The influence of gasoline fuel additive on the motorcycle PM$_{0.1}$ emission factor

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Abstract. Fuel additive has been known to improve vehicle performance by raising the octane number or cleaning the combustion system. The performance enhancement might affect vehicle emission. In this research, we aim to investigate the impact of fuel additives on the PM$_{0.1}$ emission. The commercial additives were evaluated based on the factory’s recommended concentration for the mixture fuel. The additive effect on the PM$_{0.1}$ emission was investigated by measuring the PM$_{0.1}$ concentration emitted by the motor engine operated using fuel with and without additives. The PM$_{0.1}$ concentrations were measured using a TSI P-Trak$^{TM}$ Ultrafine Particle Counter Model 8525. The exhaust emission was injected into the chamber for 100 seconds for the PM$_{0.1}$ concentration measurement. The emission factor was calculated by the total PM$_{0.1}$ concentration per the volume of the burned fuels. The result shows that fuel additives reduce the PM$_{0.1}$ emission factor depending on the type of the additive. Additives reduce the PM$_{0.1}$ emission factor depending on the type of the additive.

Keywords: Fuel additive, PM$_{0.1}$ emission, Motorcycle, Gasoline.

1. Introduction

Fuel combustion has been known to produce various types of emissions, such as carbon dioxide (CO$_2$)[1], carbon monoxide (CO)[2], black carbon (BC)[3], Poly-Aromatic Hydrocarbons (PAHs)[4], volatile organic compounds (VOCs)[5], and particulate matters or PMs[6-9]. They are acknowledged to have an impact on health[10]. Especially in particulate matter with a diameter of less than 0.1 µm or PM$_{0.1}$, the damage is found on the respiratory system[11], cardiovascular system[12], liver[13], and kidney[14]. In different with the gaseous types of a pollutant that is moved into higher altitude due to the density, PM$_{0.1}$ is mostly observed to reside on the earth's surface. However, PM$_{0.1}$ is reported to suspend in the air rather than settle on the ground due to its mass and size[15]. As a consequence, PM$_{0.1}$ are more inhaled by human among other particulate matters.

PM$_{0.1}$ are also reported to contain various types of dangerous compounds, e.g., Poly-Aromatic Hydrocarbons (PAHs)[4], volatile organic compounds (VOCs)[5], reactive oxygen series or ROS Poly-Aromatic Hydrocarbons (PAHs), volatile organic compounds (VOCs). Poly-Aromatic Hydrocarbons (PAHs) have an impact on chronic asthma and respiratory problems in children[16]. A person who is exposed to VOCs will have an impact on cancer risk[17]. Reactive compounds have been known to cause an oxidative response that is related to the development of inflammation Poly-Aromatic Hydrocarbons (PAHs), volatile organic compounds (VOCs). The PM's reactive compound is related to the development of emphysema on the lung., allergy reaction, influenza-like illness, the erythrocytes alteration, and non-alcoholic Fatty Liver Diseases.
On the other side, the increase of motorcycle usage raises awareness of the fuel sustainability. To reduce fuel usage, engineers have been developing various techniques to enhance the fuel efficiency. An advanced method is the application of the additive on fuel. The fuel additive is known to improve the fuel characteristic, e.g., raise the fuel octane [24], cleaning the engine [18], or stabilizing the fuel in extreme conditions [19]. The entire characteristic has the purpose to increases the combustion quality and reduces the quantity of the burned fuel [20]. However, adding the fuel additive may affect the emission, especially PM$_{0.1}$. Concerning the risk of PM$_{0.1}$ and a better understanding of the influence of the additive on the PM$_{0.1}$ emission, this study conducted to aim to investigate the impact of fuel additive usage on the PM$_{0.1}$ emission as well as the additive dose of the fuel mixture.

2. Material and method

2.1 Additive doses

Three different additives types were used as the samples. They were divided into three different types, namely fuel system cleaner and octane booster (ADV-1), octane booster (ADV-2), and fuel system cleaner (ADV-3). The additive dose was varied before the additive was blended into RON-90 gasoline. The dose variations were determined from the factory recommended dose (Fr). The dose variation is presented in Table 1. The factory recommended dose is shown under the Fr label (shaded column).

| Additive | Additive dose/500 ml gasoline |
|----------|-------------------------------|
|          | Fr-2(ml) | Fr-1(ml) | Fr (ml) | Fr+1(ml) | Fr+2(ml) |
| ADV 1    | 2        | 3        | 4       | 5        | 6        |
| ADV 2    | 1        | 2        | 3       | 4        | 5        |
| ADV 3    | 6        | 7        | 8       | 9        | 10       |

