The effect of sweet orange peel addition into premium gasoline on fuel consumption and flue gas emissions

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Abstract. This study offered an investigation as to how the use of sweet orange peel oil as an additive for premium gasoline can increase octane performance which influence combustion. Sweet orange peel oil—acting as a RON booster—contains monoterpenic compounds and oxygenated hydrocarbons which can improve the quality of combustion. The study also aimed to analyze the combustion characteristics of premium gasoline mixture affected by sweet orange peel additives on SI engines. This study carried out tests on an engine fuel consumption and HC emissions. The cyclic rings and methyl groups of monoterpenic compounds in sweet orange peel additives contribute to the increase of electronegativity of additives, therefore being able to interfere with the premium gasoline’s compounds which are dominated by aromatics hydrocarbons. It has an impact on the branches of single-bond molecules series of premium gasoline. This makes the premium gasoline cannot be ignited at low temperatures, which results in perfect combustion. In addition, the polarity of triacetin and eugenol, which includes oxygenated hydrocarbons, is able to reduce CO as the avoided gas in combustion. Sweet orange peel additives—processed by maceration extraction method—are added to premium gasoline. There are 3 ratios of additives in this study; orange peel essential oil extracted with a concentration ratio of dried orange peels simplicial to n-hexane (v / v) of 1% (EO A); 0.75% (EO B); and 0.6% (EO C). To determine the effect of the additive, exhaust gas emission testing and fuel consumption measurement were carried out on the 2013 Honda Absolute Revo motorcycle 4-step, SOHC, 1 cylinder, 109.17 cc engine. The exhaust gas, i.e. CO, HC, CO2, and O2 were analyzed using a Stargas-898-type gas analyzer. Furthermore, fuel consumption measurement was carried out at 3500 rpm engine speed. The results show that CO could be reduced by 37.7%, while the remaining O2 was reduced by 17%. The addition of sweet orange peel additives could increase CO2 levels in exhaust gases when compared to premium gasoline combustion without additives. However, the premium gasoline with additive A (EO A) blend tends to produce higher hydrocarbon emissions compared to other types of premium additive proportions. In conclusion, adding sweet orange peel additives to premium gasoline can reduce fuel consumption by 3.3%; 3.2%; and 3.4% for each blend, respectively.

Keywords: additive, sweet orange peel, premium gasoline, fuel, flue gas
1. Introduction
Combustion process using premium gasoline is identified to increase air pollution compared to other types of gasoline in Indonesia [1]. Exhaust gas emissions released contain CO, hydrocarbons, and SO$_2$ which have impacts on the environment and health problems. Premium gasoline has an octane number 88 which indicates that the fuel mixture contains 88% iso octane having single branched molecules and 12% n-heptane consisting of molecules bonds. The single molecules bonds are suggested to cause knocking due to the breaking of hydrocarbon bonds at low temperatures [2]. It shows that fossil fuels with low octane numbers have quite serious effects both in the combustion process and environmental degradation. The European Union issues directives to offset fossil fuels by replacing renewable biofuels 10% by 2020 (EU Directive 2009/28/EC) [3]. Therefore, one specific solution to overcome these problems is by finding new fuel sources or by adding additives to existing fuels.

Research on additives for fuels has been widely carried out [2,4]. Orange peel essential oil is one ingredient that has the potential to be used as an additive. Orange peel essential oils contain compounds such as terpenes, monoterpene, and oxygenated hydrocarbons; all of which have the potential to improve the quality of fuel combustion. The oil contains 90% limonene compound (C10H16) [5]. The compound is classified as monoterpene with cyclic-shaped structure and has a methyl branching. Limonene has a low freezing point and high density, so it has the potential to replace gasoline [6]. Methyl groups, C-C double bonds, and cyclic rings are thought to contribute to the increase of anti-knocking on premium gasoline. Carbon double bonds have been shown to improve the quality of anti-knocking fuels [3] by inhibiting the combustion using branched molecules chains at low temperatures. The presence of methyl chains in limonene can also improve the quality of anti-knocking as well as the role of lead oxide in TEL additives. Sarathy et al. [7] stated that the presence of methyl groups can stimulate the abstraction of H atoms and internal migration of H atoms. As a result, it can inhibit the occurrence of low-temperature ignition in branched carbon molecules chain. The process of abstraction of the H atom occurs when limonene reacts with premium molecules—which are made up of straight bonds of hydrocarbons—that is initially thought to form alkyl radicals and release H atoms in fuel molecules by initiation. The initiation process that requires high activation energy (> 167 KJ/mol) can make premium gasoline difficult to be burnt.

