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Biodiesel Extraction and Evaluation of Emission Parameters of a DI Diesel Engine Fueled by Pure / Used Biodiesel with Diesel and Oil with diesel Blends at High Idling operations

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ABSTRACT: Biodiesel from pure and used oil is produced by transesterification process in this study. Quality of biodiesel is examined standards testing methods. Important fuel properties of biodiesel, such as heating value, cetane index, viscosity, and others are also investigated. A direct injection (DI) diesel engine is tested with biodiesel–diesel and oil–diesel blends for performance and emissions at high idling operations. Three fuel series are examined: pure biodieselused biodiesel and pure oil series. In all the series, fuels are blended with diesel5–20 volume percentage. Engine performance is examined by measuring brake specific fuel consumption and fuel conversion efficiency. The emission of carbon monoxide (CO), hydrocarbon (HC), oxides of Nitrogen (NOx) and others are measured. Pure and used biodiesel blends show very similar fuel properties, engine performance and emissions. CO and HC emissions from biodiesel–diesel blends are significantly less than neat diesel fuel. Even pure oil up to 5% in diesel fuel can show significantly less CO emissions than that of diesel fuel. Up to 5% biodiesel and oil in diesel fuel, NOx emissions either can reduce or maintain similar level to that of diesel fuel.

I. INTRODUCTION

Climate change and mitigation of greenhouse gas (GHG) emissions are of the primary motivations for biofuels research. Furthermore, the growing concern on environmental pollution caused by the extensive use of conventional nonrenewablefuels has led to search for more environment friendly and renewable fuels. Biofuels such as alcohols and biodiesel have been proposed as alternatives for internal combustion engines [1,2]. In particular, biodiesel has received wide attention as a replacement for diesel fuel because it emits less GHG and other pollutants. Biodiesel can reduce net carbon-dioxide emissions by 78% on a lifecycle basis when compared to conventional diesel fuel [3]. United States Environmental Protection Agency (US EPA) has done a comprehensive analysis of biodiesel impacts on exhaust emissions [4] mentioning that pure biodiesel can reduce HC as high as 70% and particulate matters (PMs) and CO about 50% when compared with conventional diesel fuel. A rapid expansion in production capacity is being observed not only in developed countries such as Germany, Italy, France, and the United States but also in developing countries such as Brazil, Argentina, Indonesia, and India. Interest in and expansion of the production of the renewable fuel have been fostered by mandates and financial incentives offered by governments. This interest can be mostly attributed to the commonly cited advantages of biofuels, especially that they canreduce the emission of gases responsible for global warming, promote rural development, contribute toward the goal of energy security, are renewable, and reduce pollution. Another feature that proponents of biodiesel put forward is that the fuel can be used without modification in engines currently in use. Several countries including Canada have already begun substituting the conventional diesel by