2.2. Experiment procedure

The influence of the additive-fuel mixtures on the PM$_{0.1}$ were evaluated using a standard 100 cm$^3$ motorcycle engine. The engine was operating on the idle throttle with the engine rotation of 1000rpm. The motorcycle emission was directly drained into the measurement chamber with a dimension of 30 cm (width) x 30 cm (length) x 30 cm (height) for 100 seconds. The measurement procedure was conducted by measuring the PM concentration using a P-Trak Ultrafine particle counter (TSI, model 8525). The measurement process was stopped after the PM$_{0.1}$ concentration reached the ambient concentration $C_0$. The ambient concentration was found by measuring the measurement chamber's concentration before the motorcycle smoke was injected. The total concentration was calculated by using Eq.1. The procedure was repeated three times for standard gasoline, each additive type, and doses variation.

$$C = Q_t \int_0^t C (t) \, dt$$  \hspace{1cm} (1)$$

In the above equation, $C$ is the total PM$_{0.1}$ concentration, $Q_t$ is the sample debit, and $C (t)$ is the PM$_{0.1}$ concentration [21]. The emission factor (EF) is calculated using the equation below ($V$ is the burned fuel):

$$EF = C/V$$  \hspace{1cm} (2)$$

3. Result

3.1. PM$_{0.1}$ concentration measurement from additive recommended factory doses

Figure 1 shows the measured concentration of PM$_{0.1}$ in the chamber. The PM$_{0.1}$ concentration decreases for the longer measurement time until reaching the initial concentration. At the beginning
measurement duration, the PM$_{0.1}$ concentration is the highest concentration. The concentration of the pure gasoline (Non-ADV) is of $130 \times 10^3$ particles/cm$^3$ which is the highest among all samples. The ADV-2 has the second position with the initial value of $43.3 \times 10^3$ particles/cm$^3$, while the ADV-1 is in the third position with a value of $37.0 \times 10^3$ particles/cm$^3$. The lowest initial concentration is found in ADV-3 with a concentration of $12. \times 10^3$ particles/cm$^3$. The concentration was perceived to reduce until reaching the ambient concentration ($3.45 \times 10^3$ particles/cm$^3$). The concentration of the Non-ADV reaches the ambient concentration in 29 seconds. Meanwhile, ADV-1, ADV-2, and ADV-3 achieves to the ambient concentration in 83 seconds, 63 seconds, and 41 seconds respectively.

![Figure 1](image1.png)

**Figure 1.** Data representative of PM$_{0.1}$ is presented in the sequence of time (time).

3.2 The influences of additive type on the PM$_{0.1}$ emission

The influence of additive type on the PM$_{0.1}$ emission is presented in the figure 2. The figure shows that the higher PM$_{0.1}$ concentration is obtained in gasoline without the additive with the concentration of $(1.99 \pm 0.05) \times 10^9$ particles/cm$^3$. On the other hand, the lowest PM$_{0.1}$ concentration is quantified on ADV-3 with the concentration $(0.77 \pm 0.02) \times 10^9$ particles/cm$^3$. The ADV-2 is found in the second-highest position with $(1.59 \pm 0.12) \times 10^9$ particles/cm$^3$. Meanwhile, the ADV-1 is observed in the third-highest place with the concentration of $(0.95 \pm 0.04) \times 10^9$ particles/cm$^3$. This concentration was measured on the gasoline with additive factory-recommended dose. The result shows the application of additive on gasoline reduced the PM$_{0.1}$. The reduction was depended on the additive type.

![Figure 2](image2.png)

