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Using biodiesel fuel for gas turbine combustors

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Abstract

Biodiesel fuel (BDF) mainly refined from vegetable oil has been applied to diesel cars for more than ten years. The objective of this study is to widen the applicability of BDF to other areas to promote its production and consumption, and reducing emissions of carbon dioxide and diverting energy sources. Using BDF for gas turbine engines has various impacts on the environment and on economics, and requires a high quality of technical frame conditions. The combustion rig tests of a 20 MW gas turbine combustor at high load with two different fuels, a biodiesel fuel and a common petroleum diesel fuel, were performed to investigate the needed technical feasibility. The environmental impact was also investigated through the detailed measurement of the exhaust gas of the combustor. The results show that BDF can be technically a promising alternative fuel for land-based, marine-based and aero-space-based gas turbine engines, however it is very expensive compared with conventional fuels.

Keywords: *biodiesel fuel, environment protection, gas turbine engine, alternative fuel, exhaust gas*

Zusammenfassung

Einsatz von Biodieselkraftstoff für Gasturbinen

Biodiesel (BDF) wird hauptsächlich aus Pflanzenöl hergestellt und wird als Dieselöl in Kraftfahrzeugen seit mehr als zehn Jahren verwendet. Diese Studie hat das Ziel gesetzt, die Anwendung von BDF auf andere Bereiche zu erweitern, um die Produktion und den Verbrauch zu fördern, die Kohlendioxid-Emissionen zu verringern und die Nutzung von alternativen Energiequellen zu ermöglichen. Der Einsatz von BDF für den Gasturbinenantrieb hat verschiedene Auswirkungen auf die Umwelt. Versuche an einer 20 MW Gasturbinen-Brennkammer bei hoher Last und mit zwei verschiedenen Brennstoffen, d.h. mit einem Biodieselkraftstoff und einem handelsüblichen fossilen Dieselkraftstoff wurden mit dem Ziel vorgenommen, die benötigte technische Machbarkeit zu untersuchen. Die Umweltbelastung wurde durch die detaillierte Messung der Abgasqualität in der Brennkammer untersucht. Die Ergebnisse zeigen, dass BDF technisch ein vielversprechender alternativer Kraftstoff sowohl für Gasturbinentriebwerke in der Kraftwerkstechnik, als auch für die Luft- und die Schifffahrt ist, obwohl sie im Vergleich mit den herkömmlichen Kraftstoffen sehr kostspielig ist.

Schlüsselworte: *Biodiesel, Umweltschutz, Gasturbinentriebwerk, alternativer Kraftstoff, Abgas*

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1 Introduction

Global energy consumption is rapidly increasing due to the strong demand in developing countries. The annual increasing ratio reached 2.3 % in 2013. Today, fossil oil is the most dominant energy source making up 32.9 % of total global energy consumption (BP, 2014). However, the continuous long-term use of fossil oil may cause some serious issues such as global warming and the cost increase in the energy system. Moreover, fossil energy resources are regionally concentrated. According to the statistics, the supply is mostly dominated by the Middle Eastern countries, Russia, the United States and China. Of these, the United States and China not only supply a large amount of energy, but also consume a large amount as well.

The R/P (Reserves-to-production ratio) of fossil oil is currently considered to be between 40 to 80 years (BP, 2014; Wikipedia, 2014a; Worldometers, 2015; CNBC, 2011), depending on the development of oil mining, drilling and exploration technologies. Over the past decade, global proved reserves have increased by 27 % due to technological developments (BP, 2014), among which one of the most remarkable methods is shale mining technology in the United States. This technology is going to make the USA the world's leading oil-producing country in a few years' time. Figure 1 compares the relationship between the price of fossil oil and total global consumption in the last 10 years. It shows a clear trend of the increasing consumption with the increase in price; exceptions to this trend can be attributed to the temporal market and to various political reasons. One of the most remarkable exceptions is the recent "temporal" decrease in price, which is believed to be related to the strategy of oil producing countries against the rapid increase in the production of shale oil in the USA. However, this tendency will be recovered in a few years.

Moreover, global climate change due to the exploration for and consumption of fossil oil is an urgent issue which should be solved only from a global base with a sincere effort of cooperation from every country in the world.

Increasing the production and consumption of alternative fuels is of great importance to help solve the issues related to the worldwide consumption of fossil oil presented above. Both the diversity of energy sources and the preservation of the global environment have to be considered. Main tasks are:

1. technological developments must consider the increased utilization of wasted resources as a future feedstock
2. further technological innovations that will expand the use of the alternative energy to promote the production and consumption of bioliquids.

Biodiesel fuel (BDF) is usually made from natural fat, main components of which are fatty acid methyl esters (see Figure 8 and related descriptions below for the detailed chemical component analysis of BDF). BDF is one of the important biofuels owing to the advantage of its large potential of CO_2 emission reduction compared to the fossil oil. The average lower heating value of BDF is approximate 38 MJ/kg, which is only 10 % lower than that of usual petroleum diesel fuel (Mehta and Anand, 2009). Moreover, BDF can be refined from natural fat through a fairly simple chemical process, such as alkaline catalysed trans-esterification, which produces less amount of CO_2 through the refinery process, leading to a larger amount of CO_2 reduction evaluated through a life cycle analysis (LCA). The simple process also leads to the lower cost of production. BDF is therefore widely used for alternative fuel for diesel engines.

