Biofuels Used in IC Engines and Their Potential for Turkey

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Abstract

One of the recent problems originating from the increased energy consumption in the world is greenhouse gasses. These gasses are responsible for the global warming and climate change, which are regarded as a great threat for the world. While some portion of the world's energy demand is met by renewable energy and nuclear energy, a greater portion is met by fossil fuels such as coal, petrol and natural gas. CO_2, which is produced as a result of the combustion of fossil fuels containing hydrocarbons, is the main contributor to the greenhouse impact. The use of biofuels as alternative to fossil fuels causes a decrease in CO_2 emissions. In this study, the use of biodiesel and bioethanol in IC engines are considered. The use of these biofuels in IC engines and their potentials for Turkey are investigated.

Key words: Biodiesel, bioethanol, IC engines, fuel demand, biofuel potential

1. Introduction

CO_2 concentrations in the atmosphere were announced over 400 ppm level by United Nations in the recent past. It is well known fact that consumption of fossil fuels should be diminished and the use of renewable energy sources should be increased in order to control global warming problem arising from greenhouse gasses. Among the renewable energy sources, biofuels take attention due to their remarkable characteristics such as causing a diminishing effect on the greenhouse gases [1]. As alternative and renewable liquid fuels, biodiesel and bioethanol have come into prominence because of their diminishing effect on the main greenhouse gas, CO_2, in comparison to conventional fossil based fuels. So, they have been investigated widely for improving their properties, and commercially employed in the IC engines as fuel additives. The use of biofuels also results in economic advantages such as meeting energy demand from domestic sources and promoting employment ratio. For this reason, biofuels are used especially as fuel additives for IC engines in many countries at an increasing rate.

European Union (EU) regulated the 2003/30/EC directive and set an objective with this directive for providing %5.75 of total energy consumption of transport sector from renewable fuels by 2010 [2]. Then this percentage was increased to the value of %10 by 2020 with the 2009/28/EC directive of EU. Especially the use of biofuels, electric energy from clean sources and hydrogen are recommended for meeting this energy demand of transport sector.

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Turkey currently meets its energy demand with the use of mainly imported fossil fuels at the ratio of %88. However, the tendency of using renewable energy sources has been increased recently. In this study, it is aimed to investigate the usage and potential of biodiesel and bioethanol as IC engine fuels in Turkey.

2. Fuel demand for IC engines in Turkey

Consumption of fuels used in IC engines increases remarkably with the increase in vehicle quantity. Gasoline, diesel fuel and LPG consumption values of transport sector in Turkey are reported in Figure 1[3].

Totally, 20.12 million tons of petroleum based automotive fuels were consumed in Turkey in 2012. 15.64 million tons of diesel fuel, 1.91 million tons of gasoline and 2.70 million tons of LPG were sold in that year. Total consumption of fuels for IC engines increased 65.12%, while consumption of diesel fuel increased 91% between 1990 and 2012 in Turkey.

In recent years, a high number of SI engines run with gasoline have been converted to run as dual-fuel (gasoline and LPG) due to low price of LPG in comparison to gasoline in Turkey. Therefore, LPG consumption trend has increased while gasoline consumption trend has lessened in Turkey. Due to the fact that diesel engines have higher thermal efficiency and lower specific fuel consumption rate in comparison to SI engine, diesel fuel consumption in Turkey has sharply increased as a result of increasing number of vehicles with diesel engine.

