related with agriculture. Moreover, half of these companies are oil companies. In 2008, 22 million tons of liquid fuel in consumed in Turkey. 16 million of this fuel was diesel fuel and the maximum capacity of biodiesel production was 1.5 million tons in Turkey.⁵ It is projected that high prices of diesel fuels would likely to increase the importance of biodiesel in near future. It will most likely have an important role of solutions to high oil prices. When the technology develops, the importance and usage of biodiesel would likely increase.

Our waste oil was taken from a university cantina. This wasted oil could be taken from another countries' cantina because in southern countries another type of oil is common such as canola oil. Moreover; restaurants, cafes etc. are the places to get waste oil rather than cantinas.

⁵ http://www.albiyobir.org.tr/trde_b3.htm

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- <http://www.keystonebiofuels.com/benefits.html>
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APPENDIX

EXPERIMENTAL METHOD

Waste oil taken from student cafeteria of a university was reacted with methanol by base catalyst NaOH to obtain biodiesel with transesterification.

Yields of fatty acid esters were calculated from peak area of GC (Gas chromatography GC, is a type of chromatography used to separate volatile components of a mixture) chromatograms.⁶

The effects of oil/methanol (vol./vol.) ratio (1:2 – 1:8), catalyst concentration (0.1 -5.0 wt%), reaction time (30-120 min.) on the composition of transesterification of biodiesel were investigated. Reaction temperature influences the rate of reaction and biodiesel yield. Several researchers proposed that transesterification process may be carried out at a temperature nearer to boiling point of alcohol (e.g. methanol) (Ma et al., 1999), hence in order to optimize the reaction temperature, three samples were prepared by varying the reaction temperature (50°C, 60°C and 65°C) by keeping all other parameters (oil/methanol ratio, catalyst concentration, reaction time) constant. The maximum yield obtained at 60°C and hence, all the other experiments have been conducted at this temperature changing other parameters.

Preparation of Catalyst

A suitable volume of methyl alcohol (5 mL) was taken into a 100 mL round bottom beaker. The defined amount of catalyst (NaOH - 0.1 -5.0 wt%) in pellet form was measured to mix with methyl alcohol. For an hour, the mixture was being blended on a magnetic stirrer at 60°C. Because of the evaporation of the alcohols, a reflux condenser added to the beaker to prevent the vaporization of alcohol. Finally, an aluminium foil was used to cover the beaker to prevent the heat loss.

⁶ <http://www.wfu.edu/chem/courses/organic/GC/index.html>

The experimental setup can be seen in Figure 3.

Experimental Setup

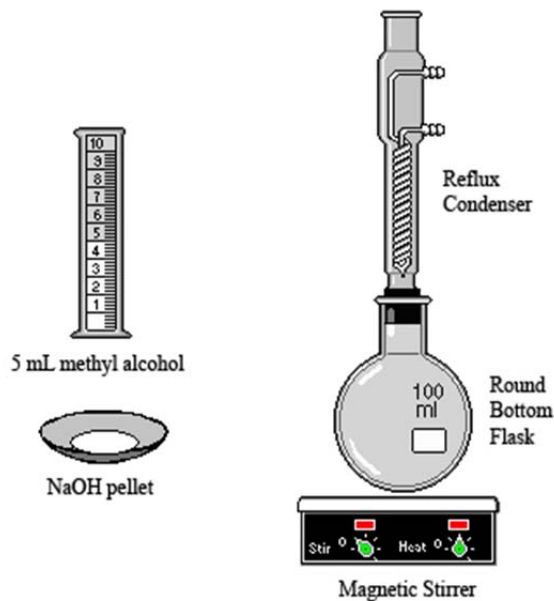


Figure 3: Experimental setup

Transesterification

Transesterification process is similar to hydrolysis. However, methyl alcohol is used instead of water. It is obviously seen from Figure 2, 1 mole of triglyceride reacts with 3 moles of alcohol to give 3 moles of fatty acid ester and 1 mole of glycerine. The rate of the transesterification reaction can be accelerated by using the catalyst NaOH.

Biodiesel Production

First of all, the oil was distilled to melt condensed oil and heated up to 50°C with the help of a water bath. 100 mL of the heated oil of was taken to the flask which has catalyst-alcohol solution. The starting time of the reaction is noted as this moment. The mixture was mixed with the help of a magnetic stirrer at a constant speed and at the same time it was heated up to desired temperatures (60 °C). When the reaction reached the desired reaction time, stirring was stopped.