Biodiesel fuel can be produced not only in large industrial facilities, but also in small factories because of the fairly simple conversion process of waste cooking oils to BDF

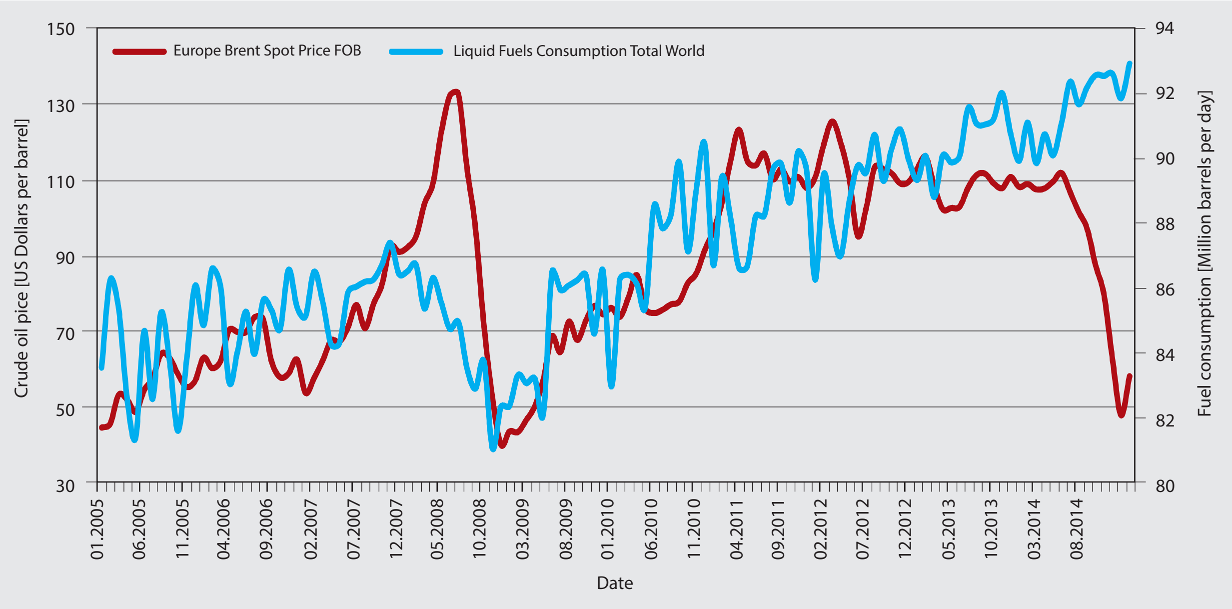


Figure 1

Relationship between pricing and using fossil fuels on the past 10 years (EIA, 2015a; EIA, 2015b) through alkaline catalysed trans-esterification technology. The refinery process can be performed under atmospheric conditions in small scale plants with low initial investment, unlike Fischer-Tropsch and hydrocracking processes which need to be performed under high pressure conditions with special catalysts and hydrogen.

The possibility of use of BDF for land-based gas turbine engines is investigated in this study to widen the applicability of BDF.

BDF and its feed stocks could further be refined to alternative aviation fuel, specified as ASTM D7566, through the deoxidation and isomerization processes with the high pressure hydrotreatment which needs a large scale chemical plant. Currently, it needs some further research to convert fat and BDF to aviation fuel in a cost-effective way at distributed small scale plants, which is out of the scope of this study.

2 Availability of the feedstock of BDF

World biodiesel production was 24.7 million tons in 2013 which accounted for 22.6 % of total global biofuel production (Rapier, 2014). The leading producer countries and the main feedstock are presented in Table 1:

Table 1

Global biodiesel production and its main feedstock in 2013 (Budiman et al., 2013)

Country	Share of the total production [%]	Main feedstock
USA	14	Soybean oil
Brazil	11	Soybean oil
Indonesia	9	Palm oil
Germany	9	Rapeseed oil
France	8	Rapeseed oil
Other countries	49	Soybean oil

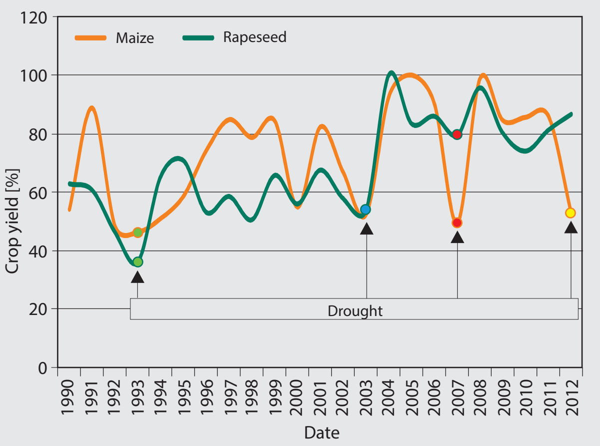


Figure 2

Impacts of climate change in the yield of bioliquid feedstock crops in Hungary compared to the highest yield year (KSH, 2012)

Figure 2 shows the fluctuations of maize and rapeseed production in Hungary. These fluctuations can be attributed to the weather and to market forces.

The use of oilseeds is growing rapidly today. For example, whereas one hundred years ago sunflower seeds were only considered food, they are now important feedstocks for BDF in Europe. Non-food crops, such as Camelina and Jatropha, have the advantage of diverting the conflict between food and energy though they are not currently successful in diverting it entirely because these energy crops often take away land meant for food crops. Therefore, on 28 April 2015, the European Parliament voted to approve new legislation, the "iLUC Directive", that limits the using food biomasses for energy production. Member States can meet the target of 10 % for renewables in transport fuels by 2020. There will be a cap of 7 % on the contribution of biofuels produced from food crops, and greater emphasis on the production of advanced biofuels from waste feedstocks (EBTP, 2015).

Another important feedstock of BDF is waste cooking oil. This might be categorized as the simple recycling of wasted energy carrier, but the total amount of this feedstock cannot be neglected as it could be a major feedstock for BDF, see Table 2. Currently, the collection systems for waste oil from cooking or from industrial production, has not yet been effectively constructed, not even in large cities. It is really disappointing that waste cooking oil containing much untapped energy is treated as nothing more than flammable garbage, and is burned thereby producing carbon dioxides. It is estimated that at least 70 % of the waste cooking oil in cities could be recovered, owing to the statistical data of gathering valuable metals like Aluminum (Diya'uddeen et al., 2012).

