The Construction of Electrostatic Air Cleaner for Exhaust Gas of Four Stroke Engine Motorcycle

Jassada Sarasook

***Abstract*— *This research presents air cleaning for exhaust pipe using electrostatics discharge which occurs from high voltage in ignition coil of four stroke engine motorcycle. Moreover, research studies the noise occurred from conductor of electrostatics discharge. Two types of cables, conventional cable and shield cable, are implemented for investigating the noise. Ozone gas is generated in order to clean exhaust gas of motorcycle. Generated ozone gas is used to remove carbon monoxide (CO) gas which is toxic gas. It uses the principle that ozone gas will change carbon monoxide to carbon dioxide (CO_2). Ozone gas is produced through corona discharge process using high voltage from ignition coil as igniter in motorcycle. To produce ozone gas, the exhaust pipe is modified by installing the electrostatic discharge set. After that high voltage from ignition coil is connected with discharge electrode by investigated cables at discharge position. For testing, the speeds of engine are set four level including 500, 800, 1,100 and 1,400 rpm (round per minute). Exhaust gas analyzer is used to measure quantity of CO gas. From experimental results show that the CO quantity decreases at maximum 54.55% at 500 rpm which it is lowest speed. However, if speed of engine increases, the rate of CO removal decreases. Considering noise occurred, it is found that the noise is the lowest for conductor with shield. The average noise reduces approximately 85.42% when compares with conventional cable.*

***Keywords*— Air cleaning, carbon monoxide, electrostatic discharge, exhaust gas, high voltage.**

1. INTRODUCTION

Presently, air pollution becomes one of important world problem which effects on human's health, the undesirable things of human or the substances these are directly or indirectly disadvantage to human life. According to World Health Organization (WHO) mentioned in [1], 7 million people die each year from air pollution especially Asia and Africa. It is very alarming that high number of deaths around the world by air pollution about 6.53 million in 2017. It is the third cause of deaths from all cause of death [2]. The most death cause by air pollution is outdoor air pollution at 3.7 million a year [3]. Therefor air pollution is the most problem which many countries focus on and find solutions to prevent and protect its effect. Also, Thailand, Pollution Control Department, Natural Resources and Environment, the organization has been founded in 2010 for solving the problem of pollution [4].

According to Thailand state of pollution report 2018 [5], it is revealed that the most cause of air pollution was in road transport. It emits the toxic air including PM_{10}, $PM_{2.5}$, CO, NOx and VOC. Since 2018, people in Thailand have more realized problem of air pollution because of PM2.5 (Particulate Matters 2.5 micron) which attacked the big city; Bangkok and perimeter [6][7]. This situation brings that the mask becoming best seller product. This cause of problem occurs by vehicle which is the third cause after open burning and factory respectively [8]. There are many researches study solutions for solving the problem for example using electrostatic [9][10][11]. It shows that the electrostatic can reduce dust and smoke. Not only the dust but also toxic gas also emits from vehicle. The data in [5] shows that the most CO gas is emitted by road transportation. Considering [12], it is found that all vehicles which registration on legal are 2,958,183 vehicles. The most vehicles are motorcycle at 63%. The CO gas is produced by engine for example car, motorcycle and so on [13]. Especially the engine in motorcycle that is used the most in Thailand [12].

Carbon monoxide gas (CO) which is a colorless, odorless and tasteless so not knew that it is in air and effected to body [14]. CO is generated by incomplete combustion in engine or stove. It is produced from the partial oxidation of carbon-containing compounds; it forms when there is not enough oxygen to produce carbon dioxide (CO_2) [15]. CO is high toxic gas for human which general body would breathe to bring oxygen for using in metabolism process. If human breathe CO to in body, the red blood cell would get with CO affected that the body not had oxygen for maintain part of body. The bodies without oxygen maybe die [16][17]. The interesting way to reduce or remove CO gas is ozone gas (O_3) using. Ozone gas can react with CO toxic gas to produce CO_2. Therefore, electrostatic is a way to generate O_3 [18].