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a certain amount of biodiesel. The use of biodiesel is being promoted by European Union (EU) countries to partly replace diesel fuel in order to reduce greenhouse effect and dependency oil. Meeting the targets established by the European Parliament for 2020 would lead to a biofuel market share of 10% [5]. Few Researchers has announced a new biofuel strategy (2% biodiesel in diesel for ground transportation and heating by 2012 and 5% by 2015). Biodiesel is mainly produced from different types of vegetable oils (e.g., rapeseed, soybean, canola, sunflower, palm oil, etc.). Canola/used canola oil is one of the leading feedstock for biodiesel production. Transesterification is regarded as one of the most efficient methods to produce biodiesel from vegetable oils due to its low cost and simplicity [6,7]. Thus, this study will choose canola oil as feedstock and use transesterification process to produce biodiesel. Many investigations have indicated that the use of biodiesel can result in a substantial reduction in PM, HC and CO emissions [8–11]. However, a slight increase in NOx emission is observed by most researchers when biodiesel is used [12–14]. Most of the researchers have found that the use of biodiesel instead of diesel can cause reduction in PM emissions [8–11,15,16].Wu et al. [15] investigated the emission performance for five pure biodiesels on a Cummins ISBe6 DI engine with turbocharger and intercooler, and found that the related biodiesels could reduce PM emission by 53–69% on average compared with the diesel fuel. Lin et al. [16] also observed that there was significant reduction (ranging from 50% to 72.73%) in the smoke emission for eight kinds of biodiesels compared with petroleum diesel. A small portion of authors found that there was no difference in PM emissions for biodiesel relative to diesel [17,18], or even there was a bit increase [19,20]. According to most of literatures, it was a common trend that CO emissions could be reduced when diesel was replaced by pure biodiesel [8–11,21–23]. Krahl et al. [21] obtained about 50% reduction in CO emissions for biodiesel from rapeseed oil compared to low and ultra-low sulfur diesel. A higher reduction in CO emissions was reported by Raheman and Phadatare (up to 73–94% for the karanja biodiesel and its blends compared to diesel) [22], and by Ozsezen (86.89% for waste palm oil biodiesel and 72.68% for canola biodiesel) [23]. However,some literature showed the less reduction. For example, Utluand Kocak [24] obtained the reduction of around 17.13% than dieselfuel. Some authors found different trend at different load conditions;for example, An et al. [25] reported that although CO reducedat high load operations, it increased significantly at light load operationswith the increase of biodiesel blend ratio. Surprisingly someauthors reported the increase in CO emissions for pure biodiesel[26,27]. Banapurmatha et al. [26] observed higher CO emissionsfor jatropha, honge and sesame biodiesel compared to diesel on asingle-cylinder, 4-stroke, DI diesel engine at a rated speed of1500 rpm at 80% load. Macor et al. [27] reported a slight CO increasewith biodiesel than diesel. Most literatures found reductions in HCemissions when pure biodiesel was fueled instead of diesel[11,15,16,26,28]. Wu et al. [15] reported that the five different biodieselscould reduce HC emission by 45–67% on average comparedwith diesel fuel. Puhan et al. [28] found that the average reductionin HC emissions was around 63% for biodiesel compared with diesel.But some authors reported the lower decreases, for example,in the range of 22.47–33.15% for the eight kinds of biodiesels fromLin et al. [16]. Ng et al. [11] showed that engine-out HC concentrationreduced with increasing biodiesel content in blend and HC concentrationof neat palm biodiesel was 26.2% lower than that of fossildiesel. However, Banapurmatha et al. [26] and Macor et al. [27]found higher HC emissions with different biodiesels compared todiesel fuel. In NOx emissions from biodiesel operation, there is a dividedopinion or results in literatures. Many literatures believe thatthe use of pure biodiesel causes the increase in NOx emissions [12–14,16,23,29]. For example, a maximum of 15% increase in NOxemissions for neat biodiesel was observed at high load conditionas the results of 12% oxygen content of biodiesel and higher gastemperature in combustion chamber [29]. Ozsezen et al. [23] foundthat NOx could increase by 22.13% and 6.48%, respectively, by wastepalm and canola biodiesels. Lin et al. [16] compared eight kinds ofbiodiesel mentioned above and found that using biodiesel in thediesel engine could yield higher NOx emissions, ranging from an increaseof 5.58–25.97% when compared to diesel. Many others[26,28,30] reported that NOx emissions reduced when using biodiesel.

II. MATERIALS AND METHODS

To produce biodiesel, pure canola oil and used/cooked canola oil are used as feedstock. Pure canola oil was purchased from a local supermarket and used canola oil was collected from research laboratory. Two main ingredients for biodiesel production were methanol and sodium hydroxide that were purchased. The physical and chemical properties of methanol and sodium hydroxide are shown in Table 1. A DI diesel engine was tested to examine its performance and emissions with biodiesel–diesel and canola oil–diesel blends at different volume proportions. The tested blends were B0 (diesel), B5 (5% canola biodiesel in diesel), B10 (10% canola biodiesel in diesel), B15 (15% canola biodiesel in diesel), B20 (20% canola biodiesel in diesel), UCB5 (5% used canola biodiesel in diesel), UCB10 (10% used canola biodiesel in diesel), UCB15 (15% used canola biodiesel in diesel), UCB20 (20% used canola biodiesel in diesel), C5 (5% canola oil in diesel), C10 (10% canola oil in diesel), C15 (15% canola oil in diesel) and C20 (20% canola oil in diesel).