Table 2

Availability of waste cooking oil (WCO) in different countries (Shi and Zhang, 2014; JFS, 2011; GF, 2011; Chhetri et al., 2008)

Country	WCO [10^3 t/year]	WCO [kg/capita]	Population [10^6]
China	6580	4.9	1 351
USA	1400	4.5	319
EU	1000	2.0	508
Japan	400	3.1	128
South Africa	200	3.8	52

Currently is great demand the use of waste cooking oil. China's biodiesel production was 1.13 billion litres in 2014. China has 53 biodiesel plants, with total capacity estimated to be 4 billion litres. The lack of capacity utilization is attributed, in part, to a lack of large-scale collection of waste cooking oil (Voegele, 2015). China implemented a trial biodiesel program in Hainan, but that trial program has been confined to only two counties since 2010, largely due to inconsistent supplies of feedstocks, mainly waste cooking oil (GAIN, 2013).

In the USA has also serious intention. In 2007 the Energy Independence and Security Act amended the Renewable Fuels Standards (RFS2), thereby setting a target of more than 136 billion litre of biofuels in 2022. At least 3.8 billion litre have to be advanced biodiesel with more than 50 % greenhouse gas savings compared to conventional biodiesel. On federal level the USA has introduced a tax credit for 1$ per gallon for biodiesel from waste cooking oil (Spöttle et al., 2013).

The EU is the world's largest biodiesel producer. Biodiesel is also the most important biofuel in the EU and, on energy basis, represents about 80 % of the total transport biofuels market. Feedstocks for advanced biofuels (such as FAME form waste cooking oils) count double toward the overall renewable energy targets in order to initiate transition to biofuels with lower ILUC risks (GAIN, 2014).

3 Economic aspects

The most sensitive key factors for the economic feasibility of the BDF plant are (Kasteren and Nisworo, 2007):

- raw material price
- plant capacity
- glycerol price capital cost

The price of the food plant-based BDF is influenced not only by the fluctuation of production depending on the local climate, but also a variety of factors such as investment of money market funds. Feedstock is the largest component of the cost of BDF, which is around 70 to 95 % of the overall cost (MSZO, 2013), see Figure 3. Using waste cooking oil is one of the recommended methods to reduce the price of BDF from the viewpoint of reduced feedstock cost. Moreover, using waste cooking oil also reduces the cost for disposal (Chhetri et al., 2008).

To date, the development of conventional biodiesel has been associated with mandates or other supportive programs such as tax incentives. Conventional biodiesel is characterized by relatively low yields per unit of land compared to other bioliquids. Biodiesel feedstocks (e.g. palm oil) are coupled with environmental problems such as deforestation and the subsequent eutrophication of water sources. Biodiesel is highly sensitive to increases in oil price (Cazzola et al., 2013).

Compared to the price of petroleum diesel, the price of traditional feedstock is too expensive to be commercialized. Using waste cooking oils for biodiesel production significantly saves cost, which is approximately 60 % lower than that of conventional vegetable oils (Predojevic, 2008), refer Table 3.

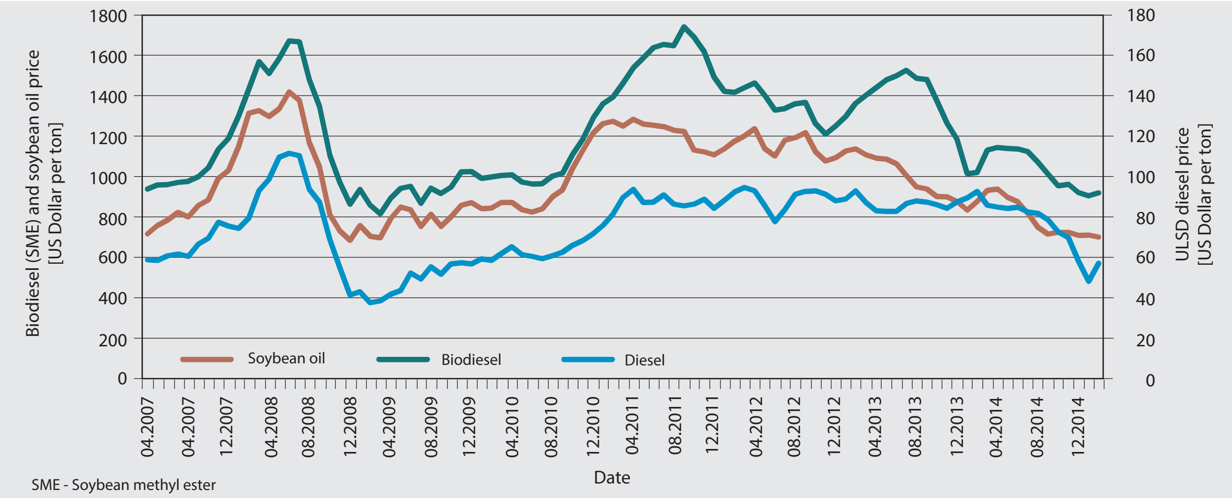
Table 3
Biodiesel raw material prices in the past 10 years (IM, 2015)

Type of oil	Price [US$ per ton]
Sunflower oil	650 - 2300
Rapeseed oil	700 - 1750
Soybean oil	400 - 1400
Palm oil	350 - 1200
Waste cooking oil	200 - 1000

Even the price of waste cooking oil is still too high to be commercially used. In addition, competition for these resources between the fuel and the food industry makes it impossible to realize a large scale introduction of bioliquids (Wang, 2012).