The research in [19] shows electrostatic technique can reduce CO gas. Moreover, research in [20] shows also it can remove and reduce CO gas in gasoline engine. For motorcycle, O_3 is applied in [21], it is still can remove CO gas. However, the electrostatic technique needs high voltage. It would generate the noise occurred by electric field. The generated noise might effect on electronic devices such as mobile phone, control system in vehicle and all electronic devices.

Therefore, the research aims to construct air cleaning

Jassada Sarasook is lecturer with Electrical Department, Srisongkham Industrial Technology College, Nakhon Phanom University, Thailand. E-mail: Jassadat77@gmail.com.

for exhaust gas of motorcycle using high voltage source from ignition coil in the motorcycle without another source. The high voltage will generate electrostatic discharge for cleaning exhaust gas. Moreover, the study of suitable conductor for connecting between ignition coil and discharge point by considering the noise is presented. Finally, the result of CO toxic gas removing by proposed electrostatic air cleaning is presented. Moreover, the reducing of noise is introduced.

2. RELEVANT PRINCIPLES

2.1 Carbon Monoxide Gas Removing

Carbon monoxide (CO) is clearly high toxic to humans and animals effecting to metabolism process of being [16][17]. This research focuses on CO gas production through motorcycle engine used the most in Thailand [13]. CO is reduced by transferring it to CO_2. For process run, one atom of oxygen is needed to react with CO gas. Therefore, ozone gas (O_3) is used. The ozone gas can be generated by corona discharge using high voltage [22]. If high voltage is applied to electrode until corona discharge, first diatomic oxygen is dissociated to the atomic form by collision with an electron and then O_2 reacts with atomic oxygen to form ozone (O_3). The process is shown in Eq. (1) and Eq. (2) [18]

$$O_2 + e^- \rightarrow e^- + O + O \quad (1)$$

$$O_2 + O \rightarrow O_3 \quad (2)$$

Ozone is a tri-atomic molecule consisting of three oxygen atoms. Although O_3 is harmful, it is unstable [23]. Ozone can have a haft-life of as short as thirty minutes under atmospheric conditions [24]. It will be changed to diatomic allotrope rapidly (for example O_2). The next step, obtained ozone gas (O_3) then is used in carbon monoxide removal process. CO which is toxic gas would pass to react with ozone to form CO_2. It is shown in Eq. (3) [25]. Finally, carbon monoxide gas reacts with ozone gas becoming carbon dioxide which is not toxic gas.

$$CO + O_3 \rightarrow CO_2 + O_2 \quad (3)$$

2.2 The Electrostatic Discharge by High Voltage

The electrostatic precipitator for air cleaning needs high voltage to generate electric field as Eq. (1). Level of voltage used depends on the feature of electric field; uniform or non-uniform. The features of electric field are difference depended on shape of electrode [26]. In this research, non-uniform electric field is selected because it has low voltage to generate corona discharge as present in [27]. The maximum of electric field stress is obtained by [28]

$$E_{\max} = \frac{U}{d\eta^*} \quad (4)$$

where, E_{max} is the maximum of electric field stress, U is the voltage value (kV), d is the distance gap, η^* is the field utilization factor.

The field utilization factor is interval 0-1 which parameter shows characteristic of electric field. If its value is high, electric field almost is uniform field but if it is less showed that high non uniform field. From Eq. (4), it is investigated that maximum of electric field stress is high if utilization factor is very low. Therefore, the electrode discharge as pin point (Rod Shape) is chosen for this research. Furthermore, corona will occur, if maximum of electric field stress (E_{max}) is less than standard condition of air at 25 kV/cm [28]. From Eq. (4), parameter distance gap (d) is an important factor. If distance is low, the stress is high. Therefore, the position to install the electrostatic discharge is in the low gap which is near the beginning of exhaust pipe as shown in Fig. 4.

The electrostatic precipitator not only generates ozone gas but electric field also. It is installed in motorcycle. That means the electric field source is run around the street. The electric field generated by pulse is a cause of the noise in electronics devices such as mobile phone [29]. According to [21], it shows that the high voltage from ignition coil is pulse wave shape. However, conventional cable of motorcycle neglects shield of noise. Therefore, the research aims to study the way to reduce the noise. The level of noise in this research is considered from electric field which occurs by high voltage [30]. The noise depends on electric field level thus the noise varies on voltage level as shown in Eq. (4). Therefore, if voltage of cable insulator is high, the electric field is high and the noise is high also. So, voltage level can measure the noise level.