Sweet orange peel oil also consists of other various compounds such as mirsen, α-pinene, sabinene, nonane, linalool, and eugenol. Monoterpene oxygenate compounds such as linalool and eugenol can improve the quality of premium combustion. Linalool is a compound with the formula C10H18O. The oxygen atom content in Linalool can reduce carbon monoxide (CO) in the combustion process [8]. Eugenol in orange peel essential oils can also act as antioxidants. Oxygen inside eugenol can be generated to oxidize CO into CO$_2$ [9].

To date, sweet orange peel oil has only been used as an additive for diesel. Its use as a bio-additive for gasoline has not been specifically studied in the case of premium fuel. If fuel’s octane number can’t be increased, additives can be added instead. The focus of this study is to examine the effect of adding sweet orange peel oil as an additive on fuel consumption and flue gas emissions in premium gasoline combustion.

2. Methods

2.1. Premium gasoline properties
The premium gasoline used in the study is a commercial fuel marketed by PT. Pertamina, an Indonesia Oil Company. Some chemical properties are presented in Figure 1. Meanwhile, the physical properties of premium are shown in Table 1. Bio-additives used are derived from essential oils of orange peel made from sweet oranges (Citrus sinensis) extracted by maceration method. Furthermore, the chemical properties of sweet orange peel essential oils were measured using GC-MS stated in Table 2.

![Figure 1. Composition of premium gasoline by hydrocarbon types [1]](image)

| Characteristics                          | Ranges            | Testing Method |
|------------------------------------------|-------------------|----------------|
| Research Octane Number (RON)             | 88.0 -            | D 2669         |
| Oxidation flame (minute)                 | 360 -             | D 525          |
| Sulphur (% m/m)                          | - 0.05           | D 2622         |
| Lead (Pb) (gr/litre)                     | - 0.013          | D 3237         |
| Metal (Mn, Fe) (mg/l)                    | Not tracked       | D 3831         |
| Oxygen (% m/m)                           | - 2.7            | D 4815         |
| Distillation                             | - 74             | D 86           |
| 10% vol. evaporation (°C)                | 75                |                 |
| 50% vol. evaporation (°C)                | - 180            |                 |
| 90% vol. evaporation (°C)                | - 215            |                 |
| Final boiling point (°C)                 | -                |                 |
| Residue (% vol)                          | - 2.0            |                 |
| Sediment (mg/l)                          | - 1              | D 5452         |
| Unwashed Gum (mg/100 ml)                 | - 70             | D 381          |
| Washed Gum (mg/100 ml)                   | - 5              | D 381          |
| Steam pressure (kPa)                     | 45 69            | D 5191         |
| Specific gravity at 15°C (kg/m³)         | 715 770          | D 4052         |
| Sulphur Mercaptan (% massa)              | - 0.002          | D 3227         |
| Visual appearance                       | Clear and bright |                |
| Smell                                    | Have distinct odor|                |
| Color                                    | Yellow           |                |
| Coloring compound (gr/100 l)             | - 0.13           |                |

Table 1. Fuel properties of premium gasoline [11]
2.2 *Sweet orange peel additives production*

The research used sweet orange peel in the form of essential oil processed by maceration extraction method as a bio-additive. It was added to premium gasoline. For making the essential oil, solvent was needed in the sweet orange oil extractions. The solvent used in the extraction process is n-hexane PA. We made 3 types of additives in this study, in which the orange peel essential oil was extracted using concentration ratio of 1% (EO A); 0.75% (EO B); 0.6% (EO C) between the simplicial of dried orange peel with n-hexane (v/v). The extraction process was carried out at room temperature in a closed container for 24 hours. Then, the pure oil produced was stored in a previously purified dark glass bottle using anhydrous Na$_2$SO$_4$ and the bottle was sealed, after which it was filtrated to be heated using a rotary vacuum evaporator at 45 °C. The chemical properties were identified by measuring sweet orange peel essential oil additives by means of GCMS. The molecular structure of dominant compounds listed in Table 2 are considered as the most influential factors in the mixing process. Also, the molecular structures are illustrated in Figure 2. In addition, the physical properties of produced sweet orange peel additives consist of calorific value, viscosity, and density using standardization measurements ASTM D 250, ASTM D 445, and ASTM D 92 methods that can be seen in Table 3.