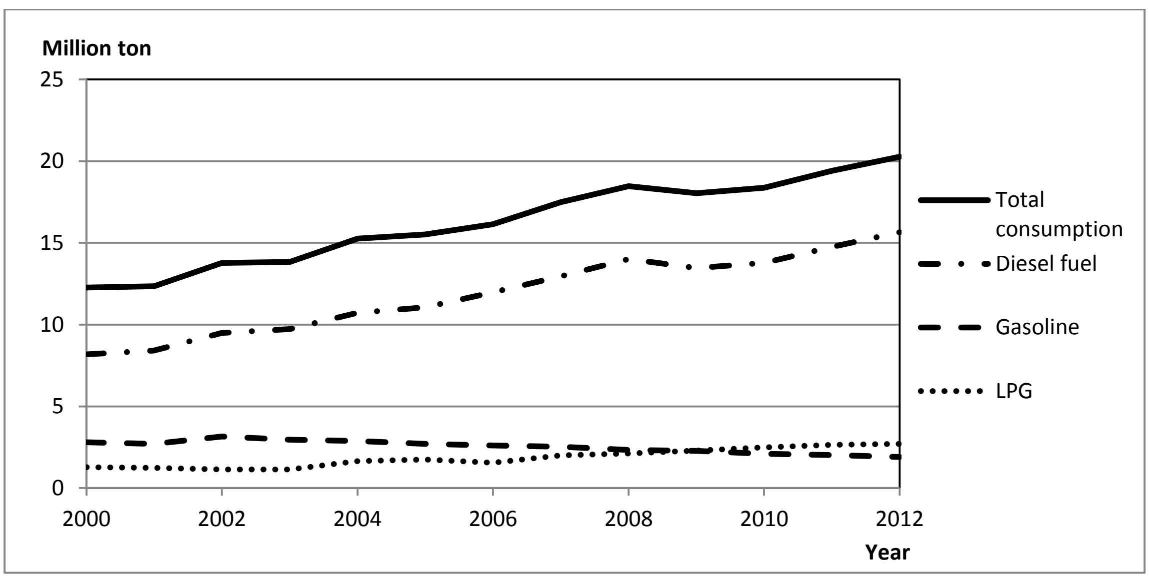

Figure 1. Fuel consumptions of transport sector in Turkey [3].

3. Biofuels Used in IC Engines

Common liquid biofuels for IC engines are biodiesel and bioethanol. Depending on their properties, these fuels can be used in gasoline or diesel engines as a pure fluid or as a blend.

3.1. Biodiesel

3.1.1. Properties of biodiesel and its use in diesel engines

Vegetable oils can partially be used in diesel engines. However, because vegetable oils have considerably high viscosity and low volatility, they cause engine and fuel system damages. Therefore, it is necessary to decrease their viscosity [4]. One of the methods to be used for this aim is to produce low viscosity fatty acid methyl esters (FAME), namely biodiesel, by means of transesterification.

Biodiesel is an alternative fuel for diesel engines which can be produced using soybean, rapeseed, sunflower, cottonseed and palm oils. The type of vegetable oil used for biodiesel production change mainly depending on the oil production potential of a country. Additionally, waste vegetable oils with domestic and industrial origins and non-edible oils are used widely for biodiesel production with an increasing rate, which enables disposal of waste oil and production of low-cost biodiesel [5,6]. Because raw vegetable oils are produced at limited amounts and they are too expensive to be used as a biodiesel source. Biodiesels are not a full substitute for diesel fuel but they can be used as blends at low ratios with diesel fuel. In order to produce biodiesels, vegetable oils are usually transesterified using an alcohol catalyser like methanol or ethanol [7].

As shown in Table 1, the properties of biodiesel are similar to that of diesel fuel. Therefore, they can be employed in diesel engines without requiring important modifications [8]. An important advantage of biodiesels is their high cetane number, which results in better mixture formation with air, thus eventually promoting combustion and improving exhaust emissions. Another important feature of biodiesels is their high oxygen content, which causes a better combustion and increased combustion efficiency, thus yielding lower CO emissions as well as lower particle matter (PM) emissions [9]. On the other hand, biodiesels yield higher NO_x emissions as a result of high combustion temperatures in comparison to diesel fuel [10].

Density and viscosity of biodiesels obtained from different sources are higher than that of diesel fuel [11-13]. Biodiesels are not toxic, and they can be dissolved easily in nature [14]. Because biodiesels have a lower flash point, they are safer in terms of transportation, storage and utilisation compared with diesel fuel [5]. Moreover, because biodiesels have almost no sulphur content, they result in substantially lower SO_2 emissions [15]. Furthermore, when the courses of the cultivation of vegetables in agricultural areas and the use of biodiesels obtained from them in IC engines are taken into consideration, biodiesels are more advantageous in terms of total CO_2 release and carbon cycle. Therefore, the use of biodiesels is an important remedy for reducing CO_2 emissions, which substantially contributes the greenhouse effect promoting global warming [15].

