Tube catalyst (TK\textsuperscript{plus}) to crack gasoline fuel vapor in motor vehicle

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Abstract. This study aims to test ability the catalyst tubes to reduce exhaust emissions, save fuel and increase power and torque engine on vehicle. The catalyst tube named TK\textsuperscript{plus}. TK\textsuperscript{plus} catalyst tube filled with NiFe\textsubscript{2}O\textsubscript{3} which was created with sol gel method and calcined on temperature 600°C, characterized by XRD, FTIR, SEM EDX, and BET test. Exhaust emission test results show motor vehicles equipped with TK\textsuperscript{plus} can reduce CO\textsubscript{2} emissions; between 36\% - 48\%, and CO\textsubscript{2} emissions fall between 7\% - 42\%, decrease fuel consumption by 23\% - 33\%. Dyno test shows that in the presence of TK\textsuperscript{plus} engine performance increased compared with engine without TK\textsuperscript{plus}. At the revolving round of the engine at 5781 rpm or at a speed of 120 km/h, the power value increased by 5.8\% and the torque value increased by 7.8\% compared to the vehicles not equipped with TK\textsuperscript{plus} value.

1. Introduction
For reducing air pollution due to exhaust emissions from the transportation sector, it is necessary to control the source of vehicle exhaust emissions. Various efforts have been made to reduce exhaust emissions of vehicles such as by using environmentally friendly fuel such as biodiesel, bio ethanol and bio gas. Another effort is developing a catalyst tube which is a developed catalyst tube, a tool containing catalyst which can break down hydrocarbons into carbon atoms (C) and Hydrogen (H\textsubscript{2}). The component of the catalyst tube comprises a catalyst pipe containing the catalyst and casing as a catalyst pipe protector. The catalyst tube is placed on a high temperature exhaust manifold. The catalyst present in the catalyst tube will split the vapor of the fuel into carbon atoms and hydrogen gas. The hydrogen is then fed into the combustion chamber, mixed with the fuel originating of the fuel tank.

The catalyst tube is very effective at saving fuel and lowering exhaust levels. Using a catalyst tube, the mileage of fuel by volume can increase to 13 – 15 km / liter compared to a non-catalyst mileage of fuel by volume that is only 10 km/liter, producing as much as 3 - 5 Lpm (liter per minute) of hydrogen gas H\textsubscript{2} [1]. Research results Subchan (2013), regarding influences cylinders catalyst on fuel consumption, showing vehicles equipped with catalyst tubes can save 60 – 65\% fuel. [2]. The percentage saving vehicles of the cylinder. The catalyst depends on the diameter, length of the catalyst pipe, vapor volume nad hydrocarbon vapor flow [3].
As catalyst are usually used vanadium, platinum and rhubenum, all of which are metals nobles ones that cost a fortune. To lower the cost of the catalyst researchers have developed various types of catalysts including zeolite, alumina. Yi et al [4] has using SrO/ NiO – Al₂O₃ catalyst to break down fuel. The result showed that the yield of H₂ OF 74.8% was obtained if the content of SrO 5%. The results of the Justyna et al (2016) study show that the Co / ZSM-5 catalyst, prepared by impregnation of Co ions on a zeolite containing SiO₂: Al₂O₃ = 25: 30, is very effective for breaking methane vapor into hydrogen gas and carbon nanomaterials such as carbon nanotubes, while the results of Josefinas research (2015), show that hydrotalcite catalysts are very effective for break down toluene vapor compared with rhodium catalyst. Waleed et al (2017) reported that CO₃O₄ / TiO₂ catalysts prepared by the wet method incipient wetness impregnation catalyst can oxidize CO gas by 44% while with method wet impregnation can only oxidize CO gas by 34%. In his research Abdallah et al (2014) using zeolite with share Si/Al ratio of 30, 80, 180) to crack (crack) naphtha at 400 °C for 20 seconds. They research showed that zeolite catalysts with Si/Al ratio 30 were able to convert naphtha into C3 and C4 carbon compounds respectively by 48% and 27%.