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Table. 1The physical and chemical properties of methanol and sodium hydroxide

Chemical formula	**CH3OH**	**NaOH**
Molecular weight	32.04	39.997
Purity (%)	100	99
Flash point (°C)	12	–
Boiling point (°C)	64.5	1390
Autoignition temperature (°C)	464	–
Specific gravity	0.8	2.13
Vapor pressure (mmHg)	97 @ 20 _C	1 @ 739 (°C)
Melting point (°C)	–	318
pH (of a 5% solution)	–	14

Biodiesel production and properties

The most commonly used method of biodiesel production is thetransesterification of triglycerides with methanolin the presence of a catalyst, which gives biodiesel and glycerol(by-product). The basic biodiesel reaction and flow chart of biodieselproduction is illustrated in Fig. 1. The procedure to make biodieselfollowed in this study is similar to that described in [45].The final collection efficiency is 86% for pure canola oil and 90%

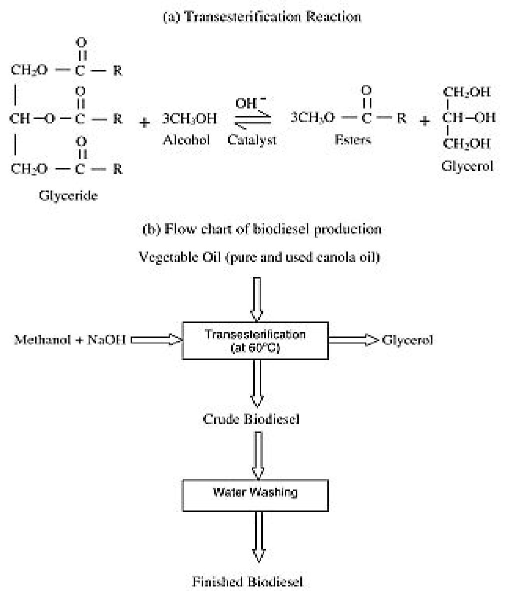

Fig. 1. Basic biodiesel reaction: (a) transesterification reaction and (b) flow chart of biodiesel production.

The basic biodiesel reaction and flow chart of biodieselproduction

Engine test

Fig. 2 shows the schematic diagram of engine experiment. The engine used in this study was a four-stroke two-cylinder naturally aspirated DI diesel engine. All experimental data were taken after engine warm-up (about 20 min after start). In this condition, there was almost no fluctuation of emissions. Tests were carried out at the warmed up condition of the engine under high idling (i.e., 1200 rpm) and with 15% engine loads, as summarized in Table 2. Loads were measured by a water brake dynamometer. Fuel temperatures are important, which affect viscosity and atomization of canola oil and other biodiesels. Fuel temperatures are kept constant keeping the engine room temperature constant at 20 ^{0}C for all the tests. The fuel supply system was modified to switch between the diesel fuel used as a standard and the test fuels. The engine was started using diesel; once the engine warmed up, it was switched to biodiesel–diesel or canola oil–

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diesel blends. After concluding the tests the engine was again switched back to diesel before stopping the engine until the blends were purged from the fuel line, injection pump and injector. Engine load and fuel consumption were measured to calculate brake specific fuel consumption (BSFC) and fuel conversion efficiency (GF) of the engine. The difference in engine torque as well as power at a certain engine speed for different fuels was insignificant; that is why only one value of engine power at each speed for biodiesel– diesel and canola oil–diesel blends.

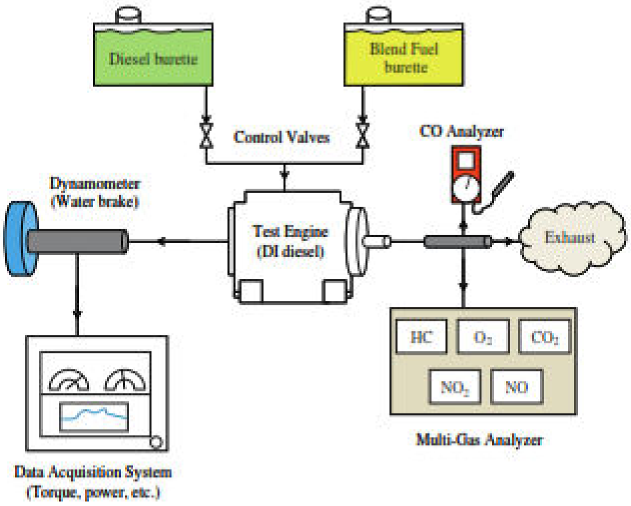

Fig. 2 shows the schematic diagram of engine experiment.

