Comparison of metallic (FeCrAl) and Ceramic Catalytic Converter (CATCO) in reducing exhaust gas emission of gasoline engine fuelled by RON 95 to develop health environment

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Abstract. Environmental and human health problems caused by high air pollutant which contributed by transportation sector become main issue in the world. There are some pollutant from gasoline engine such as Carbon Monoxide (CO), Nitrogen Oxide (NOx) and Hydro-Carbon (HC). Therefore, the objective is to investigate the effectiveness of catalytic converter (CATCO) as pollutant converter in reducing harmful exhaust gas and improving the conversion efficiency. The exhaust emission analysis is conducted by gasoline engine model Mitsubishi 4G93 in various engine load of 10%, 20% and 30% and various speed of 1000, 2000 and 3000 rpm fuelled by RON 95. The result shows that the ceramic material more effective to reduce the CO and HC as compared to metallic material with maximum conversion is 99.02% at speed of 1000 rpm in engine load of 20% and 97.66% at speed of 1000 rpm and 10% engine load. Meanwhile, Metallic CATCO shows the lower NOx emission as compared to ceramic with the lowest NOx is 128.27 ppm which shown by speed of 1000 rpm and 10% engine load. The lowest emission mostly at speed of 1000 rpm and at lower engine load. It caused by engine load and speed increased as CO, NOx and HC increased as well.

1. Introduction
Currently, there are many health problems which contributed by inappropriate air quality from several sources such as industry, transportation, building activity and etc. [1]. Mobile sources contribute for about 44% of outdoor toxic emissions, approximately 50% of cancer risk and at around 74% of non-cancer risk health problems [2]. According to the Department of Environment (DOE) Malaysia (2014) [3], in the southern region of the West Coast of Peninsular Malaysia (Negeri Sembilan, Melaka and Johor) that generally have air quality in between good and moderate level. However, there are some hazardous days in southern region of 12 days and unhealthy days of 94 days as well as very unhealthy days of 7 days. The improvement of air quality report on 2014 [3] as compared to air quality status on 2013 that the air quality is in good and moderate level but there are decreasing unhealthy days become 63 days. It may caused by high level of O₃ and PM₂.₅ which produced by trans-boundary pollution of several resources such as transportation, industrial and home sectors [3]. From that sources,
transportation sector has the largest pollutant contributor as compared to industrial and home sector. It approved by Kaspar et al., (2003) that at the normal engine operating condition, the exhaust gas composition are 0.5 % vol. CO, 350 ppm HC, 900 ppm NOx, 0.17 % vol. Hydrogen (H2), 10 % vol. water (H2O), 10 % vol. Carbon Dioxide (CO2) and 0.5 % vol. (Oxygen) O2.

First Catalytic converter prototype is developed by ceramic honeycomb substrate that developed based on cordierite (2MgO. 2Al2O3. 5SiO3 - 14% MgO. 35% Al2O3 and 51% SiO2) and it developed from natural and plastic material. These materials is selected because it has low thermal expansion, high shock resistance, softening points with higher attrition resistance, high melting and lower pressure losses as compared to pellet converter [5]. Meanwhile, metallic material status is built up from 1970s with the main component is Iron (Fe), Chromium (Cr), Aluminum (Al) and Yttrium (Y). FeCrAlY protected by Alumina (Al2O3) in order to achieve the withstand high temperature and corrosive condition in exhaust. That material is coupled by high thermal shock resistance, softening, high melting, high cell densities and low pressure losses [6]. Ceramic and metallic catalytic converters are shown in Figure 1.

![Figure 1](image1.png)

**Figure 1.** (a) Ceramic substrate converter; (b) Metallic substrate converter[6]

There are many studies which explore the metallic catalytic converter and investigate the exhaust emission control [3, 7-9]. The HC, CO and NOx is controlled by metallic catalytic converter through mass transfer limited in high space velocity that effect to the less conversion to the CO, NOx and HC pollutants (Santos and Costa, 2008). Exhaust emission control in diesel engine influenced by some factors such as chemical reaction, A/F ratio and temperature of diesel exhaust system in different types.