In this regard, the use diesel fuels containing certain ratios of biodiesels are compulsory or incentivised in various countries. For example, EU aims at using biofuels to meet 10% of its total energy consumption for transportation purposes [6].

Table 1. Comparison of the properties of diesel fuel and biodiesel (soybean oil methyl ester) [12]

Property	Unit	Diesel Fuel	Biodiesel
Density	g ml^{-1}	0.84	0.87
Kinematic viscosity (at 40°C)	mm^2 s^{-1}	3.11	7.8
Moleculer weight	kg $kmol^{-1}$	170	296
Cetane number	-	46	52
Carbon content	wt %	87	78
Hydrogen content	wt%	13	12
Oxygen content	wt%	0	10
C/H ratio	-	6.69	6.5
Flash point	°C	78	166
Boiling point	°C	180-330	330
Lower calorific value	Mj kg^{-1}	42.50	38.812
Stochiometric air/fuel ratio	-	14.5	12.5
Self ignition temperature	°C	250	363
Latent heat of vaporization	kj kg^{-1}	250	200

3.1.2. The use and potential of biodiesels in Turkey

Raw material cost is an important portion of biodiesel price. In Turkey, a special consumption tax (SCT) of 0.91 TL/litre is applied to biodiesel starting from 2011. As a result of this tax and increases in production costs, the development of biodiesel sector in Turkey has ceased noticeably, and some companies cancelled their licenses. In spite of these cons, 34 companies got a licence for biodiesel production in Turkey. Total biodiesel production capacity of Turkish companies in 2011 was 0.561 million tons as reported by Turkish Energy Market Regulatory

Authority (EMRA) [17]. However, when the production of the companies without a licence is taken into account, the biodiesel production capacity of Turkey is about 1.5 million tons [18]. On the other hand, most of this capacity is currently idle and remains unutilised.

According to a regulation issued on September 27, 2011, it is compulsory to use diesel fuel with biodiesel additives obtained from domestic sources in Turkey. The additive ratios must be 1% in 2014, 2% in 2015 and 3% in 2016. Although the additive biodiesel ratio is low, considering that diesel fuel consumed in 2012 in Turkey was 18.51 million m^3, it can be stated that a total amount of about 0.55 million m^3 biodiesel will be required in 2016.

Then, the regulation regarding the addition of biodiesels to diesel fuel has been updated by EMRA [3]. The ratio of FAME blended with diesel fuel was revised as 0.3% in 2014 and 0.5% in 2016. Recently, the obligation of blending biodiesel with diesel fuel was repealed by a new regulation of EMRA due to difficulties related with raw material procurement [19]. Furthermore, it is accepted that 2% SCT will be refunded to the distributors when FAME obtained from domestic sources is used as additive in diesel fuel [20].