Table 2 Fuel properties of biodiesel–diesel and canola oil–diesel blends.

Fuel	Density (kg/m3)	Viscosity (cSt)	Heating value (kJ/kg)	Cloud point (°C)
B0	844	2.68	44,861	-26
B2	845	2.72	44,711	-23
B5	846	2.89	44,601	-22
B10	848	3.07	44,297	-22
B20	850	3.22	43,715	-19
B100	870	4.26	39,369	-3
UCB 2	845	2.72	44,732	-22
UCB 5	846	2.77	44,556	-22
UCB 10	849	2.93	44,266	-22
UCB 20	851	3.07	43,643	-20
UCB 100	872	4.22	39,289	-4
C2	846	2.8	44,826	-26
C5	848	2.98	44,653	-26
C10	852	3.63	44,398	-26
C20	858	4.28	43,758	-26

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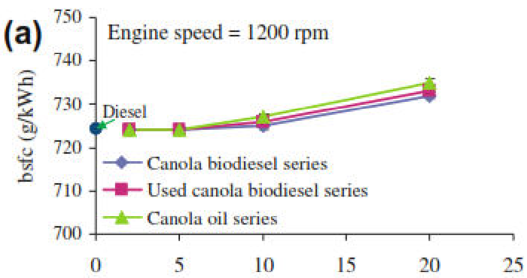

Fig. 4 The variation of BSFC of the engine

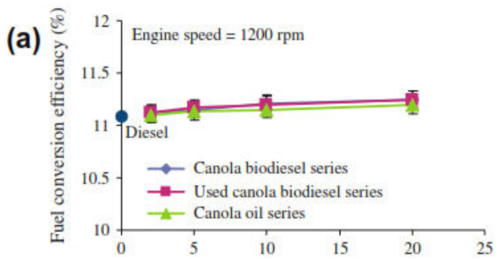

Fig. 5 Fuel Conservation Efficiency

III. RESULTS AND DISCUSSION

Engine performance

Fig. 4 shows the variation of BSFC of the engine with canola biodiesel–diesel, used canola biodiesel–diesel and canola oil–dieselseries at engine speed of 1200 rpm, At this speed, there is no significant increase in BSFC with biodiesel–diesel and canola oil–diesel series up to 15% blends; however,20% blends of biodiesel and canola oil with diesel show about1.1–2.3% BSFC increase, respectively, than neat diesel operation atdifferent engine speeds. B20 and UCB20 have, respectively, 2.55%and 2.7% lower heating value than diesel fuel.This indicates that biodiesel–diesel blendshave higher fuel conversion efficiency than that of diesel fuel.The variation of fuel conversion efficiency of the engine withvarious fuels is demonstrated in Fig. 5. Canola oil–diesel serieshas pretty similar efficiency to that with diesel at each enginespeed. There is no significant change in fuel conversion efficiencywith biodiesel–diesel series up to 5% blends in comparison to dieselat all engine speeds. However, 10% and 20% biodiesel blendsshow 1–1.5% efficiency increase than neat diesel operation. A littlehigher efficiency with biodiesel–diesel series at each engine speedinduces less BSFC increase of these blends than they should havebeen according to their calorific values. Furthermore, the higherefficiency with biodiesel–diesel series than diesel indicates thatblend fuels combustion is better than diesel fuel combustion. Thisis attributed to oxygen content of biodiesel. Due tobetter combustion with biodiesel, less emission of CO and HC is expected.