After transesterification step, the mixture in the reaction beaker was released to immerse for a night to obtain different phases. One of these phases is glycerol-which is at the bottom of the beaker- and the other one is ester on the top of the liquid. A sample of 1 μL from the ester phase was taken and analyzed by the Gas Chromatogram (GC-2010) in the laboratories of Ankara University, Faculty of Science. The analysis of GC is shown below:

Carrier Gas: N_2

Column: TR-CN100, 0.25mm x 0.20 mm x 60 m

Flame Ionization Detector: 240 $^\circ\text{C}$

Peaks of fatty acids were resulted from the chromatogram.

The flame ionization detector for gas chromatography is shown schematically in Figure 4 below:

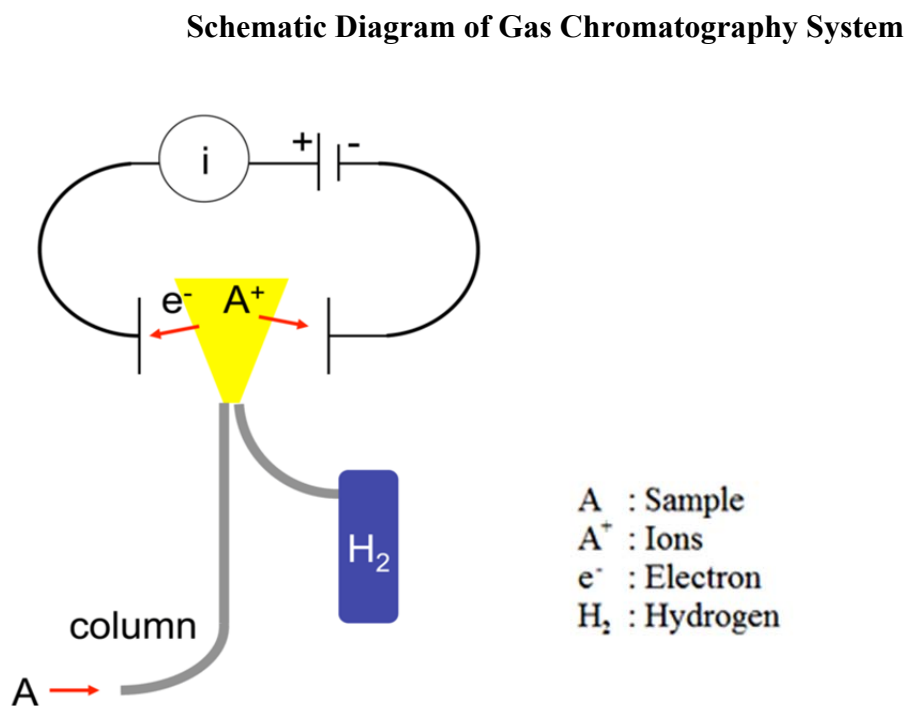


Figure 4: Schema of a flame ionization detector for gas chromatography

MATERIALS**Materials for Transesterification**

- Round bottom flask (quick fit) (250 cm³) x 1
- Reflux condenser (quick fit)
- Magnetic stirrer and heater x 3
- Measuring cylinder (10cm³) x 2
- Measuring cylinder (200cm³) x 2
- Metal spatula
- Water bath
- Watch glass
- Stopwatch
- Clamp stand x 2
- Clamps x 5
- Electronic Scale (0.1 mg sensitivity)
- Thermometer (max 100 °C)
- Beaker (200 cm³) x 2
- Glass tubes (10 cm³) x 10
- NaOH (200 grams)
- Methanol (2 dm³)
- Waste sunflower oil (2 dm³)
- Aluminium foil
- Filter paper
- Funnel

Materials for Gas Chromatography

- Capillary tube (60 m x 0.25 mm x 0.20 mm)
- Syringe (1 μL) x 2
- N₂ – Gas Cylinder
- Gas Regulator

CALCULATION OF LINOLEIC ACID (wt%)

The results are shown in tables as the mean value of two experiments. For example, the wt % of linoleic acid methyl ester is calculated from the following data:

$$A_L = 54.48$$

$$A_{IS} = 13.4$$

$$\sum A = 100$$

$$L = (54.48 / (100 - 13.4)) \times 100 = 62.91 \pm 0.02 \text{ (wt \%)}$$

It fits the value which was given in Table 1.

Linoleic acid(C18:2n6c)	62.913±0.02
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Here, (C18:2n6c) Linoleic acid is an 18-carbon containing acid chain. “2” shows the number of double bonds. The first double bond is located at the 6th carbon atom from the methyl end which known as the “n” end. “c” represents cis / “t” represents trans isomer position.

PHOTOGRAPHS ABOUT THE EXPERIMENT