According to DOE, (2014) [3] that the emission is depend on the air to fuel (A/F) ratio. The correlation of the A/F ratio and the pollutant emission is shown in Figure 2.

![Figure 2](image2.png)

**Figure 2.** a) Effect A/F ratio on pollutant emission in rich and lean condition [3,10] and b)Three way catalyst: simultaneous conversion of CO, HC and NOx [11]
Highest power output is produced when the engine tuned to the rich condition. However, it will be
effect to the higher fuel consumption as compared to lean condition. Meanwhile, in lean condition
produce lower NOx emission caused by lower combustion temperature [10]. However, highest A/F led
to engine jammed and leading to highest HC emission. Therefore, catalytic converter which
appropriate amount at stoichiometric conditions is needed for reducing and oxidizing agent in the
exhaust system to conduct the catalytic reaction [3].

Under lean condition, the oxygen in exhaust system will oxidize the HC and CO and it also
can be stored within the catalyst's washcoat. Meanwhile, under rich condition the NOx will be reduced
significantly by assist of the catalyst. Under this condition the catalyst is referred to as a NOx catalyst
[12-13]. The comparison of exhaust emission which fuelled by RON 90 and 95 has been investigated
by several researchers [14-22]. The results shows that higher octane number produce less exhaust gas
emission as compared to lower octane number and it effect to the increment of engine performance
where octane number increased as engine performance increased as well. However, the comparison
between ceramic and metallic catalytic converter is not fully investigated. Therefore, it will be
conducted through the gasoline engine which fuelled by RON 95. The results will show the exhaust
emission pattern and will recommend to industry and customer in usage catalytic converter either
ceramic or metallic catalytic converter.

2. Method

Conventional ceramic and metallic catalytic converter is used as tools for investigating exhaust gas
emission system in gasoline engine. The metallic and ceramic is scathed by ANSYS R16.2where the
length of 100 and 200 mm, respectively as shown in Figure 3.

(a)  
(b)

Figure 3. 3D drawing of (a) metallic catalytic converter and (b) ceramic catalytic converter

2.1 Exhaust emission analysis

Exhaust emission analysis in emulsion fuel and petroleum oil was investigated by using engine model
mitsubishi4G93. The specification of mitsubishi4G93 with 1.8 L and 10.5 compression ratio is
listed in Table 1 and shown in Figure 4. They found that the exhaust gas temperature of emulsion fuel
is lower than petroleum oil because it have low carbon content in the exhaust gas. That phenomena is
observe when using the conventional catalytic converter.

Table 1. Engine specification

| Description       | Specification                  |
|-------------------|--------------------------------|
| Engine model      | MITSHUBISHI 4G93               |
| Engine type       | Petrol 4 stroke , single engine|
| Bore x Stroke (mm)| 81 x 89                        |
| Displacement (L)  | 1.8                            |
| Compression ratio | 10.5                           |
| Maximum output (kW)| 81kW (110PS; 109bhp)          |
| Maximum torque (N.m)| 154N.m (114 ft.lbf)           |
The conventional catalytic converter is also generated as comparison of the result. The four-stroke cycle engine was used and it operated at 1000, 2000 and 3000 rpm with various engine loads of 10, 20 and 30% which adjusted using hydraulic dynamometer. The comparison between conventional metallic and ceramic catalytic converter is performed in order to investigate the appropriate material for reducing exhaust emission of gasoline engine.

Figure 4. Mitsubishi 4G93

3. Result and discussion

3.1 Exhaust emission analysis

Exhaust emission analysis was conducted the effect of conventional ceramic and metallic catalytic converter in reducing exhaust emission gases such as CO, NOx and HC. The exhaust emission of conventional ceramic catalytic converter (catco) with various speed of 1000, 2000 and 3000 rpm and various engine load of 10%, 20% and 30%.