Various government interventions are fighting to bring the cost of bioliquids down. Low fossil fuel prices are very disadvantageous for bioliquids production because they hinder technological development (Carriquiry and Babcock, 2008).

Using a supercritical trans-esterification process for biodiesel production from waste cooking oil leads to processing high purity of methyl esters (99.8 %) and almost pure glycerol (96.4 %) is processed as a by-product. The globally



SME - Soybean methyl ester
ULSD - Ultra.low-sulphur diesel

Figure 3
Comparing the price of soybean oil, biodiesel and diesel between 2007 and 2014 (IM, 2015; CARD, 2015)

increasing production of biodiesel and fatty acids leads to an oversupply of the generated by-product glycerol. The glycerol can use among other things in the food and pharmaceutical industries, but it is much larger volume is formed as could be applied. As a result, the glycerol price declines significantly, but can reduce some extent the costs of biodiesel production (ab&cd, 2014).

4 Environmental benefits of BDF

There has been some research and development with biodiesel combustion. The reduction of GHG emissions can reach up to 86 % (EPA, 2010), see Table 4.

Table 4

Decreasing emissions by using biodiesel in heavy duty highway engines (EPA, 2002)

Pollutants	Emissions [%]
PM	-30
CO	-50
Ozone-forming (smog)	-50
PAH	-80
Unburned HC	-93
SO_2	-100

BDF based on waste cooking oil basically adds no extra CO_2 greenhouse gas to the atmosphere except for some power needed to operate the plant and transportation. Moreover the use of waste cooking oil as BDF feedstock reduces the harmful load in sewers, sewage treatment plants, landfill, soil and living aquatic ecosystem (HE, 2014).

In an effort to avert political conflicts and reduce foreign oil dependency, the increased use of bioliquids may be justified. This increased usage would also have environmental benefits. Due to the high use of fossil fuels, the number and the severity of oil spill accidents in extraction, transport and processing into the environment. Over the past ten years 613 thousand tons of oil has spilled by accident worldwide (Wikipedia, 2015).

Currently, BDF is not generally popular for industrial gas turbines, but it could be a promising alternative fuel for gas turbines operating with diesel fuel. Biodiesel operated diesel engines, combined with other renewable energy sources such as solar or wind power, may be suitable for electricity generation for consumers outside the current energy grid.

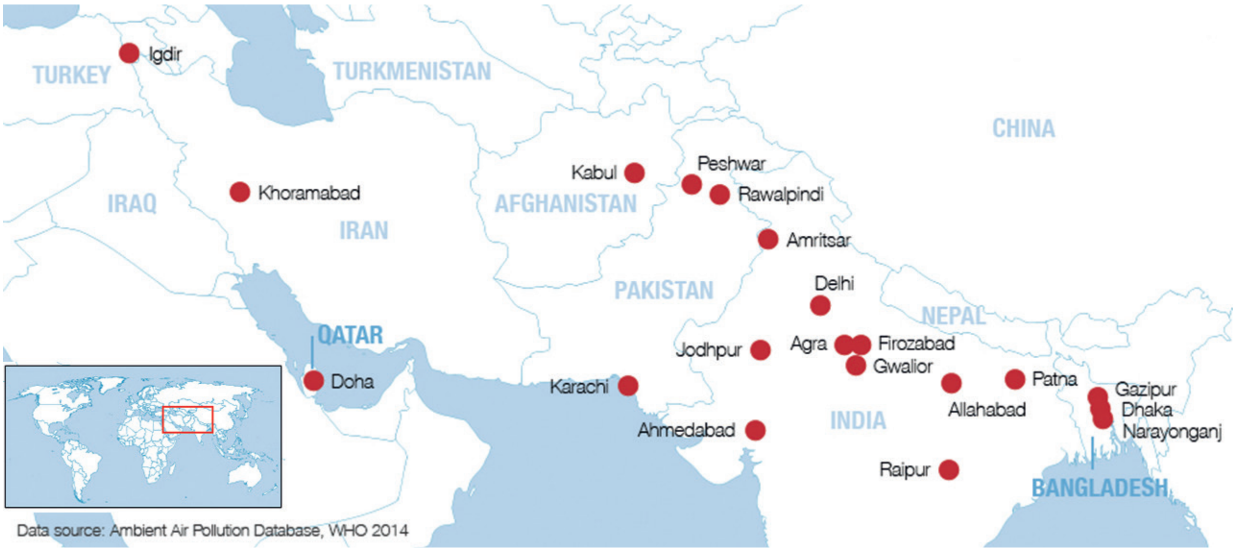
There are further application possibilities in highly polluted cities with environmentally sensitive areas by supply with peak electricity, see Figure 4.

5 BDF application to gas turbines

Gas turbine manufacturers currently tend to design combustors operating with multi fuels such as natural gas, diesel and heavy oils, responding to the strong demand of the customers for diversity of the fuel used.

Diesel fuel is not specifically applied in large power plants, but it is especially used in peak power turbines for the purpose of electricity generation, and has a significant role in transportation (Wikipedia, 2014b). Most peak power turbines use gas as fuel. In the EU the market for gas-fired power plants will grow very intensively. Between 2001 and 2011 natural gas dominated the fuel type for gas turbines by 40 % and diesel fuel by 16 %. The Far East claimed the top geographical location for gas turbine orders by 35 % (Haight, 2012).

The nuclear phase-out in Germany, which is one of the largest markets for nuclear power, will result in a growing



Data source: Ambient Air Pollution Database, WHO 2014

Figure 4

Top 20 most polluted cities in the world in 2014 (CNN, 2014) need for alternative energy sources like biodiesel as well (Ecoprog, 2011). Worldwide, the market for natural gas–fired power generation equipment is highly concentrated. The current global natural gas–powered capacity stands at around 1300 GW, out of which over 35 % is located in North America (Sontakke, 2015).