Table 2. Gas Chromatographic peak ID and relative area percentage

| Chemical composition | Formulae | Compositions (%) | Molecular mass (g/mole) |
|----------------------|----------|------------------|------------------------|
| Beta-myrcene         | C$_{10}$H$_{16}$ | 2.35             | 142.27                 |
| Limonene             | C$_{10}$H$_{16}$ | 92.06            | 136.23                 |
| Triacetin            | C$_{6}$H$_{14}$O$_{8}$ | 4.59          | 218.2                  |
| Eugenol              | C$_{10}$H$_{12}$O$_{2}$ | 1.00          | 164.2                  |

![Chemical structures](image)

*Figure 2. The molecular structure of sweet orange peel essential oil components. (a) Limonene, (b) Triacetin, (c) Eugenol, and (d) Beta-myrcene*
Table 3. Physical properties of sweet orange peel additive

| Properties         | Sample A | Sample B | Sample C | Testing methods |
|--------------------|----------|----------|----------|-----------------|
| Calorific value (cal/g) | 10476    | 6182.66  | 5264.3   | ASTM D 250      |
| Density (g/cm³)    | 0.81     | 0.8      | 0.81     | ASTM D 445      |
| Viscosity at 40ºC cSt | 3.22     | 3.48     | 3.52     | ASTM D 92       |

2.3 Experimental procedures

This experiment measured and analyzed the flue gases as conducted using 2013 Honda Absolute Revo 4-step SOHC motorcycle. The specifications of the engine test machine are 1 cylinder with a capacity of 109.17 cc, air cooler, and fuel tank capacity of 4 liters. Flue gas emission test used a gas analyzer type 898. This study aimed to determine the effect of adding sweet orange peel additives to premium gasoline combustion. Initially, the motorcycle engine test was tuned up to obtain standard motorcycle conditions. Then, each premium gasoline blended with sweet orange peel additive samples of EO A, EO B, and EO C was put into the fuel tank to measure its fuel consumption and flue gas emissions. Before testing exhaust emissions, the engine was started at 3500 rpm. After the stationary conditions were reached, the gas analyzer was connected to electricity and the measuring process took ± 6 minutes. Then, the exhaust probe on the test equipment was inserted into the exhaust. The measurement was conducted by pressing the enter button on the gas analyzer. Then, CO, HC, CO₂, and O₂ were identified from the exhaust. This was carried out on all of the samples and then it was compared to the pure premium gasoline without the sweet orange peel additive. Each measurement was repeated for 3 times to obtain precise data.

Furthermore, fuel consumption testing was carried out on the engine in a stationary condition, i.e. the engine was idle and not moving. Similar to the previous flue gas emission testing procedure, tune-up was first done to ensure that the test machine was in a standard condition. The engine speed used was equal to 3,500 rpm. The initial measurement was done without using bio-additives where 100 ml of premium gasoline was put into the fuel tank. Using a stopwatch to keep track of time, the engine was started and turned off after 10 minutes. The remaining fuel was measured by calculating the residual volume of the fuel with which the difference between the initial and final volumes was recorded. The test was carried out in 3 replications with the same procedures carried out for each sample blend; premium added with sweet orange peel additives A, B, or C. This measurement was intended to determine fuel consumption per minute.

3. Results and Discussion

The experimental results showed an improvement in some performances of combustion in fuel blends of premium gasoline with the addition of sweet orange peel oil bio-additives as RON boosters. In the research, all results show improvement in fuel consumption and flue gas emissions which are explained in Figure 2 to Figure 6.

Figure 3 shows that the addition of sweet orange peel additives can reduce CO at the combustion products. The decrease of CO levels in all premium blends proves that the addition of bio-additives generates more perfect combustion process. The addition of bio-additives into premium gasoline can reduce CO emissions by 37.7% when compared to pure premium without additives. The lowest CO emission was found in a blend of premium gasoline with the smallest concentration of sweet orange peel additive, i.e. in sample C (EO C) which was around 0.6%. Premium gasolines mixed with additives A (EO A) and B (EO B) can reduce CO emissions by 36% and 29%, respectively. The reduction of CO emissions in fuel blend can be attributed to the high content of hydrocarbon oxygenate compounds in sweet orange peel additives which reach 6% (Table 3). The higher the additive concentration in the fuel blend, the lower the CO compound in
the exhaust gas. It is due to Oxygen contained in triacetin and eugenol compounds capable of binding with CO compounds to produce CO$_2$. As a result, the bio-additive can function as a more perfect combustion process. In addition, the sweet orange peel additives dominated by monoterpenes compounds (90% limonene) are thought to be one of the causes of more perfect combustion.