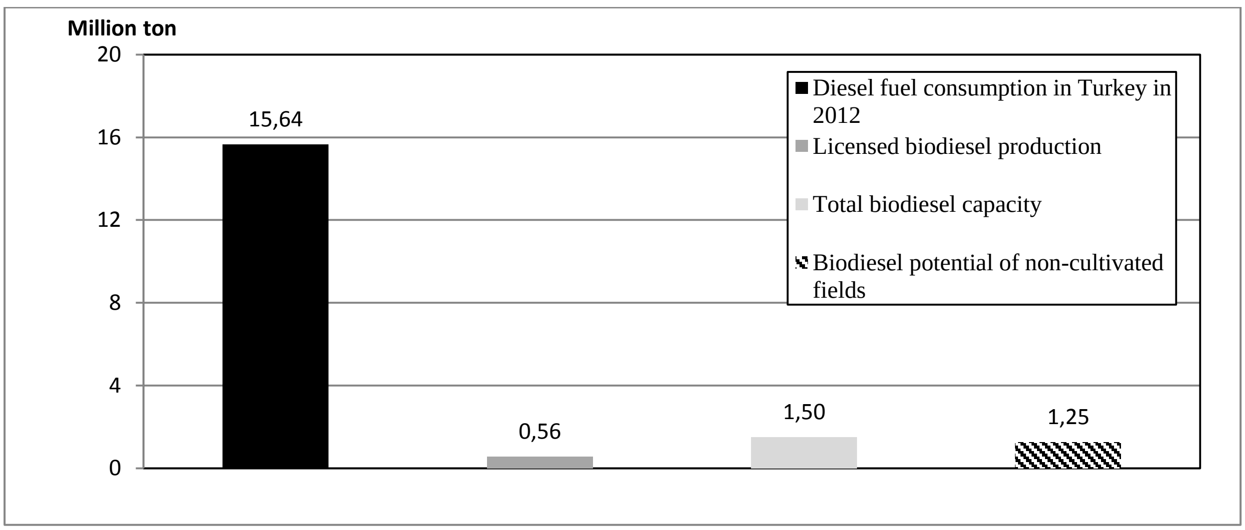

Figure 2. Biodiesel potential in Turkey

Table 2 reports the approximate amounts of biodiesel to be blended with diesel fuel in accordance with the cancelled regulations in Turkey. It is estimated that 90000 m^3 FAME will be needed to add 0.5% biodiesel produced from domestic sources to diesel fuel in 2017. Considering the biodiesel production capacity of Turkey, 0.561 million tons in 2012 as shown in Figure 2, the biodiesel demand in 2017 can be met easily. However, Turkey produces only about 30% of its vegetable oil requirement from domestic sources [21]. This fact can be regarded as the greatest handicap for biodiesel production in Turkey. On the other hand, considering non-cultivated fields, Turkey has a high production capacity of vegetable oil. It is estimated that by growing rapeseed, safflower, wheat and sugar beet in non-cultivated areas, it is possible to obtain 1.25 million ton biodiesel and 3.25 million ton bioethanol annually. [22]. As another source of biodiesel, it is estimated that annually about 0.4 million ton of waste vegetable oil can be collected with a wise planning. [23].

Considering low CO_2 emissions and economic advantage of biodiesels, it is clear that biodiesel blending ratios should be further increased. Although Turkey has enough plant capacity for biodiesel production, the growing of raw material for biodiesel production is insufficient. Therefore some incentives and planning should be made to increase the cultivation of vegetable oils for biodiesel production.

Table 2. Approximate amounts of biodiesel to be blended with diesel fuel in accordance with the cancelled Turkish regulations.

Year	2013	2014	2015	2016	2017
The ratio of biodiesel in diesel fuel (%) [3]	–	0.3	0.4	0.5	0.5
Biodiesel demand (m^3)	–	54000	72000	90000	90000
The ratio of biodiesel in diesel fuel according to cancelled regulation (%)	–	1	2	3	3
Biodiesel demand (m^3)	–	185000	370000	555000	555000

3.2. Bioethanol

3.2.1. Fuel properties of bioethanol and its use in IC engines

Bioethanol is obtained either by fermentation of agricultural products containing starch such as sugar beet, sugar cane, corn, wheat and potatoes or by acidic hydrolysis of cellulosic substances such as wood [24]. Bioethanol is obtained from the conversion of starch in agricultural products into sugar and then, fermentation of sugar. Molasses, a side product obtained in sugar production, is a substance used for alcohol production.

Because bioethanol is an alternative fuel obtained from renewable sources, it is useful for lessening environmental contamination. Since bioethanol is obtained from agricultural crops, it is advantageous in terms of CO_2 emission cycle when the courses of its production and its use in IC engines are taken into consideration. Therefore, bioethanol is either incentivised or obliged to be used as an additive to gasoline in some countries. Furthermore, it is reported that using 85% bioethanol is more effective in terms decreasing greenhouse gas emissions [25].