Japan consumes a large amount of electricity; its consumption per capita reached 7700 kWh in 2010, i.e. the same level as the OECD, but 30 % higher than the EU average. The share of electricity represented about 25 % of total energy consumption in 2010. Nuclear power contributed more than 25 % to electricity production, which is about the same contribution as coal and gas.

Power generation from nuclear energy has been considerably reduced since Fukushima. In 2011 only 11 % of reactors were in operation. As a result, total power production decreased by 5 % in 2011 and nuclear power production was reduced by 43 % between 2010 and 2011. In the same time interval, thermal production increased substantially. In 2011, this demand increased by 18 % (Sebi, 2012).

It is widely known that the most effective power generation plant is a combined cycle, in which gas turbines operate with the steam turbines connected with the exhaust heat of the gas turbines. The combined cycle plant tends to be a large scale one because it uses a lot of water. The power plants with only gas turbines are more compact and flexible, and are often used to respond to peaking power demand. Due to their compactness, they are often applied for as a source of distributed energy, such as the co-generation of heat and electricity for shopping malls or large buildings. Gas turbines are also suitable for remote military facilities, mine sites and rural or isolated communities. Moreover, gas turbines, which can start very quickly reaching full power in a few minutes, play an important role in power generation during emergency situations when there may be power outages. Many large hospitals currently equip gas turbines for use in emergency situations. A combination of a compact and simple gas turbine operating with a small refinery plant treating waste cooking oil could be one of the best energy supply systems in small communities.

6 Technical feasibility

6.1 Combustion rig test

A combustion rig test of a 20MW gas turbine combustor at high load was performed with two different fuels, a biodiesel fuel and a usual petroleum diesel fuel. The combustor of the gas turbine consists of ten single can combustors located circumferentially. Each of them has an air blast fuel nozzle at the head and some dilution holes on the liner wall, see Figure 5. A combustion rig test was performed with the single can combustor test model. The effect of the fuel change was investigated on the emission, such as NOx, CO, hydrocarbons, particular matter, stability, ignition, blow out and exit gas temperature. The combustion test was performed in JAXA-AP7 rig, see Figures 5 and 6.

Type-B thermocouples were used to measure the combustor exit temperature distribution. Horiba MEXA7000 was used to measure the chemical component of exhaust gas, where NOx, CO and hydrocarbons were measured through chemo-luminescence detector (CLD), non-dispersive infrared detector (NDIR) and flame ionization detector (FID), respectively. Soot concentration was measured through AVL 415SE, a filter type smoke meter.

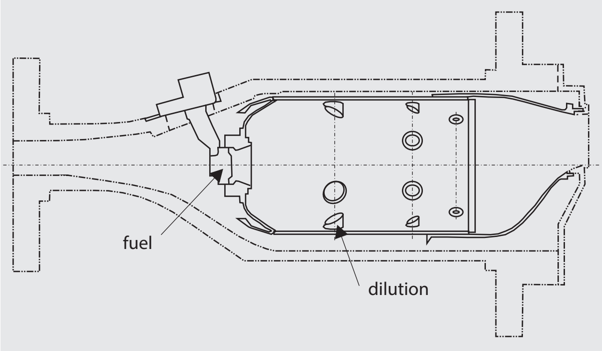


Figure 5
Schematic view of the can combustor

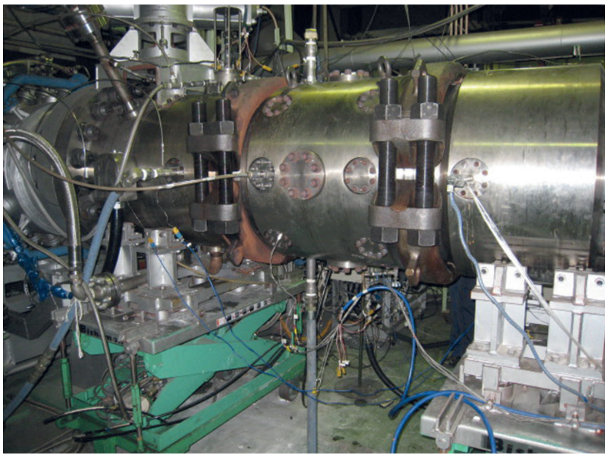


Figure 6
JAXA AP7 combustion test rig

The feedstock of the BDF was waste cooking oil, which was gathered and refined with Alkali catalysed trans-esterification reaction at the facility of Fuchigami co Ltd. located in the southern part of Japan, see Figure 7.

The main component of the BDF was a fatty acid methyl ester (FAME), which consists of various compounds with various length of the carbon chain. According to the chemical analysis of the BDF used in this study, presented in Figure 8, the representative chemical formula can be shown as $C_{17}H_{33}$-CO-O-CH_3. This is fairly different from that of the usual diesel fuel, CnHm (n is usually ranging from 10 to 20 with the peak value at around 17) which does not contain any oxide.