3. EXPERIMENTAL SETUPS

3.1 Design of Electrostatic Discharge

The structure of electrostatics discharge in this paper consists of two electrodes like rod-plane gap which is non-uniform because it can generate high corona [27]. The first electrode is discharge electrode which it is made of wire metal with 1 mm of diameter as shown in Fig. 1. Head of electrode is shape for easy corona generating. It is coved by ceramic insulator. For another electrode, area inside of exhaust pipe in motorcycle looks like plane electrode as in [27]. Also, it is ground of system and it was connected with metal which covers on insulator. The metal connector is connected with exhaust pipe of motorcycle. High voltage from ignition coil is connected to wire discharge electrode by junction plug. They are shown in Fig. 1.

3.2 Experimental Circuit

The experimental circuit is shown in Fig. 2. The circuit applies generated high voltage which occurred by ignition coil generally. But in this research, the ignition coil is added another one. Another added ignition coil is connected parallel with conventional circuit. This parallel ignition coil is the same model of conventional ignition coil by depending on the model of motorcycle. The reason why parallel ignition coil is added because

avoid problem which probably effect on engine system of motorcycle. From testing, it is found that if it used high voltage from the together same ignition coil without adding a new coil, it affected that engine of motorcycle cannot run. Generated high voltage from parallel ignition coil is feed to discharge electrode throughout cable.

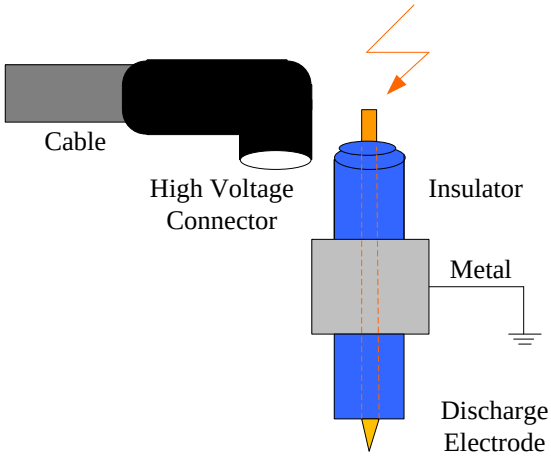


Fig. 1. Structure of Electrostatic Discharge.

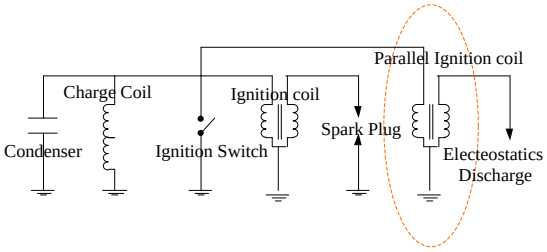


Fig. 2. Testing Circuit.

3.3 Metal Shield Box

The added parallel ignition coil is installed in the in the metal shield box as shown in Fig. 3. Because output voltage is high so the electrostatic stress is high also. This effects more generated noise especially connection point. To prevent noise generated by electrostatic field, the metal shield box is used as introduced in [30]. The shield box makes of cylinder steel. It is closed both side of them by aluminums sheet. The one side is used to hold with parallel ignition coil and structure of motorcycle as ground. By the way, another side is used to connect with high voltage cable into electrostatics discharge. This metal shield is held with the structure of motorcycle.

3.4 The Installation of Discharge Electrode

The discharge electrode as shown in Fig. 1 is installed in the position as shown in Fig. 4. The position is selected by relation in Eq. (4). The electrode gap likes rod plane gap to more produce corona [27]. It is non-uniform field. The pin electrode is discharge while area in exhaust pipe is as the plane. For gap distance, if it is less, the corona is easy to be generated [26][27][28] following as Eq. (4). Finally, it is placed in near of combustion or head of exhaust pipe because it needs the time to change CO becoming CO_2 [24]. The discharge electrode is received high voltage from parallel ignition coil.