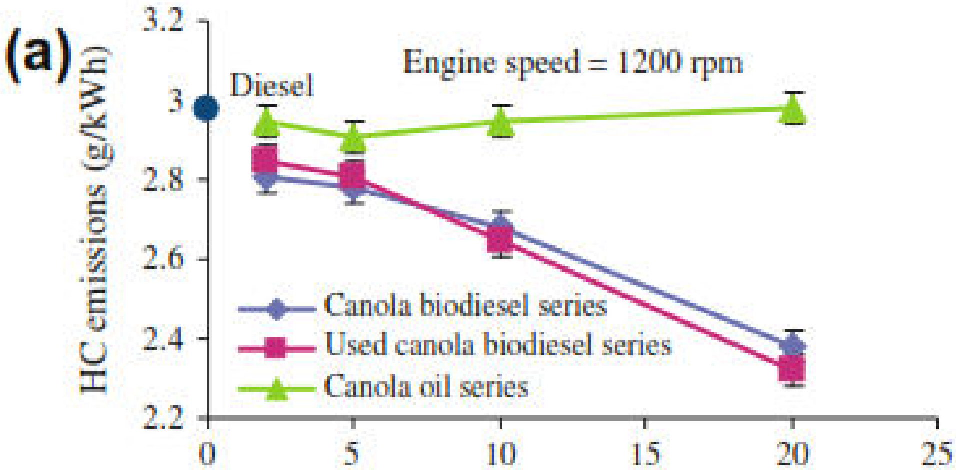

Fig. 6 shows CO emissions

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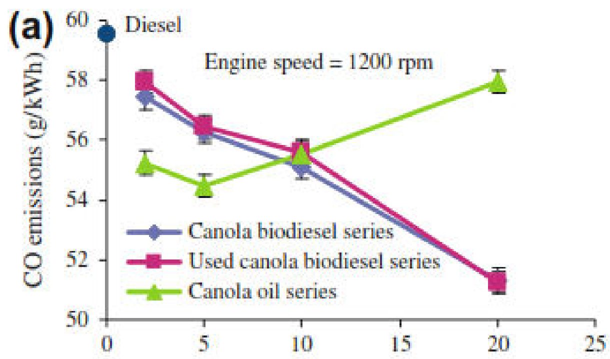

Fig. 7 HC emissions

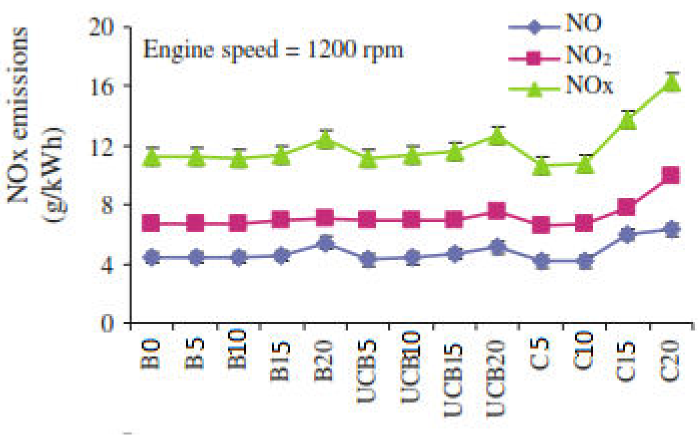

Fig. 8NOx emissions

Emissions

The emissions of CO, HC, and NOx are illustrated inFigs. 6–8. Fig. 6 shows CO emissions at the engine speed of 1200 rpm for various fuels. At 1200 rpm, diesel fuel produces the maximmCO (59.53 g/kW h), which decreases gradually with biodiesel–diesel blends and becomes the lowest (51.24 g/kW h) for B20 orUCB20 (approximately 14% lower). However, CO emissions withcanola oil–diesel series are different than the biodiesel–diesel series.There is a gradual decrease in CO emissions up to C5, which iseven better than the biodiesel–diesel series. The main observations from CO emission results are as follows:
(1) the higher the engine speed, the lower the CO emissions for allof the fuels. This is due to better mixing of air and fuels at higherspeeds for higher turbulence;
(2) the higher the biodiesel percentagein biodiesel–diesel blends, the lower the CO emissions. Thiscould be due to higher O2 concentration in the air–fuel mixture,which can improve combustion and enhance further CO oxidation;
(3) canola oil–diesel blends shows lower CO emissions than diesel;
and (4) the higher the engine speed and the lower the canola oilpercentage in diesel fuel perform better than similar biodiesel–dieselblends, such as up to C5 at 1200rpm. The lowerpercentage of canola oil in the blends has very similar fuel propertyto diesel, however a bit of O2 can help better combustion and lowerCO emissions than diesel. On the other hand, the question is whythis is better than similar biodiesel–diesel blends, when biodieselhas similar O2 content in it.