Downstream view of the single can combustor test model is shown in Figure 9, in which a thermo-couples rake and an exhaust gas sample probe are also shown; both of

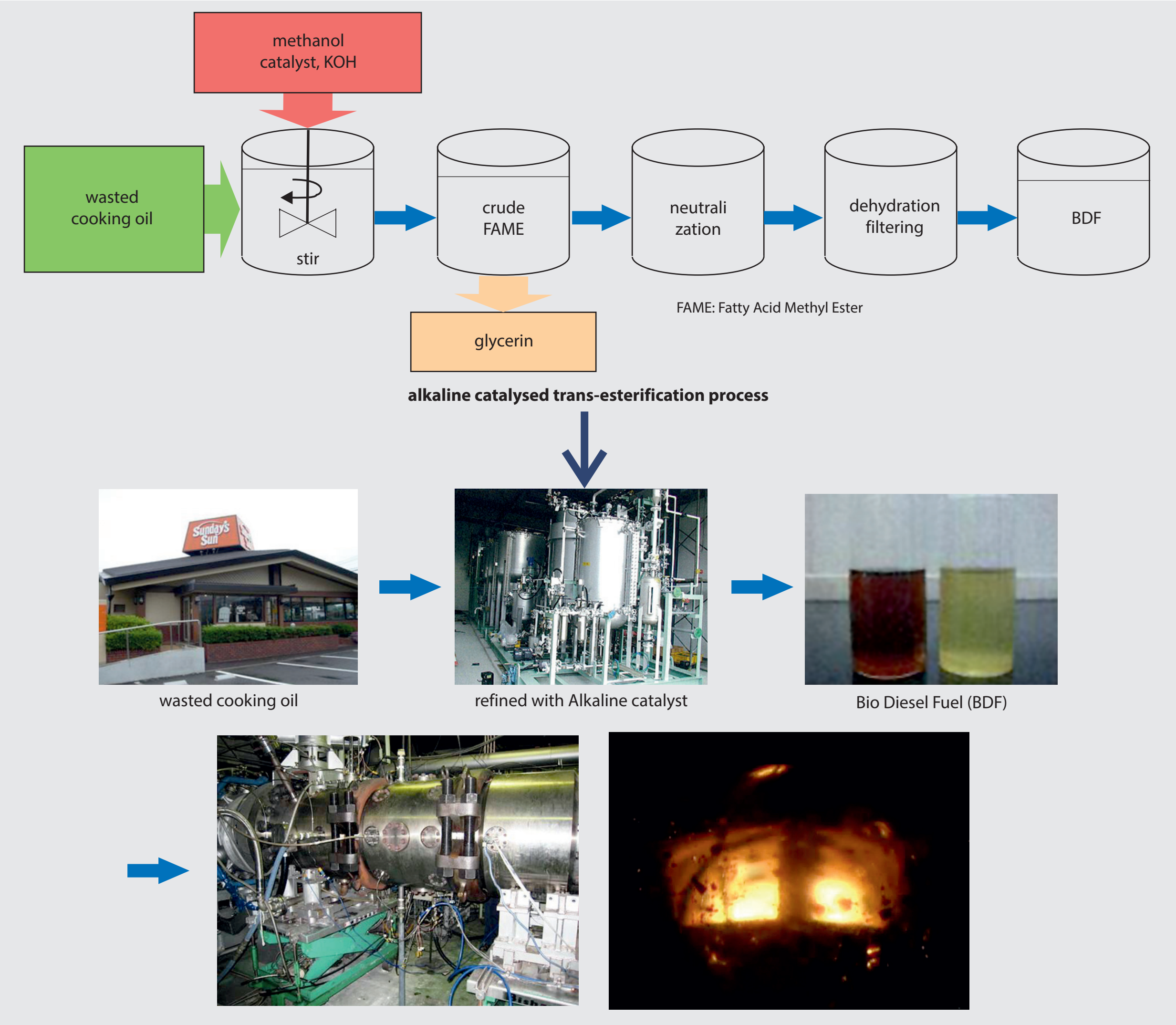
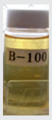
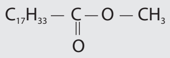


Figure 7
BDF refinery and combustion test

them move for circumferential direction to measure the distribution of temperature and components of the exhaust gas on the exit surface of the can combustor.

Fatty acid methyl ester
(FAME) = BDF





$C_{17}H_{33}-\underset{\underset{\displaystyle O}{\|}}{C}-O-CH_3$ $C_{19}H_{36}O_2 \Longleftrightarrow$ diesel $C_{15}-C_{17}$

total molecular weight of BDF
12 x 19 + 1 x 36 + 16 x 2 = 296

theoretical mass percentage
C : 12 x 17 / 296 = 0.770 (77.0 %)
H : 1 x 36 / 296 = 0.122 (12.2 %)
O : 16 x 2 / 296 = 0.108 (10.8 %)

Chemical analysis of BDF

	Unit	BDF
carbon	mass %	76.5
hydrogen	mass %	12.4
oxygen	mass %	10.9
sulfur	mg/kg	< 10
nitogen	mass %	< 0.01