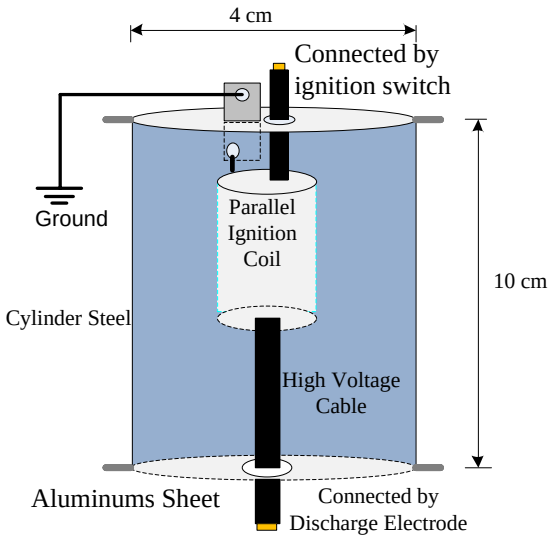


Fig. 3. Metal Shield Box of Parallel coil

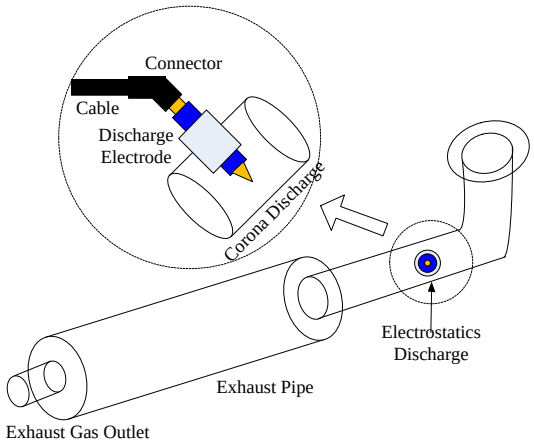


Fig. 4. Position of Electrostatic Discharge installation.

3.5 Experimental Cables

The cable is a factor important because conductor of high voltage generates high electrostatic field becoming noise for electronics device especially mobile phone. To understand the noise, in this research measures the electrostatic through the voltage level of cable. The voltage levels are compared between two types of cables. It will show the different voltage between generally convention cable, which used in region, and modified shield cable for preventing the noise. Feature of two cables is shown in Fig. 5. They are two types of cables used in experiment such as conventional cable and shield cable. First cable, a conventional cable is generally found in commercial region market. Generally, this cable is used in motorcycle. It can be seen normally as conductor between ignition coil and spark plug. Its diameter is 7 mm and it consists of copper conductor with insulation covering on conductor. Another cable is cable adding shield. This cable occurs from general cable adding PVC

insulator until diameter 9 mm and covers it by aluminum foil sheet after that it is covered by PVC again. Therefore, this cable has diameter of 11 mm. All types of cable are shown in Fig. 5.

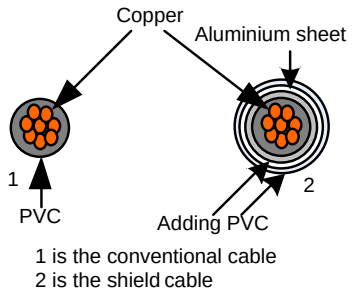


Fig. 5. Two Types of Cables.

3.6 Test Procedure

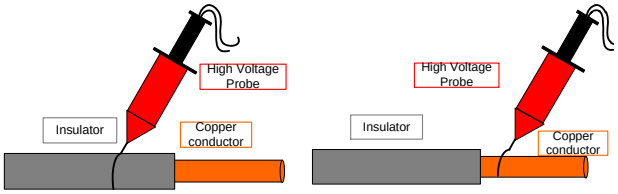
To implement, the devices was set following Fig. 2. The four-stroke engine was used for testing. The modified exhaust was installed in 100 CC engine of motorcycle. To testing, four speeds of engine were set at 500 rpm, 800 rpm, 1,100 rpm and 1,400 rpm. When motorcycle starts, high voltage is distributed to discharge electrostatic by ignition coil. The CO was measured 5 times a speed and average value was calculated. Quantity of CO gas by exhaust gas of motorcycle was measured by Automotive Emission Analysis of HESHBON model HG-510 as shown in Fig. 6. To investigate, exhaust gas was measured the both of installing electrostatic air cleaning and without for each speeds of engine.