**Figure 3.** Comparison of CO emission concentration for each fuel blend composition

**Figure 4.** Comparison of CO$_2$ emission concentration for each fuel blend composition

Furthermore, during the observation of CO$_2$ flue gas, CO$_2$ content in each fuel blend showed a higher value compared to that of without additives (Figure 3). Sequentially, fuel blends with additives A (EO A), B (EO B), and C (EO C) produced CO$_2$ contents as many as 2.44%; 2.49% and 2.11%. Meanwhile, the pure premium gasoline without additive has CO$_2$ emission of 2.24%. This indicates that more perfect combustions took place which were caused by sweet orange peel additives. Limonene contained in sweet orange peel additives consists of methyl groups and cyclic-ring-structured molecules which can inhibit any branching of molecules chains at low temperatures. Consequently, the fuel is not easily burnt at low temperatures and is not combusted rapidly due to these molecules being able to withstand higher temperature and pressure In the combustion process, the limonene compound is thought to undergo termination of
the methyl group. The methyl group is synergistic with the premium’s unstable aromatic hydrocarbon compounds. The reaction between them can stimulate the initiation and branching of chains in a single straight bond into branched double bonds. This has the potential to reduce the occurrence of knocking in the combustion process. However, the emission levels of the C (EO C) fuel blend are thought to be the influence of several factors. One of them is the low production of CO emissions, therefore the produced CO$_2$ is also low. Previous researchers also reinforced this discovery by stating that the reduction in CO levels in the flue gas is influenced by the decrease of combustion temperature [12]. When the calorific value is low, the heat from the combustion process will decrease, thus also reducing CO levels.

![Figure 5](image5.png)

*Figure 5. Comparison of O$_2$ emission concentration for each fuel blend composition*

![Figure 6](image6.png)

*Figure 6. Comparison of Hydrocarbon emission concentration for each fuel blend composition*

Meanwhile, the O2 flue gas in various fuel blends shows satisfying results (Figure 4). The addition of sweet orange peel additives into premium gasoline can reduce the remaining O2 up to 17%. However, the hydrocarbon emissions results (Figure 5) show inversely-proportional outcomes. The fuel blend of A (EO A) produces the highest hydrocarbon emissions of 1750 ppm. It shows that there is an abnormal combustion in the blend of
premium gasoline with the sweet orange peel additive A. The most perfect combustion is in the fuel blend B, resulting only 1169 ppm of remained unburned hydrocarbons. Another factor considered to be the most influential is the magnitude of the dominant compounds’ molecular weight in sweet orange peel additives; beta myrcene, limonene, tricetin, and eugenol, respectively. Each of them contain the number of carbon atoms 9-10 and H atoms 12-16. Meanwhile, the dominant compounds contained in premium gasoline are aromatic compounds which contain the number of atoms C and H are only 6 atoms. Positively, overall results obtained from hydrocarbon emissions, Indonesian government has established that the allowed maximum limit of HC values are at around 4500 ppm

Another result of the study is concluded by Figure 6, showing the values of fuel consumption per minute for each fuel blend. In the research, the values of fuel consumption were calculated using Eq. 1. It can be seen that the fuel blend A has a value of 193,236 ml, while the fuel blend B increases to 193,548 ml. Whereas for the C, it then decreases to 193,019 ml. Fuel consumptions are less when compared to pure premium gasoline with the same amount of time measured. It shows that the addition of sweet orange peel additives can reduce the level of fuel consumption. Premium gasoline mixed with additive sweet orange peel A (EO A); B (EO B); C (EO) reduces its fuel consumption by 3.3%; 3.2%; and 3.4%, respectively.

\[ FC = \frac{60}{t} \times b \]  

(1)

\( Fc \) is fuel consumption (ml/minute), \( b \) represents volume of fuel during combustion (ml), and \( t \) is the time need to spend “b” ml of fuel (minutes).

**Figure 6.** Comparison of fuel consumptions at each fuel blend composition

4. **Conclusion**

This study that investigate bio-additive sweet orange peel oil generally concludes that:

- Any compounds contained in sweet orange peel additives can improve the combustion quality of premium gasoline as indicated by the significant effect of fuel consumption values and the improvement level of flue gas emissions produced by each fuel blend.
- The addition of sweet orange peel additives to the premium gasoline (fuel blend) can improve combustion on SI engines by reducing carbon monoxide (CO) emissions by 37.7% and decreasing the residual combustion \( O_2 \) to 17%. Each fuel blend has higher \( CO_2 \) emission levels compared to pure premium gasoline without additive. However, the fuel blend A (premium + EO A) tends to produce higher hydrocarbon emissions when compared to other types of the fuel blends.
• Adding sweet orange peel additive to the premium gasoline A (EO A) additives; B (EO B); C (EO) reduces fuel consumption by 3.3%; 3.2%; and 3.4%, respectively.

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