**Figure 2.** The additive type influences PM$_{0.1}$ concentration.
3.3. The dose variation impact on PM$_{0.1}$

As present in the figure below, the PM$_{0.1}$ concentration changes as a function of the fuel dose with the trend of a second order of the polynomial equation. In the ADV-1, the total concentration of PM$_{0.1}$ with the additive dose of 2.00 ml/500 ml gasoline is obtained of $(1.23 \pm 0.04) \times 10^9$ particles/cm$^3$. Raising the additive dose to be 3 ml/500 ml gasoline reduces the PM$_{0.1}$ concentration to be $(1.11 \pm 0.03) \times 10^9$ particles/cm$^3$. In the additive dose of 3 ml/500 ml gasoline (ADV-1 factory recommended dose), the PM$_{0.1}$ concentration is presented at the lowest position with the concentration of $(0.95 \pm 0.04) \times 10^9$ particles/cm$^3$. In the additive dose of 4 ml/500 ml gasoline and 5 ml/500 ml gasoline with the concentration of $(1.03 \pm 0.03) \times 10^9$ particles/cm$^3$ and $(1.04 \pm 0.03) \times 10^9$ particles/cm$^3$ respectively. The influence of ADV-1 follows the polynomial trendline. Similar result is perceived on the ADV-2 with the lowest concentration on the factory recommended dose. In the ADV-2, the recommended factory doses (4 ml additive/500 ml gasoline) generated $(1.59 \pm 0.12) \times 10^9$ particles/cm$^3$ that is also observed as the lowest concentration in the Figure 2. Reducing the ADV-2 concentration result in the increases of PM$_{0.1}$ concentration that was measured of $(2.53 \pm 0.12) \times 10^9$ particles/cm$^3$ and $(4.42 \pm 0.12) \times 10^9$ particles/cm$^3$ respectively for dose of 3 ml/500 ml gasoline and 2 ml/500 ml gasoline. Both ADV-1 and ADV-2 PM$_{0.1}$ concentration trails polynomial correlation with the $R^2 > 0.85$.

![Figure 3](image-url) 

Figure 3. The influence of additive dose on the total PM$_{0.1}$ concentration.

In the case of ADV-3, the PM$_{0.1}$ concentration is obtained to follow a negative polynomial correlation. As present in the figure above, the concentration of PM$_{0.1}$ increases by applying the higher additive dose. The peak of PM$_{0.1}$ is obtained on the dose of 9 ml ADV-3/500 gasoline with the total PM$_{0.1}$ concentration of $(0.83 \pm 0.03) \times 10^9$ particles/cm$^3$. Meanwhile, the factory recommended dose
(8 ml additive/500 ml gasoline) produces PM0.1 with the total concentration of \((0.77 \pm 0.02) \times 10^9\) particles/cm³ that become a second-highest concentration in the usage of ADV-3. Mixed 6 ml ADV-3 into 500 ml gasoline generates \((0.44 \pm 0.02) \times 10^9\) particles/cm³. Meanwhile, in the dose of 7 ml 500 ml gasoline and 10 ml/500 ml gasoline generates the PM0.1 total concentration of \((0.72 \pm 0.01) \times 10^9\) particles/cm³. Although ADV-3 PM0.1 emission characteristic is observed oppositely with the ADV-1 and ADV-2, the PM0.1 concentration is observed at the lowest level. While the ADV-1 and ADV-2 produced PM0.1 in the range of \((0.95 - 4.42) \times 10^9\) particles/cm³ for all additive doses, the ADV-3 only has PM0.1 of \((0.44 - 0.83) \times 10^9\) particles/cm³.

Further analysis shows that the factory recommended dose is not always the best amount of additive in PM0.1 generation. For example, in the case of ADV 1 and ADV-2, the factory recommended dose was obtained on the lowest concentration compared to any other additive dose in the same type. Meanwhile, the lowest PM0.1 concentration for ADV-3 was found in the dose of 6 ml/500 ml gasoline or 2 ml lower than the factory recommended dose.

3.4. Emission factor

The additive type is found signifigantely not influencing the fuel consumption. In our measurement, 100 seconds of the active engine only consumed about 15 ± 1 ml fuels. This number was obtained on all additive types, including the variation of additive doses. Due to similar fuel usage, the emission factor was not observed to have different PM0.1 emission characteristics. The lowest emission factor is perceived in the factory recommended dose for ADV-1 and ADV-2 with a level of \(0.06 \times 10^9\) particles/cm³ per ml fuel and \(0.11 \times 10^9\) particles/cm³ per ml fuel. In the ADV-3, the lowest emission factor was calculated in Fr-2 with the level of \(0.03 \times 10^9\) particles/cm³ per ml fuel that also became the lowest emission factor compared with the rest of the sample. The Fr-2 was calculated to have the highest emission factor with the level of 0.29 \(x 10^9\) particles/cm³ per ml fuel. The complete emission factor analysis is presented in the table below.

| Additive Samples | Emission factor (x10⁹ particles/cm³ per ml fuel) |
|------------------|-----------------------------------------------|
|                  | Non Additive | Fr-2(ml) | Fr-1(ml) | Fr (ml) | Fr+1(ml) | Fr+2(ml) |
| ADV-1            | 0.13         | 0.08     | 0.07     | 0.06    | 0.07     | 0.07     |
| ADV-2            | 0.13         | 0.29     | 0.17     | 0.11    | 0.11     | 0.13     |
| ADV-3            | 0.13         | 0.03     | 0.05     | 0.05    | 0.06     | 0.05     |

4. Discussion

The function of the fuel additive depends on the chemical. For example, the octane booster additive type changes the fuel composition with a certain chemical compound to increase the Octane number. As a result, the fuels would be combusted when the correct pressure and gas and fuel ratio are achieved. On the other hand, fuel system cleaner cleans the fuel path from gasoline crust that may be developed inside the engine[22-30]. The crust that was developed in the engine may affect the quantity of the combustion fuel. When the crust was developed, the fuel injection may clog and reduces the amount of fuel. As the result, the ideal fuel-air ratio may not be accomplished. Both methods have been proved to cause imperfect combustion processes that lead to the development of unwanted emissions such as CO, BC, PAH, VOC, and PM in various sizes (1-5).