The tests were performed by using two cables for each speed. The parallel ignition coil was contained in metal shield box for testing both of cables. The noise was investigated by measuring the voltage level that occurred from two types of cable. The voltage levels were measured conductors and insulator of cables by using high voltage probe as shown in Fig. 7. High voltage probe help divide voltage level in the rate ratio of 1000:1 and it was displayed by oscilloscope GW INSTEK model GDS-2062. The voltage levels were measured in 5 times for each cable and finally average values were found.

Fig. 6. Automotive Emission Analysis.

It is clear that the electric field generates noise. The high voltage level is a main thing which generates the electric field so it generates noise also. If voltage level is high, the noise is high. For the cable testing to investigate the noise, the voltage level is measured by high voltage probe at 2 points including insulator of cable as shown in Fig. 8 a) and copper conductor as shown in Fig. 8 b). From Fig. 8 a), the noise is the electrostatic field on cable which really it is no needed because it interferes communication or electronic devices. For Fig. 8 b), it is the voltage of electrostatic discharge which obtained by parallel ignition coil. The voltage level is displayed on oscilloscope.

Fig. 7. High Voltage Probe.



a) Noise Voltage **b) Discharge Voltage**

Fig. 8. Positions of Measuring.

4. EXPERIMENTAL RESULTS

4.1 Carbon Monoxide (CO) Quantity

The research idea is tested by measuring CO gas quantity in exhaust gas of motorcycle by automotive emission analysis. To understand the results of electrostatic air cleaning, CO measurements were done under three conditions including the general condition which the condition had not the electrostatic discharge (ESD), the condition within electrostatic discharge by using general cable and finally the condition within electrostatic discharge by using modified shield cable. The results are shown in table 1. For the efficiencies of CO remove as shown table 1, it is obtained by following Eq. (4).

$$Eff = \frac{B - A}{B} x100\% \quad (4)$$

which, B is quantity of CO gas before ESD installing, A is quantity of CO gas after ESD installing, and Eff is efficiency of CO removal.

From Table 1, it is obtained the CO gas quantities from four speeds. Overall, the CO gas depends on engine speed. Considering without electrostatic air cleaning condition, CO gas is 0.11% at 500 rpm (round per minute) while Quantity of CO is 0.49% at the tested maximum speed at 1400 rpm. The average CO gas is 0.31%. It shows that if engine speed increases, CO gas is increased.

Table 1. Carbon monoxide (CO) quantity

Engine Speed	Without ESD*	Within ESD*			
	%CO	Cable		Shield Cable	
		%CO	Eff.**	%CO	Eff.**
500	0.11	0.05	54.55	0.05	54.55
800	0.27	0.15	44.44	0.16	40.74
1100	0.35	0.20	42.86	0.19	45.71
1400	0.49	0.29	40.82	0.30	38.78
Average	0.31	0.17	45.67	0.18	44.94

* ESD is electrostatic discharge
** Eff is percent of efficiency (%)