In addition to zeolite and alumina, compounds of ferrite compounds, can also be used to break down the carbonaceous into hydrogen and carbon dioxide. The results of Xiaoliang et al (2016) showed that the catalytic power of MnFe₂O₄ to formic acid, influenced by the temperature of calcination. Calcination at temperatures above 400 °C, causes a decrease in the catalytic power of MnFe₂O₄. The catalytic process of methanol using CuFeO₄ catalyst produces more CO and methane, less CO₂ (12%), methylformiat (1-4%) and C2 – C3 hydrocarbons 1-2% (Tsoncheva et al, 2014).

The NiFe₂O₄ catalyst demonstrates good catalytic power to break down methane into hydrogen gas and carbon atoms at temperature 475 °C, (Shiran, 2016). Using the Mo Fe₂O₄ catalyst, converting methane gas to hydrogen gas and carbon nano tube achieved at 400 °C (Torres et al, 2014). Markova et al (2016) in his study found that the oxidation mechanisms of the three carbon compounds of methane, toluene and hexane using YFeO₃ and LaFeO₃ catalysts follow kinetics Langmuir & Hinshelwood, and did not follow Mars kinetics & van Krevelen. Florea et al (2016) reported that the structure of the catalyst greatly affected the catalytic power. Catalysts containing only ferrite compounds have a lower catalytic power than catalysts containing a mixture of ferric oxide.

The higher the calcination temperature the greater the surface area, and the higher the oxidation power of the catalyst. FeCO₄0, FeCO 40 calcined at a temperature of 200 to 400 °C, has a surface area of 94m² / g with a particle size of 12-15 nm, can oxidize all CO gas to CO₂ gas, while FeCO₄0 is calcined at 400-800°C, has a surface area of 22m² / g with a particle size large, only able to oxidize CO gas to CO₂ gas by 69.2% (Jian et al, 2014). M-ferrite (M: Co, Ni, Cu, and Zn) produced by reacting their salts with sodium hydroxide, is used to break down CO₂: research results show that Ni ferrite was able to break down CO₂ by 76%, followed by Zn ferrite by 73% and Cu by 76% (Jiaowen et al 2016).

ZnFe₂O₄ / MnFe₂O₄ breaks CO₂ into C and O2 that occur during contact of CO₂ with catalyst surface, oxygen from CO₂ will fill the surface of oxygen deficient catalyst. At the same time ZnFe₂O₄ / MnFe₂O₄ donate electrons to produce C or CO (Chao et al, 2017)

From described above, it can be seen that ferrite catalysts have been developed and widely used to break down carbon compounds especially methane gas into CO₂ gas, hydrogen gas and nano tube carbon. In research nickel ferrite (NiFe₂O₄ / Al₂O₃) used as a catalyst to lower catalyst cost and increases its catalytic power in combustion pertamax as fuel in motor vehicles. The first combustion reaction in the fuel chamber is as follows equation (1):

\[ 10 \text{C}_3\text{H}_{16} (l) + 90 \text{O}_2 (g) + 1235 \text{O}_2 (g) + 3.7 \text{N}_2 (g) \rightarrow 790 \text{CO}_2 (g) + 890 \text{H}_2\text{O} (g) + 4569.5 \text{N}_2 (g) \]  

In the catalyst tube, the CO₂ gas and H₂O gas will be broken down according to the reaction with use equation (2) and (3).

\[ \text{CO}_2 (g) \rightarrow \text{C} (g) + \text{O}_2 (g) \]  
\[ 2 \text{H}_2\text{O} (g) \rightarrow 2 \text{H}_2 (g) + \text{O}_2 (g) \]
H₂ and O₂ will be flowed to the fuel chamber and C coating the catalyst tube is removed using carbon cleaner.

2. Methodology

2.1 Material and apparatus

2.1.1 Exhaust gas emissions measurements
The exhaust gas emitter used is Gas Analyzer Ultra 4/5 Gas Analyzer. Type IM 2400 with Specification:
- Measurement of O₂ content : 0-25% Vol
- Measurement of CO₂ content : 0—19.9% Vol
- Measurement of CO content : 0-9.99% Vol
- Measurement of HC content : 0-9999 ppm
- Measurement of NOₓ content : 0% Vol

2.1.2 Car Test
Test car used is toyota Avanza 2005 with specification machine as the following:
- Engine : 4 cylinder 16 valve DOHC
- Fuel system : EFI (Electric Fuel Injection)
- Diameter x step : 72,0 mm x 79,7 mm
- Volume cylinder : 1289 cc

2.1.3 Dyno test
The dyno test aims to measure the power (torque) and the resulting rotary force of the engine at a given speed. This tool consists of a Sensor to read the speed of the engine rotation. The roller connected to the wheel, the tire lock which serves to lock the tire during the test is performed, and the computer is connected to the sensor and the roller, so that the torque measurement results, and the power can be displayed on computer screen.