3.1.1 CO emission analysis.

CO emission inlet and outlet conventional ceramic catco is shown in Figure 5. It shows that CO emission inlet ceramic catco is higher than outlet ceramic catco. It means that conventional ceramic catco is effective to reduce CO emission of gasoline engine fuelled by RON 95. CO emission inlet and outlet conventional ceramic catco is increased as engine load increased as well in constant speed. Figure 5 shows the highest CO emission inlet and outlet are shown by speed of 3000 rpm and engine load of 30% for 7.67% and 3.14%, respectively. Meanwhile, the lowest CO emission inlet and outlet catco at speed of 1000 rpm and engine load of 10% for 0.6% and 0.02%. Its means that the catalytic converter is fulfill the requirement of maximum CO emission that in the range of 0.1-6 ppm [3,23]. The decrement of CO emission of inlet and outlet conventional ceramic catco is shows by constant speed of 1000 rpm with various engine load of 10%, 20% and 30% for 96.67%, 99.02% and 87.5%, respectively. For speed of 2000 rpm, CO emission decrement is 97.13%, 90.98% and 83.95% which shown by engine load of 10%, 20% and 30%, respectively. Moreover, in speed of 3000 rpm and engine speed of 10%, 20% and 30% shows the CO emission decrement for 89.31%, 91.74% and
59.06%, respectively. From that data can be seen that the most effective for conventional ceramic catalytic converter for reducing CO emission when operated in 10% and 20% engine load. It may be caused by over CO emission in engine load of 30% cause the conventional ceramic catco could not be able to reduce CO emission number in short time retention. It approved by Macklini (2015) [24] that higher speed cause less homogenous mixture which led to higher CO emission and less conversion efficiency.

![Figure 5. CO emission of conventional ceramic catco fuelled by RON 95](image)

CO emission for conventional ceramic and metallic catco in various speed and engine load is listed in Table 2. It shows that the CO emission of conventional ceramic catco is more effective in reducing CO emission as compared to conventional metallic catco due to mass transfer limited in high space velocity was occurred in conventional metallic catco[9].

| Speed | CO emission (%) |
|-------|-----------------|
|       | 1000 (rpm)inlet | 2000 (rpm)inlet | 3000 (rpm)inlet | 1000 (rpm)outlet | 2000 (rpm)outlet | 3000 (rpm)outlet |
| Load  |                  |                  |                  |                  |                  |                  |
| 10%   | 0.6             | 2.79             | 3.46             | 0.02             | 0.08             | 0.37             |
| 20%   | 2.05            | 3.88             | 6.05             | 0.02             | 0.35             | 0.5              |
| 30%   | 4.88            | 5.11             | 7.67             | 0.61             | 0.82             | 3.14             |
| 10%   | 0.64            | 1.46             | 5.12             | 0.02             | 0.69             | 3.97             |
| 20%   | 4.57            | 5.07             | 5.84             | 3.53             | 4.6              | 4.72             |
| 30%   | 5.01            | 6.05             | 9.62             | 4.61             | 4.61             | 4.76             |

At engine load increase and increment of 1000 rpm and 2000 rpm caused by over CO emission in engine load of 30% cause the conventional ceramic catco could not be able to reduce CO emission number in short time retention. It approved by Macklini (2015) [24] that higher speed cause less homogenous mixture which led to higher CO emission and less conversion efficiency. In addition, CO emission of inlet is higher than outlet due to it flow through conventional metallic catco. The highest and the lowest CO emission inlet and outlet is at 3000 rpm (30%) and 1000 rpm (10%) for 9.62% and 476%, 0.64% and 0.02%, respectively. For the decrement of CO emission in speed of 1000 rpm and engine load of 10%, 20% and 30% are 96.88%, 22.76% and 7.98%, respectively. Moreover, for speed of 2000 rpm are 52.74%, 9.27% and 23.8% shown by engine speed of 10%, 20% and 30% respectively. Different pattern of CO emission decrement is shows by speed of 3000 rpm and engine speed of 10%, 20% and 30% are 22.46%, 19.18% and 50.52%. At speed of 1000 rpm and 2000 rpm effect to increment of engine load increase and decrement of metallic catco efficiency. Meanwhile, in speed of 3000 rpm effect to increment of engine load and increment of metallic catco efficiency as well. It may caused by fluctuate engine condition that may cause unstable catco efficiency in reducing the pollutant. However, Figure 6 shows a normal pattern that higher speed and engine load will be produced higher CO emission as well.
Conversion efficiency of conventional ceramic catco is higher than metallic material in reducing CO emission. It may caused by not balance reaction in metallic catco due to not enough oxygen content (under rich condition) which led to incomplete reaction inside the metallic catco. In addition, ceramic catco adsorb the oxygen in lean condition that led to enhancement in converting 3 pollutants while engine condition is buffered around stoichiometric points [25].