Showing good agreement with the theoretical percentage

Figure 8
Chemical analysis of BDF

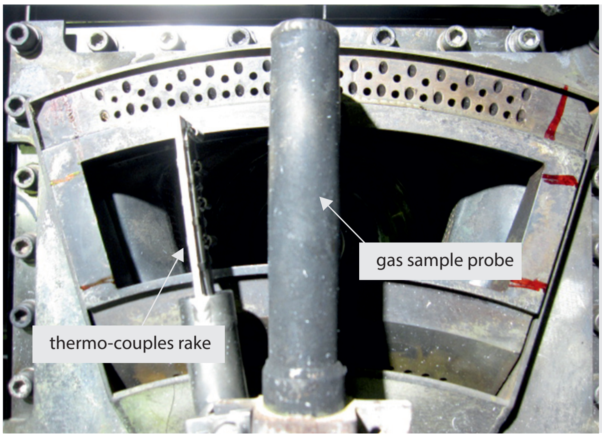


Figure 9
Downstream view of the can combustor test model

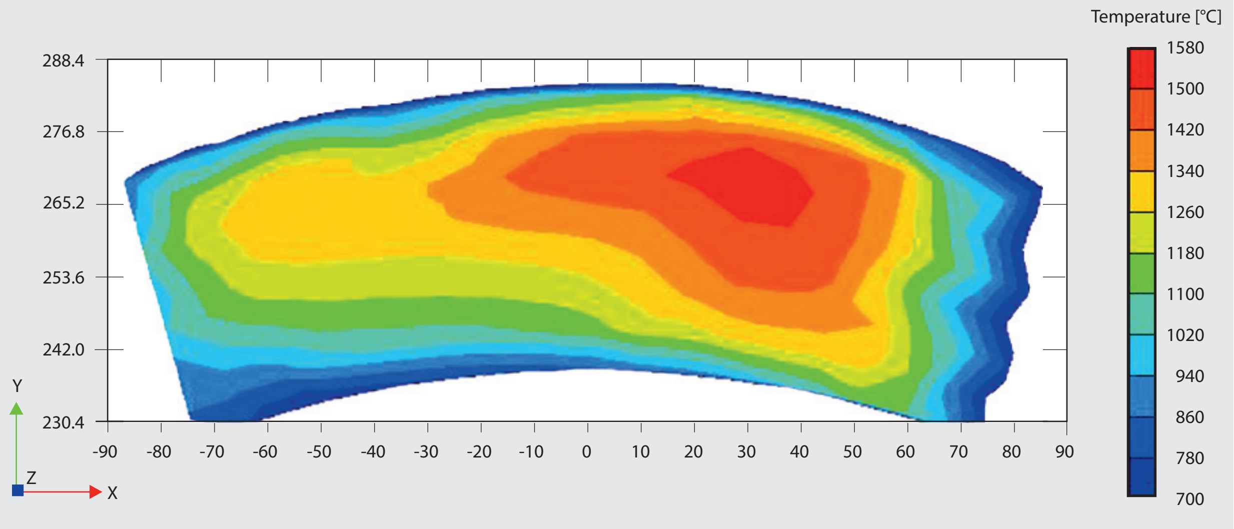


Figure 10
Exit temperature distribution at diesel fuel [°C]

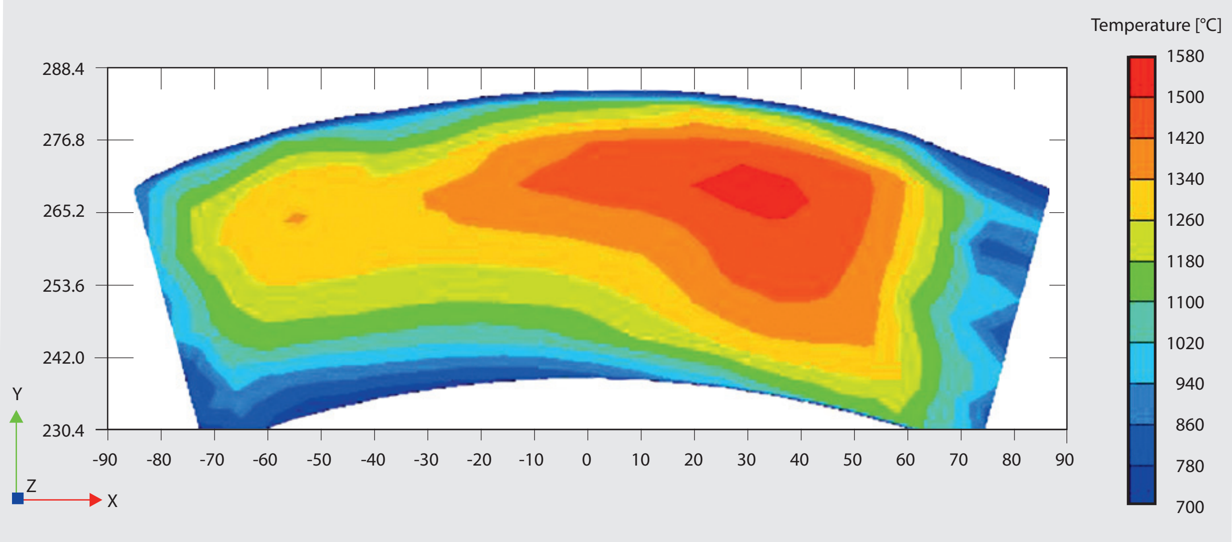


Figure 11
Exit temperature distribution at BDF [°C]

6.2 Test conditions and results

Inlet air pressure was 1220 kPa and temperature was 750 K, and the maximum outlet temperature reached 1800 K. The fuel flow at the rig tests of BDF and diesel could be carefully controlled so that the exit temperature of the combustor was nearly equal to each other to evaluate the difference of emission at the same operating condition of the gas turbine. Figures 10 and 11 present the exit temperature distributions of diesel and BDF combustion tests, showing that the exit temperature distributions are fairly similar to each other.

The fuel-to-air ratio was 2.01 % for petroleum diesel fuel and 2.22 % for BDF, implying that around 10 % additional fuel mass flow is needed for BDF to achieve the same exit temperature due to the smaller net heat release per unit mass of BDF compared with the usual diesel fuel. The similarity of the exit temperature distribution implies that the effect of the fuel change from diesel to BDF on turbine blades and nozzles is small and that the output of the turbine will be nearly the same if the mass flow of BDF is 10 % more than that of the diesel fuel.

Figures 12 and 13 present the distribution of NOx and CO concentrations on the exit surface of the combustor along the circumferential direction ranging from -18 degree to +18 degree. The NOx emission of BDF is lower than that of diesel, though the difference is small. CO emission of BDF also tends to be lower. THC (Total Hydrocarbon) concentration was measured as well, but was negligibly small in both cases.