2.1.4 Catalyst tube (TK
plus
)
To make the catalyst tube (TK
plus
) required NiFe₂O₄-Al₂O₃ in the form of stick, the copper catalyst pipe with the length of 10 cm, the diameter of 0.8 mm as many as 11 pieces (Figure 1), tube U-shaped copper with a length of 12 cm, a diameter of 3 cm and a copper dop (Figure 2). The catalyst pipe is pressed, then inserted into a copper tube, cover both ends with a copper dop. The outside of the copper tube is wrapped with a capillary pipe and fitted with a handle made of stainless steel as shown in Figure 3. The catalyst tube with a TK
plus
brand is placed over the exhaust manifold (Figure 4).

Figure 1. Catalyst pipe

Figure 2. (a) Copper tube; (b) copper dop
Figure 3. Catalyst tube (TKplus)

Figure 4. The car engine is equipped with Catalyst tube

2.2 Experiment

2.2.1 Procedure

2.2.1.1 The synthesis of NiFe₂O₄
NiFe₂O₄, prepared by mixing 1,188 grams of Nickel (II) chloride and 2,071 grams of Iron (III) chloride dissolved in 20 mL aquadest and stirred to homogeneous. It is then added with 50 mL of 3 M NaOH solution and stirred for 60 min. at a temperature of 80 °C. The solution was then filtered and rinsed with aquadest until neutral pH and the resulting precipitate dried in an oven at 110 °C for 24 hours. The dried precipitate is then calcined at 600 °C for 3 hours, characterized and pressed to change NiFe₂O₄ powder into lidi form.

2.2.1.2 Exhaust emissions test
The first step for the exhaust emissions test is to enter the vehicle data into the computer system, clean the drain / exhaust, insert the probe on the exhaust pipe, accelerate to the desired spin as much as 3-10 times. The average value of exhaust emissions will be displayed or recorded on the monitor screen. Note or print the resulting emissions gas data

2.2.1.3 Test torque and power
Tests on torque and power are performed using the dyno test. The test is done as follows: make sure all computer systems are connected to the roller and sensor function. Raise the car on the dyno test, then to the four tires tied up, and one of the rear tires is connected to the roller. Turn on the car at a certain speed. Observe and note the torque and power values displayed on the monitor screen.

3. Result and discussion

3.1. Characterization Test of NiFe₂O₄
3.1.1 Characterization of NiFe$_2$O$_4$ using Fourier Transform Infrared Spectroscopy (FTIR)
Identification the functional groups of the NiFe$_2$O$_4$ sample were analyzed using FTIR. From the results obtained, there is an FTIR absorption spectrum that appears in the range of 500–4000 cm$^{-1}$ waves. In the wave number 3466.08 cm$^{-1}$ there is a peak of O-H stretching. While the wave number 1608.63 cm$^{-1}$ is the peak bending O-H. The characteristics of the metal ion groups with oxygen associated with the ferrite spinel structure can be observed in the 590.22 cm$^{-1}$ wave number which is the absorption of atoms located at the tetrahedral site (vibrations between Fe atoms with O) and at the wave numbers 416.62 cm$^{-1}$ is the absorption of atoms located at the octahedral site (vibrations between Ni and O atoms). The following is the FTIR spectrum of NiFe$_2$O$_4$ shown Figure 5.

3.1.2 Characterization of NiFe$_2$O$_4$ using X-Ray Diffractometer (XRD)
XRD is used to identify the crystalline structure of the NiFe$_2$O$_4$ sample. The wavelength used is 1.5406Å. Then, the results of XRD characterization processed using High Score applications. Based on the x-ray diffraction characterization that has been done, there are several main peaks that are in position 2θ 18.41°, 30.29°, 35.67°, 37.32°, 43.36°, 47.48°, 53.80°, 57.36°, 62.99°, 66.24° and 67.31° respectively with their respective orientation fields, respectively are (111), (220), (311), (222), (400), (331), (422), (511), (440), (531) and (442) respectively. The main diffraction peaks of NiFe$_2$O$_4$ are in position 2θ 18.41°, 30.29° and 35.67° and has cubic crystals with space group Fd-3m with lattice parameter a = b = c = 8.34Å and its crystallinity percentage of 5.70%. Figure 6 shows the peaks showing the hkl of the NiFe$_2$O$_4$ sample that identifies the formation of NiFe$_2$O$_4$ phase in the sample.
3.1.3 SEM–EDX
The morphology of NiFe$_2$O$_4$ has been characterized using SEM–EDX. The data obtained can be analyzed quantitatively and qualitatively, because the data obtained can be known type and number of mineral elements contained in the catalyst. The results of the SEM test are shown in Figure 7 and 8.