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Higher heating value of C5 thanB2, UCB2 or B5, UCB5 (Table 2) may be one of the main reasons.The degradation of performance in CO emissions with canola oil–diesel blends with respect to biodiesel–diesel blends could beattributed to improper combustion due to shorter combustion periodat higher engine speeds. Lower cetane number of canola oil–diesel blends will increase ignition delay that causes higheramount of fuel accumulation before combustion starts. Higher viscosityof canola oil–diesel blends will degrade spray characteristicsespecially for low injection pressure engines (e.g., the one used inthis work), and cause improper mixture formation. Higher amountof improper mixtures and shorter combustion period make canolaoil–diesel blends combustion poorer. It seems that proper mixtureformation at higher engine speeds plays an important role forbetter combustion and lower CO emissions. Higher biodiesel–dieselblends can supersede similar canola oil–diesel blends at higherengine speeds in proper mixture formation and combustion.Fig. 7 demonstrates HC emissions at specific speed forvarious fuels. At 1200 rpm, diesel fuel produces 2.98 g/kW h of HC;it decreases gradually with biodiesel–diesel blends and becomes22% lower for UCB20 and 20% lower for B20. No significant changeis observed for canola oil–diesel series. At this speed, canola oil–diesel series shows approximately6% increase than that of diesel. Here also:

(1) the higher the enginespeed, the lower the HC emissions for all fuels. This phenomenoncan be attributed to better mixing of air and fuel at higher enginespeeds;

(2) the higher the biodiesel percentage in biodiesel–dieselblends, the lower the HC emissions. This is due to the fact that thehigher O2 concentration in the air–fuel mixture can help enhanceoxidation of unburned hydrocarbons;

(3) canola oil blends arenot a good candidate for HC reductions; although at lower speeds,there is no significant change in HC emissions, at the engine speedof 1200 rpm, HC is increased by 6% than diesel and a lot more thanbiodiesel–diesel series. It seems that detrimental cetane andviscous effect have overturned the positive effect of O2 content incanola oil–diesel blends at higher engine speeds again due toshorter combustion period, which is in agreement with COemissions.Fig. 8 illustrates NO, NO2 and NOx emissions at 1200rpm speed for various fuels. At light load operations, the engineruns at a very lean state and with a small biodiesel or canolaoil blends. Hence, higher amount of NO2 is producedat light load operations. This suggests that a proper care beneeded to report NOx emissions from biodiesel combustion, especiallyat high idling operation. This also suggests that NOx abatementtechnology must include a system to address both NO2 and NO reduction.

IV. CONCLUSIONS

Pure and used canola biodiesels have been produced and theirquality and fuel characteristics have been investigated. An experimentalinvestigation has been conducted to explore the performanceand emissions of biodiesel and canola oil blends at highidling operations on a small DI diesel engine.The results obtained suggest the following conclusions:

(1) Quality biodiesels are produced from pure and used canolaoil by base catalyst transesterification process that satisfiesASTM standard. The conversion rate is 100% and collectionefficiency 86–90%. Its cetane index is about 50 and heatingvalue about 10% less than diesel fuel.

(2) The viscosity of pure canola oil is very high and it reduces toabout 10 cSt level at 90 ^{0}C which is higher than ASTM limitof 6 cSt. However, up to 30 vol.% of canola oil in diesel showsthe viscosity values less than ASTM limit. Its heating value ispretty similar to biodiesels.

(3) There is no fuel penalty up to 5% blend of biodiesel or canolaoil in diesel, but with 20% blends the fuel penalty is about1.1–2.3% at different speeds. Biodiesel–diesel and canolaoil–diesel blends show higher fuel conversion efficiencythan that of neat diesel.

(4) CO emissions for all fuels are lower at higher engine speeds,and the higher the biodiesel percentage in biodiesel–dieselblends, the lower the CO emissions are. B20 or UCB20 showsaverage CO reduction of 13%. Up to 5% of canola oil in theblends, CO emissions are even lower than similar biodiesel–diesel blends, but for higher canola oil in the blends,CO is higher than that of similar biodiesel–diesel blendsbut lower than diesel.

(5) HC emissions for all fuels are also lower at higher enginespeeds, and the higher the biodiesel percentage in biodiesel–diesel blends, the lower the HC emissions are, a similartrend to that of CO emissions. B20 or UCB20 shows averageHC reductions of 22%. There is a small reduction in HC up toC5 at lower speeds, but higher blends of canola oil andhigher speeds deteriorate HC emissions.