Table 3. Fuel properties of gasoline and ethanol [26]

Property	Unit	Gasoline	Ethanol
Molecular weight	kg $kmol^{-1}$	114.15	46.07
C-fraction	mass %	87.4	52.2
O-fraction	mass%	-	34.7
H-fraction	mass%	12.6	13
H/C	-	1.795	3
Density (at 15°C)	kg m^{-3}	750-765	785-809
Stoichiometric air/fuel ratio		14.2-15.1	8.97
Kinematic viscosity	mm^2 s^{-1}	0.5-0.6	1.2-1.5
Research Octane No. (RON)	-	91-100	108.61-110
Cetane number	-	8	5
Lower heating value	Mj/kg	44	26.9
Latent heat of vaporization	kj/kg^{-1}	380-400	900-920
Boiling point	°C	27-225	78
Auto ignition temperature	°C	257	425

The fuel properties of gasoline and ethanol are indicated in Table 3. The most important fuel property of bioethanol is its considerably high octane number (RON110). However, it has extremely low cetane number of below 5. As a result of these properties, bioethanol can be used in gasoline engines as pure fuel or blended with gasoline. The high octane number of bioethanol improves its an anti-knock characteristics, thus allowing higher compression ratios in gasoline engines, which eventually causing increased thermal efficiency and improved specific fuel consumption [27]. Moreover, because bioethanol has high oxygen content, it increases the oxygen content of the blended fuel, thus improving air-fuel mixture formation and combustion. Consequently, the improved combustion yields decreased CO and HC emissions [28,29]. Bioethanol also increases volumetric efficiency of gasoline engines due to its high latent heat of vaporization. Furthermore, bioethanol absorbs more heat from the cylinder as a result of its high heat of vaporization, thus causing lower in-cylinder temperatures and eventually lower NO_x emissions [30]. Extremely low cetane number of bioethanol makes self-ignition of air-fuel mixture difficult, thus not enabling the use of bioethanol in diesel engines as pure fuel. Another obstacle precluding the use of bioethanol in diesel engines is its extremely low viscosity and density, which deteriorates lubrication characteristics of fuel passing through the injection system. On the other hand, low ratios of bioethanol blended with diesel fuel can be used in diesel engines. It was reported that the use of bioethanol blended with diesel fuel improves PM emissions [31]. Furthermore, biomethanol with low viscosity is blended with biodiesel to decrease its viscosity. Moreover, the stratification observed when ethanol is added to diesel fuel can be prevented by using biodiesel additive [32].

3.2.2. The use and potential of bioethanol in Turkey

Since there was not a legal obligation for using bioethanol as IC fuel or additive in Turkey for many years, it was not considered as a fuel seriously. However, as a result of recent incentives and legal obligations regarding the use of biofuels as additives, the number of studies on the production of bioethanol has increased. It was stated that Turkey has currently a bioethanol production capacity of 149.5 million litres [33]. Turkey has three large-scale plants for bioethanol production. The largest of them is Konya Sugar Factory, which produces about 56% of total bioethanol production in Turkey. This plant uses sugar beet and molasses as raw material. Other two plants located in Bursa and Adana use corn and wheat as raw material for bioethanol production.

In addition to the current bioethanol production potential of Turkey, there is an important unutilised production potential as well. Studies have shown that Turkey has an annual bioethanol production capacity of 2.50 million tons from sugar beet [34,35] as shown in Figure 3. This value can meet almost the entire gasoline consumption of Turkey in 2012, which was 1.91 million tons.