![Figure 7. SEM of NiFe$_2$O$_4$ 5000 x magnification](image)

![Figure 8. SEM of NiFe$_2$O$_4$ 10,000 x magnification](image)

The morphology of the NiFe$_2$O$_4$ sample is observed at magnification 5000X and magnification 10,000X. The surface morphology of the sample consists of crystallized granules with a homogeneous distribution. The elements contained in the NiFe$_2$O$_4$ catalyst can be seen in Figure 9 and Table 1. Based on Table 1, it is known that the NiFe$_2$O$_4$ catalyst contains Oxygen (O) of 28.79%, Iron (Fe) of 47.64% and Nickel (Ni) of 23.57%.

![Figure 9. The elements contained in the NiFe$_2$O$_4$ catalyst](image)

| Element | Mass % | Atom % |
|---------|--------|--------|
| O       | 28.79  | 58.92  |
| Fe      | 47.64  | 27.93  |
| Ni      | 23.57  | 13.15  |

3.1.4 Brunauer Emmet Teller (BET) test
To measure pore size, pore volume and pore distribution. From NiFe$_2$O$_4$ characterized by Brunauer Emmet Teller (BET) test The test results are shown in Table 2.
Table 2. BET of NiFe$_2$O$_4$

| Catalyst     | Surface area (m$^2$/g) | Pore size (nm) | Volume Pore (cm$^3$/g) | Particle size (nm) |
|--------------|------------------------|----------------|------------------------|--------------------|
| NiFe$_2$O$_4$| 50.077                 | 17.815         | 0.223                  | 119.815            |

Based on Figure 10, the adsorption and desorption patterns of NiFe$_2$O$_4$ are included into type IV which gives mesoporous adsorbent type information with maximum pore volume at $P / P_0$ of 0.992: 0.223 cm$^3$ / g.

![Graph of adsorption-desorption NiFe$_2$O$_4$.](image)

Figure 10. Graph of adsorption-desorption NiFe$_2$O$_4$.

3.2 Effect Test of TK$^{plus}$ Catalyst Tube on Exhaust Emission.

TK$^{plus}$ Catalyst Tubes filled with NiFe$_2$O$_4$- Al$_2$O$_3$ catalyst. Tested its catalytic power against the Pertamax fuel. Its catalytic power capability is shown by CO$_2$, CO$_2$ and HC exhaust emissions generated at various rounds without use and using TK$^{plus}$. Figure 11 to Figure 13 shows the exhaust gas emissions using Pertamax as fuel. CO emissions fall between 36% - 48%, CO$_2$ falls between 7% - 42% but 4500 plays increase emissions by 2% and HC falls between 44% - 53%.

From Figure 11 it can be seen that the faster the rotation, the more the emissions of CO are generated, both on vehicles equipped with kindergartens plus and those not installed TK$^{plus}$. Also it is seen that vehicles using TK$^{plus}$ emis CO gas are lower compared to vehicles not installed TK$^{plus}$. Unlike CO emissions, emissions & CO$_2$ gas generated by vehicles using TK$^{plus}$ as well as vehicles not using TK$^{plus}$ up to 4500 rpm rotation is almost the same, but large differences occur at 5000 rpm upward rotation, where CO$_2$ emissions generated by the vehicle using TK$^{plus}$ less than those with the TK$^{plus}$ as shown in Figure 12.
For HC emissions indicate that the rotation does not affect the emission of HC produced either on vehicles using TK$^{\text{plus}}$ or on vehicles not using TK$^{\text{plus}}$. Similarly, CO emissions and CO2 emissions of HC emissions produced by vehicles using TK$^{\text{plus}}$ are fewer than those with vehicles not using TK$^{\text{plus}}$. 