(6) Up to 5% biodiesel and canola oil in the blends, there is noincrease in NO, NO2 and NOx emissions, in fact canola oilup to 5% in the blends shows a little reduction of NO, NO2and NOx emissions than diesel. However, B20 or UCB20has 12–26% NOx increase and C20 shows 44–58% NOxincrease at different engine speeds. NO2 production at highidling operations is found very significant and even higherthan NO production and its share in total NOx is more than50%.

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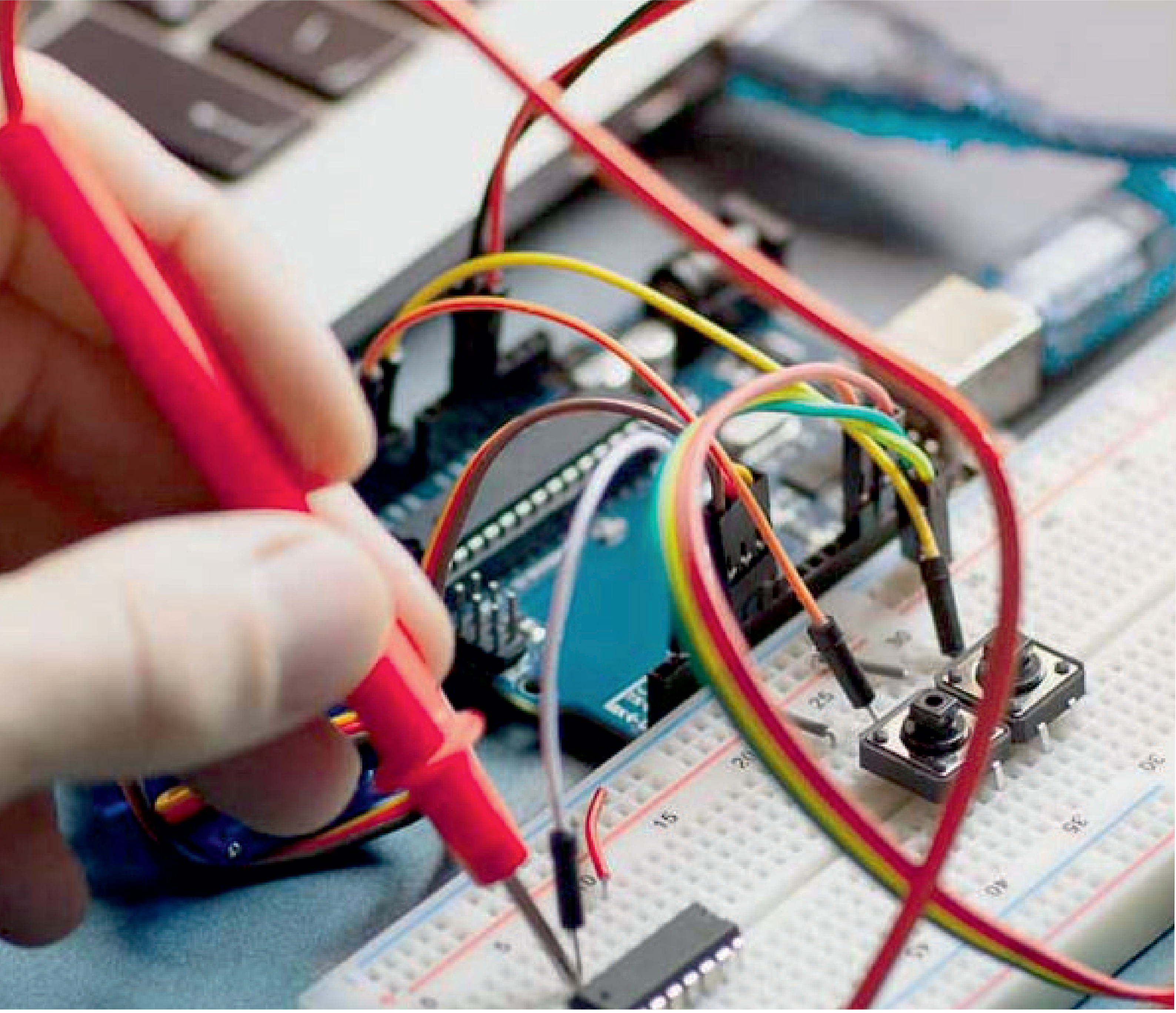

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