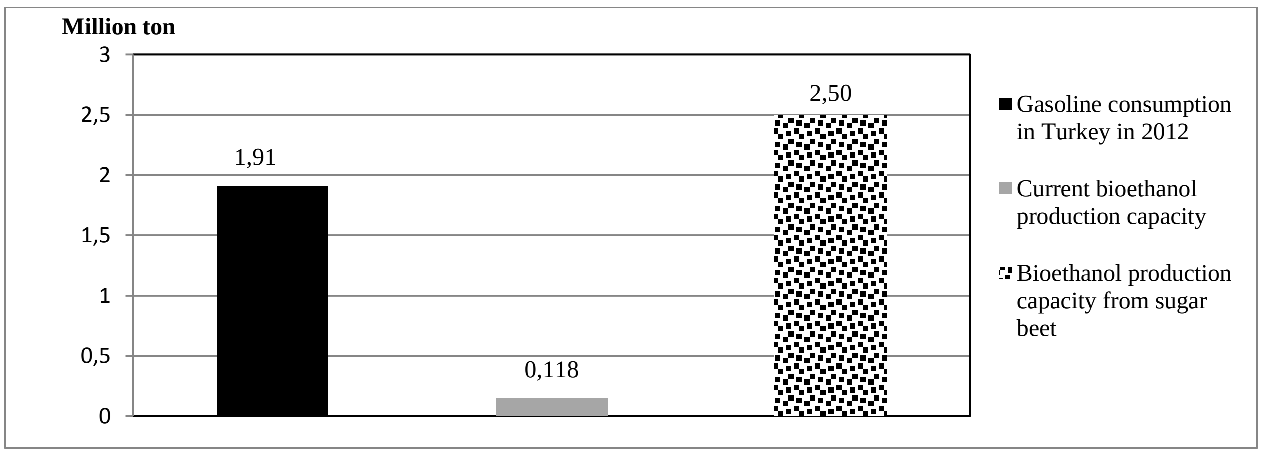

Figure 3. Bioethanol potential in Turkey

Various legal regulations for the use of biofuels in IC engines have been issued in Turkey. According to the regulation dated September 27, 2011, it is compulsory to use bioethanol obtained from domestic sources blended with gasoline at ratios of 2% and 3% in the years of 2013 and 2014, respectively [36]. Similar to practices in biodiesel, 2% of the bioethanol produced from domestic sources is exempted from SCT.

Table 4. Bioethanol requirement of Turkey produced from domestic sources for blending with gasoline

Year	2013	2014
Bioethanol ratio in gasoline (%)	2	3
Bioethanol demand (m3) (according to gasoline demand in 2012)	49341 m^3	74012 m^3

Considering the current gasoline requirement, approximate bioethanol amount demanded in Turkey according to the above regulation is reported in Table 4. When preparing the table, the gasoline demand of 2.467 million m^3 in 2012 was taken into account. It can be estimated that bioethanol amount produced from domestic sources is 74000 m^3. It is clear that this demand is reasonable, and can be provided easily when considering the present bioethanol production capacity of Turkey. Furthermore, bioethanol–gasoline blends containing over 3% bioethanol can be obliged by new regulations in Turkey. The blending ratio of bioethanol in gasoline for transportation sector in EU will be 10% by 2020. This ratio can also be adopted in Turkey in near future. Moreover, it is seen that Turkey has a potential production capacity of bioethanol to be used in diesel engines as a low ratio additive to diesel fuel.

Conclusions

- Diesel fuel consumption in Turkey was 15.64 million tons in 2012. Biodiesel production capacity of the licensed plants in Turkey was 0.56 million tons. However, this capacity was about 1.5 million tons when productions in unlicensed plants are taken into account.
- Currently, there is not a regulation specifying an obligatory blending ratio of biodiesel with diesel fuel in Turkey. However, this ratio should be increased to at least to 3%, which was the ratio in the previous regulations.
- Gasoline consumption in Turkey was 1.91 million tons in 2012. Current bioethanol production capacity, on the other hand, is 149.5 million litres. Turkey has a considerable potential of producing bioethanol using various agricultural crops. It is estimated that the bioethanol production capacity only from sugar beet can be as high as 2.5 million tons.
- Bioethanol produced from domestic sources is currently added to gasoline at the ratio of 3% in Turkey. This ratio should be increased immediately.
- When considering current plants and production potentials in Turkey for bioethanol and biodiesels, it is possible to use higher ratios of biofuels as additives. It will be a very easy and effective method to use fuels containing higher ratios of biofuels to decrease greenhouse gas emissions such as CO_2 caused by IC engines.

- Considering the cultivation of the crops used in the production of biofuels, the use of biofuels at higher blending ratios will increase the ratio of employment and will have a positive impact on the economy of the country.
- In order to utilise the renewable fuels more efficiently, some precautions such as incentives and tax exemptions should be taken. Therefore, the ratio of tax exemptions for the use of biofuels produced from domestic sources should be increased in Turkey.

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