**Figure 11.** CO emissions from vapour pertamax without and with TK$^{\text{plus}}$ tube Catalyst

**Figure 12.** CO$_2$ emissions from vapour pertamax without and with TK$^{\text{plus}}$ tube Catalyst

**Figure 13.** HC emissions from vapour pertamax without and with TK$^{\text{plus}}$ catalyst
3.3 Test of Fuel Consumption
Figure 14 shows the mileage per liter of Pertamax fuel without catalyst and with the catalyst. Without \( \text{TK}^{\text{plus}} \) is 10 km per liter is not affected by the rotation, with \( \text{TK}^{\text{plus}} \) increased anatra 13-15 km per liter influenced by rotation. The results show there is fuel oil sparing between 23\% - 33\%.

![Figure 14. Pertamax consumption without and with \( \text{TK}^{\text{plus}} \) tube catalyst](image)

3.4 The influence of \( \text{TK}^{\text{plus}} \) on the power
Power is done at engine speed 4355 rpm up to 5942 rpm or with speed 38km / h up to 136 km / h. Power test results which is obtained is shown in Figure 15 and Table 3. Pertamax Consumption Based on the data in Table 3 it can be seen that there is a change in power at low, medium to high engine speed. The largest power change (HP) occurs at engine speed of 5781 rpm or at a speed of 120 km / h with a change of 5.8\%, whereas the smallest power changes occur at 4391rpm engine speed or at a speed of 50 km / h with a change of 0.4\%. The resulting data shows that \( \text{TK}^{\text{plus}} \) with NiFe2O4 catalysts are able to change the engine performance power is greater than the engine performance power that does not use \( \text{TK}^{\text{plus}} \) pipe.

![Figure 15. Pertamax consumption](image)

Table 3. Test power of engine

| Rotation of engine (rpm) | speed (km/h) | Power (HP) |
|--------------------------|--------------|------------|
|                          |              | without \( \text{TK}^{\text{plus}} \) | with \( \text{TK}^{\text{plus}} \) |
| 4355                     | 40           | 50.9       | 51.6       |
3.5 Effect of TK\textsuperscript{plus} against torque.

The NiFe\textsubscript{2}O\textsubscript{4} catalyst which has been installed in TK\textsuperscript{plus} gives effect to torque measurement. Measurements performed starting from the engine rotation 4220rpm to 6032rpm or speed at a range of 40 km / h up to 130 km / h. Here is the result of the effect of the TK\textsuperscript{plus} catalyst tube to the torque. Table 4 shows the difference in torque generated on vehicles using TK\textsuperscript{plus} and which do not use TK\textsuperscript{plus} at all machine rotation frames.

| Rotation of engine (rpm) | speed (km/h) | Torque (Nm) |
|--------------------------|--------------|-------------|
|                          | Without TK\textsuperscript{plus} | With TK\textsuperscript{plus} |
| 4355                     | 40           | 83.2        | 85.9        |
| 4391                     | 50           | 93.2        | 93.6        |
| 4508                     | 60           | 98.8        | 97.8        |
| 4618                     | 70           | 100.1       | 96.5        |
| 4899                     | 80           | 94.6        | 97.5        |
| 5121                     | 90           | 95.2        | 97.1        |
| 5315                     | 100          | 91.6        | 93.3        |
| 5582                     | 110          | 86.3        | 90.2        |
| 5781                     | 120          | 84.1        | 87          |
| 5942                     | 130          |             |             |

4. Conclusions

Modification of combustion chamber on motor vehicles using catalytic tube (TK\textsuperscript{plus}) able to break the fuel vapor pertamax. The result of motor vehicle exhaust emission test that CO, CO2 and HC gas emissions in both fuels can be reduced by using TK\textsuperscript{plus} at 3500 -5500 rpm. The test results on fuel consumption for mileage per liter showed that without TK\textsuperscript{plus} of 10 km per liter, with TK\textsuperscript{plus} increased between 13-15 km per litre. These results show there is fuel oil sparing between 23% - 33%. The dyno test results show that value increased torque by increasing the rotation of both vehicles using TK\textsuperscript{plus} and those not using TK\textsuperscript{plus}, and torque value on vehicles using TK\textsuperscript{plus} higher than with vehicle who does not use TK\textsuperscript{plus}.

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