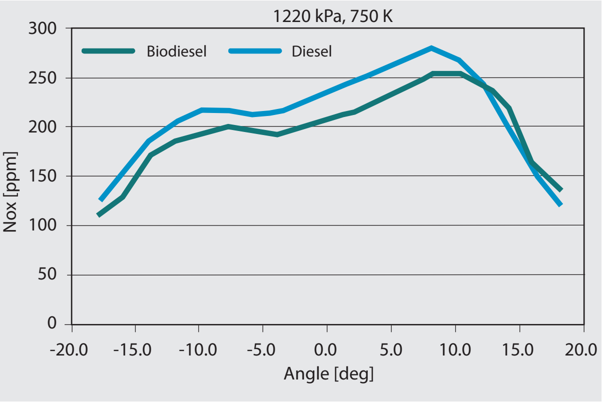


Figure 12
NOx concentration at combustor exit surface

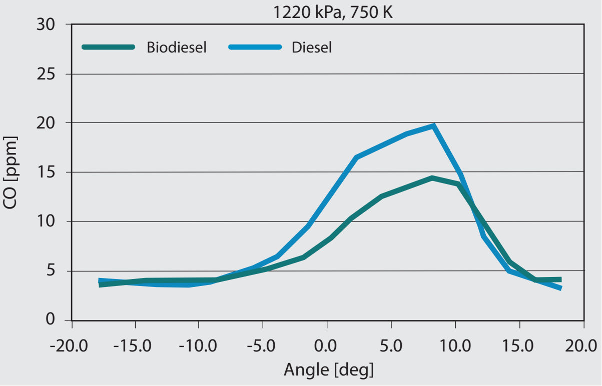


Figure 13
CO concentration at combustor exit surface

Soot concentration, mg of soot per unit m^3 of exhaust gas, was measured with AVL 415S filter type smoke meter only when the gas sample probe was located at the central position (0 degree) with various values of air/fuel ratio of diesel (AFR_diesel) and that of BDF(AFR_BDF). The result is shown in Figure 14. It should be noted again that 10 % more fuel is needed for BDF compared to diesel fuel as is explained above, therefore, it is reasonable to make the horizontal axis AFR*, where AFR* = AFR_diesel for diesel combustion, while AFR*=AFR_BDF×1.1 for BDF combustion to compare exhaust soot concentration of diesel and BDF at the same operating condition. The soot emission of BDF has been clearly lower than diesel. The common petroleum diesel fuel contains 15 to 20 % of aromatics, while the chemical analysis of the BDF showed that the aromatics are not contained, which is considered to have a favourable effect on the suppression of PM (Particulate Matter) formation through the combustion process of BDF. Ignition and blow out characteristics of BDF have been excellent at the rig test though they have not yet been surveyed over the whole operating condition.

The inspection of the combustor test model after the BDF combustion test showed that some brown tar was attached around the lip of the fuel atomizer, which has been not observed after the diesel combustion test. This might degrade the atomization of BDF causing instability and inefficiency of combustion after a long time use; however, such tendencies could not be observed during the combustion rig test.

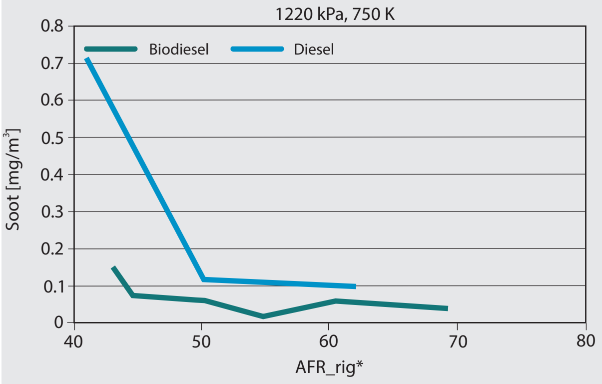


Figure 14
Soot concentration at combustor exit surface

6.3 Summary of the combustion test experiences

A combustion rig test of a 20 MW gas turbine combustor at high load was performed with two different fuels, a biodiesel fuel (BDF) and a usual petroleum diesel fuel, showing that

(1) Combustor exit temperature distributions were fairly similar to each other when 10 % additional mass flow of BDF was supplied compared with diesel fuel implying that the effect of the fuel change from diesel to BDF on turbine blades and nozzles is small and that the output of the turbine will be nearly the same if the mass flow of BDF is 10 % higher than that of the diesel fuel. The possibility of major design change of the gas turbine cannot be identified with the introduction of BDF.

(2) Both of NOx and CO emissions of BDF were nearly equal or slightly lower than those of diesel fuel. Soot emission of BDF was smaller than that of diesel, which is considered to be caused by the lack of aromatics content of BDF.

As long as the above results are considered, BDF is considered to be a promising alternative fuel for gas turbines, producing cleaner exhaust gas compared with diesel fuel. Further research on the performance at medium to low power settings, ignition and blow off, and the degradation of seals for fuel passages and so on should be performed to make BDF permanently used for gas turbines without serious troubles.

7 Concluding remarks

This study has searched for the possibility of widening the applicability of BDF to promote its production and consumption. Special focus has been paid to its application to gas turbine engines. The study on the availability of the feedstock and the economical aspect of BDF has showed that even though both the price and production totals tend to fluctuate due to weather and market factors, collecting more waste cooking oil can be one of the solutions for feedstock in future. This might be categorized as the recycling of wasted energy, but the total amount of this feedstock should not be neglected as it could be a major feedstock for BDF. Today, the recycling rate of waste cooking oil is low because effective systems for collecting have not been fully constructed, not even in large cities. This situation could be improved by up to 70 % through an efficient collection system and an adequate public support.

From the viewpoint of environmental protection and technical feasibility, a combustion rig test of a 20 MW gas turbine combustor at high load was performed with petroleum diesel fuel and BDF, showing that BDF is considered to be a promising option to alternative fuel for gas turbines, producing cleaner exhaust gas.

The combination of a compact gas turbine and a simple chemical process system of refining waste cooking oil to BDF could be one of the best energy supply systems in small towns, which can also be applicable to a local community in large cities all over the world, leading to an increased awareness and understanding of the importance of environmental protection at a global level.

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