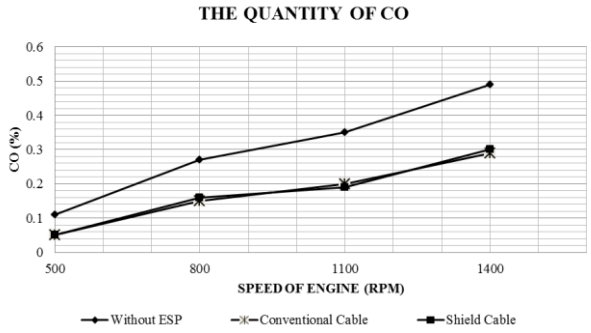


Fig. 9. CO quantity for each cable

From Fig. 9, considering the CO gas quantity in without electrostatic air cleaning, it shows the relation between engine speed and CO quantity. It is found that CO gas quantity of exhaust gas is directly varied by speed of engine. The graph is linear function. CO gas increases in the rate 0.0004% per speed. After the electrostatic air cleaning is installed, the CO gas is reduced clearly for all engine speed as shown in table 1. This research used two cables for electrostatic air cleaning to study the noise. From Fig. 9, it is found that the proposed idea can remove CO gas. The maximum CO gas occurs at the maximum engine speed at 1400 rpm. It is 0.29% for general cable and 0.30% for cable adding shield. The minimum CO gas occurs at low speed of engine at 500 rpm. It is the same 0.05% for both of cable. Like without air cleaning, the CO gas quantity increases following engine speed. From Fig. 9, two cable of electrostatic air cleaning is rather equal result. They can decrease CO gas. The CO gas quantity is reduced by it still is just 0.0003% per speed. That means cable type no effects on the CO removal capacity. It is investigated by two lines in graph which almost completely overlapping. In conclusion, it can be said that the effect of cable type is very less. However, from table 1, it is investigated that cable type has a little effect on performance of CO gas removing. Comparing three conditions as table 1, it is investigated that the CO is emitted the most when it is without electrostatic air cleaning at average of 0.31% while in another leave two conditions are less than once. The averages CO gas are 0.17% for within air cleaning using conventional cable condition and 0.18% for modified shield cable (cable adding shield). From average of CO gas, it found that the electrostatic air cleaning can be reduced CO highly at 45.67% and 44.94% for general cable and modified shield cable respectively. It can be seen that both of cable is almost equally CO gas removing.

From Eq. (4), the efficiency is calculated and shown in table 1. The graph of efficiency is shown in Fig. 10. It is investigated that proposed device is high performance at low speed of engine. The maximum efficiency is 54.55% occurring at low engine speed at 500 rpm in both of cables. While the minimum is 40.82% and 38.78 in general cable and modified shield cable respectively. The efficiency is changed by engine speed; if engine speed increases, the efficiency decreases. The reason is that probably engine speed is high so exhaust gas will flow at high flow rate also. While O_3 needs a time for reaction [24] but at high speed it has some a little time so CO is less change than low speed. Not only that but also the generated high voltage by ignition coil is a cause. According Fig 12, the voltage level will decrease if the speed of engine increases. It is surely that the voltage effects on electrostatic discharge following Eq. (4). The electric field stress is reduced by voltage level. Therefore, generated corona is low also. This is cause of O_3 is low down. Therefore, the CO gas removal will decrease if the engine speed increases. However, rate of CO removal is the high.

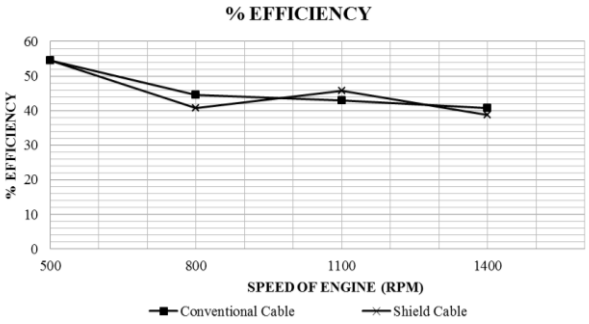


Fig. 10. Percent of Efficiency

4.2 Discharge Voltage

The feature of discharge voltage is shown in Fig. 11. It is high voltage obtained from parallel ignition coil added to generally conventional ignition circuit of motorcycle. The circuit is shown in Fig. 2. From Fig. 11, it is investigated that wave shape is pulse voltage. The voltage wave shape has both of positive and negative cycle. The maximum of positive cycle is about 15 kV while negative cycle is about 22 kV. Moreover, time period (T) is about 220 μs. Considering the circuit in Fig. 2, it is investigated that the voltage wave shape of ignition coil of motorcycle and added parallel ignition coil is the same because they are the same model. The voltage level also is equal. It means that generally motorcycle emits the noise. Therefore, not only CO gas removal, but also this research focus the noise and modify to remove noise.

To obseve voltage level in each engin speed, the

voltage level was measured. The circuit is set by Fig. 2. The conventional cable was install from conventional ignition coil to discharge electrode. The position of measurment refers to Fig 8 (b). Five engine speeds was tested and volatge was measured 5 times for find average. This volatge was the voltage of discharge electrode which measured in position of conductor. While the noise was studied by investigating the voltage level of cable insulator. The position of measurment is shown in Fig 8 (a). The results is shown in table 2.