In our study, the usage of octane booster increased the concentration of PM0.1. Using the factory recommended can reduce the PM0.1 by 15.4%. Reducing the additive dose of 1 ml and 2 ml was found to increases the PM0.1 concentration of 30.8% and 123.1%. Our evaluations predict that mixed incorrect additive concentration may cause the additive to not diverse well. As a result, the combustion process becomes more unstable. The combustion process is a matter of timing and fuel-air ratio. The
Fuel shall inject with the correct number and the right time to achieve perfect combustion. When the fuel with incorrect additive was burned, the combustion process may happen too fast or late. As a result, combustion became more unstable and produced more PM$_{0.1}$. A low additive dose may be combusted too fast in the octane booster before the engine reaches a full circle. When the fuel with higher additive was injected in the next circle, the combustion is done fully. Repeating this process may increase the number of PM$_{0.1}$.

In our data, using Fr-1 was found to increase PM $0.72 \times 10^9$ particles/cm$^3$. This number is higher than Fr-2 that was obtained from $0.44 \times 10^9$ particles/cm$^3$. Using a factory-recommended dose was raised the PM concentration to be $0.77 \times 10^9$ particles/cm$^3$. Meanwhile, using Fr+1 and Fr+2 increased the PM to be $0.83 \times 10^9$ particles/cm$^2$ and $0.72 \times 10^9$ particles/cm$^2$ respectively. When the additive was injected, it will clear the fuel system from the gasoline crust. Using low concentration may only be able to remove a small amount of crust. In the result, PM$_{0.1}$ concentrations are obtained in the lowest concentration. In this study, using Fr-2 dose from fuel cleaner additive can reduce the PM$_{0.1}$ up to 78%. When a high additive concentration was applied, a sudden high gasoline crust concentration may also burn together with the fuel. As a result, the ideal fuel combustion is not achieved. Based on this result, it became clear that using a low fuel cleaner additive to reduce slowly may be the best method to lower the PM$_{0.1}$ concentration.

In the additive sample with both types (fuel system cleaner and octane booster), the lowest PM$_{0.1}$ concentration was observed on the factory recommended doses. In the factory recommended dose, the PM$_{0.1}$ was measured at $0.95 \times 10^9$ particles/cm$^3$. This concentration is 53.8% more lowly in comparison with non-additive gasoline. Reducing the additive dose was found to raise the PM$_{0.1}$ to be $1.23 \times 10^9$ particles/cm$^3$. An increase in the additive dose was also obtained to increase the PM$_{0.1}$ concentration to be $1.04 \times 10^9$ particles/cm$^3$.

The emission factor showed similar behavior. The lowest emission factor was obtained in the ADV-3 with the dose of Fr-2 (emission factor of $0.03 \times 10^9$ particles/cm$^2$ per ml gasoline). The higher emission factor was observed in the ADV-2 with the emission factor of $0.29 \times 10^9$ particles/cm$^2$ per ml gasoline. The impact of the additive dose was also obtained similarly. In the ADV-1, applying the additive with the dose of Fr-2 resulted in the emission factor of $0.08 \times 10^9$ particles/cm$^2$ per ml gasoline. The emission factor was increased when the Fr-1 dose is applied to be $0.07 \times 10^9$ particles/cm$^2$ per ml gasoline. The emission factor for Fr was obtained from $0.06 \times 10^9$ particles/cm$^2$ per ml gasoline. In the case of Fr+1 and Fr+2, the emission factor was perceived as $0.07 \times 10^9$ particles/cm$^2$ per ml gasoline.

5. Conclusion

In conclusion, the additive types affect PM$_{0.1}$ emission. Fuel additive has an impacts on the PM0.1 emission with decreasing the emission factor in the range of 20% to 60% depending on the fuel additive type. The fuel additive dose influence of the PM$_{0.1}$ emission factor. Factory recommended dose for fuel additives is the right dose for reducing the PM$_{0.1}$ emission.

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