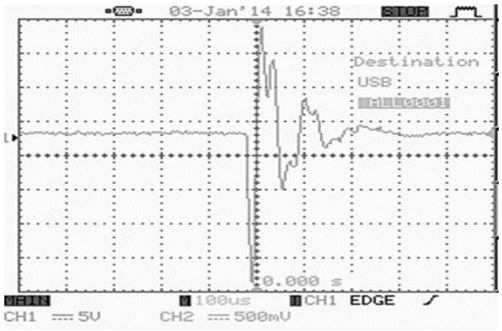


Fig. 11. Wave Shape of Discharge Voltage.

Table 2. Voltage level of conductor and cable insulation

Engine Speed	Conductor		Cable Insulator		
	Cable	Shield Cable	Cable	Shield Cable	Effc***
500	17.40	17.00	12.80	1.84	85.63
800	15.00	14.40	11.40	1.64	85.61
1100	11.40	11.00	8.70	1.28	85.29
1400	8.60	8.32	6.80	0.86	85.17
Average					85.42

*** Effc of cable is efficiency of cable (%)

From Table 2, the efficiency of cable insulator in the view of noise is analyzed by using EQ. (5). The efficiency is obtained by comparing with conventional cable. Conventional cable is cable which normally can buy in region and it is used in motorcycle. This means it is normally phanomenon. The shield cable is modified by add aluminium foil and PVC insulator to prevent generated noise emite to environment. The efficiency is obtained by

$$Effc = \frac{V_1 - V_2}{V_1} x100 \quad (5)$$

in which, Effc is efficiency of cable (%), V_1 is voltage of general cable insulator, and V_2 is voltage of modified shield cable.

From Fig. 12, two types of conductors were tested. The peak voltage of wave on positive cycle side is plotted. It is investigated that the voltage is inverse varied by engine speed. If engine speed increases, the voltage will decrease for both of them. However, the result in Fig. 12 shows that shield cable is very small different voltage generation from cable without shield. It can be said that the shield cable not effect on the discharge voltage which generates the O_3 gas.

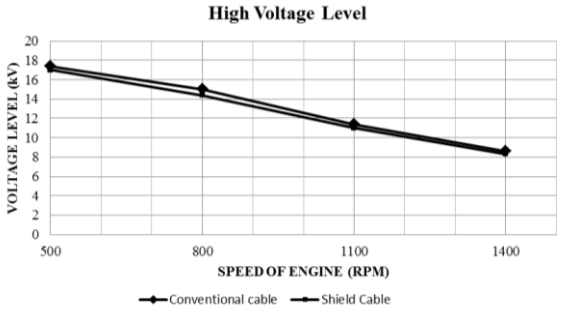


Fig. 12. Voltage Levels of Conductors.

To observe the noise occurred by high voltage in cables, the instruments were set. The position of measurement is shown in Fig. 8 (a). Results are shown in Fig. 13. It is investigated clearly that noise voltages of two cables are very different. Noise voltage of conventional cable is very higher than modified cable which the discharge voltage of conductor almost equal. That means the shield cable can reduce the noise well while it effects discharge very low which it can be neglected. The noise inverse varies on engine speed. If engine speed increases, the noise would decrease. The noise relates with discharge voltage which considering Fig. 12 and Fig 13, it found that the noise directly varies on discharge voltage. Discharge voltage is high, the noise is high also. However, the way to reduce the noise in this research, the shield is used by applying aluminum foil sheet covering cable.

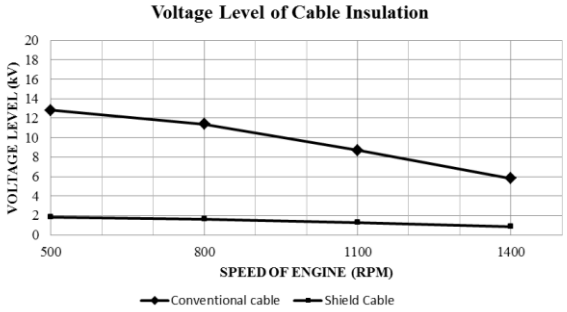


Fig. 13. High Voltage Levels in each Engine Speeds.

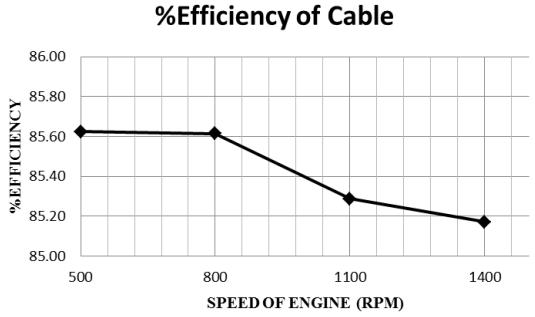


Fig. 14. Efficiency of Noise Prevention.

However, efficiency of noise prevention is not still 100%. The efficiency is in the range of 85.71-85.63%.

From Fig. 14, it shows that the maximum noise prevention efficiency occurs at low engine speed but it is low down at high speed of engine.

5. DISCUSSIONS

According to all presented above, it can be revealed that CO gas relates with engine speed which speed increases, CO gas increases also. That is correspondent to [20]. Likely [31], it shows that CO gas of gasoline engine increases by engine speed. Moreover, the research [32] and [33], they show the CO gas directly varies on engine speed also. It is very frighteningly that the fuel emitting CO to environment the most is gasoline [34]. This research aims to reduce the CO gas in gasoline engine also. The results show that presented electrostatic air cleaning can reduce CO just about average of 45% each speeds and maximum is 54.55% at 500 rpm engine speed. In [20] it is maximum reduced at 26.22% but the speed of engine is high at 1000-3000 rpm while in this research is just 500-1400 rpm. In [32] shows the CO gas can be reduced 86.52% at speed of 2200 rpm by using electrostatic discharge also but the modified exhaust is more difficult than this research. This research uses just small discharge electrode, parallel ignition coil and cable while [32] needs modify cylinder and wire electrostatic which all are contained in exhaust pipe. It needs more modify exhaust pipe than this research. However, the efficiency of CO removal is decreased if the engine speed is increased. This is corresponding to [20] and [32]. From results it is shown that the voltage is decreased if engine speed is decreased. That means the corona is reduced also therefore O_3 is reduced. These effects on the CO and O_3 gas reaction is less down. Another reason, the engine speed increases, the gas flow increases also [35]. Therefore, the CO gas is drained out rapidly so CO and O_3 gas reaction is lower because O_3 needs some time for reacting [24].

By the way, the voltage wave shape is pulse voltage which corresponding with [36][37]. The voltage level is in range of 8.32-17.40 kV. This is corresponding with [37] which use the same four strokes engine which the voltage is in range of 10.30-23.10 kV. It is the high voltage. According to [38], it found that the generated pulse voltage level relates with the noise interference. Noise directly varies on voltage level. Considering the voltage noise in cable by measure on insulator of conventional cable, it is found that the voltage is high about 8.7-12.8 kV which still be high. However, after modified cable by shielding, the noise reduced just left 0.86-1.84 kV only. This means the shield cable is high efficiency noise prevention which average is 85.42%.

For the future research point, the electrostatic produces electric charge (positive and negative charges). The different charges will suck together. In the case of PM2.5 which long time floats in the air, if it is charged negative and the ground is positive, it probably rapidly falls to ground.

6. CONCLUSIONS

From experimental results in above able to summarize as following.

1. Engine speed influences on CO gas quantity. If speed increases, CO will linearly increase.

2. Proposed electrostatics air cleaning can reduce CO gas of exhaust pipe in motorcycle at average 45.76% and 44.94% for conventional cable and modified shield cable respectively.

3. Efficiency of CO removal depends on engine speed. Efficiency is high at low speed but it is decreases if the engine speed increases.

4. Discharge voltage of conductor is decreased following the engine speed increase so it inverses varies by engine speed.

5. Discharge voltage of two conductors; conventional and modified shield cable is almost equal. So, it can be said that modify the insulator of conductor not effect on the generated discharge voltage.

6. Noise in conventional cable is generated. The voltage on cable insulator is varied by discharge voltage of conductor and inverse varied by engine speed.

7. The modified shield cable can reduce noise voltage still average of 85.42%. The efficiency of noise prevention decreases if engine speed increases.

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