3.1.2 NOx emission analysis.
NOx emission inlet and outlet conventional ceramic catco fuelled by RON 95 is shown in Figure 7. NOx emission inlet is higher than outlet ceramic catco. The reducing of NOx emission is shown in each variation of speed and engine load. In constant speed of 1000 rpm, Decreasing NOx is shown by outlet ceramic catco with percentage of 99.83%, 99.3% and 95.58% in engine load of 10%, 20% and 30% respectively. That pattern also shown in speed of 2000 rpm and 3000 rpm where the engine load increased as NOx emission increased as well in constant speed. In line with that, when speed increased as NOx emission increased as well. However, the NOx requirement meet a standard in untreated exhaust system that standard NOx levels between 100-3000 ppm. Therefore, NOx value of 100-3000 ppm is needed to ensure that the engine issues the emission in standard level which not disturbing the air environment quality and human health [23]. Furthermore, NOx removal is easier in lean condition as compared to rich condition and the highest NOx content under stoichiometric condition at temperature of ≤800 to 850 °C as well as when temperature engine is reached 1000 °C, it will be decrease catco durability [10].

Comparison of NOx emission inlet and outlet conventional ceramic and metallic catco is listed in Table 3. It shows that the metallic catco has lower number of NOx emission as compared to ceramic catco. The highest number of NOx emission inlet and outlet ceramic and metallic catco is shown by speed of 3000 rpm and engine load of 30% for 2384 ppm, 230.77 ppm and 505.33 ppm, 413.4 ppm,
respectively. Meanwhile, the lowest NOx emission inlet and outlet conventional ceramic and metallic catco is shown by speed of 1000 rpm and engine load of 10% for 1219.4%, 2.07% and 128.27%, respectively. According to Santos and Costa (2008) [9], metallic catco controlling the NOx pollutant through mass transfer limited in high space velocity. Therefore, the number of NOx pollutant in metallic catco is lower than ceramic catco.

### Table 3. NOx emission of conventional ceramic and metallic catco

| Speed  | 1000 (rpm/inlet) | 2000 (rpm/inlet) | 3000 (rpm/inlet) | 1000 (rpm/outlet) | 2000 (rpm/outlet) | 3000 (rpm/outlet) |
|--------|------------------|------------------|------------------|------------------|------------------|------------------|
| Load   |                  |                  |                  |                  |                  |                  |
| 10%    | 1219.4           | 1712.47          | 1869.33          | 2.07             | 132.07           | 137.4            |
| 20%    | 1897.4           | 2044.6           | 2049.87          | 13.2             | 171.07           | 155.27           |
| 30%    | 2341.8           | 2329.07          | 2384             | 103.53           | 225.13           | 230.77           |

Metallic catco RON95

| Load   | 10%    | 20%    | 30%    |
|--------|--------|--------|--------|
| ceramic catco | 128.27 | 128.27 | 128.27 |
| RON95   | 168.8  | 299.93 | 427.67 |

| Engine load | NOx emission (ppm) |
|-------------|---------------------|
| 10%         | 1219.4              |
| 20%         | 1897.4              |
| 30%         | 2341.8              |

The effect of engine and speed on NOx emission inlet and outlet conventional metallic catco is shown in Figure 8. The overall NOx emission is meet the requirement that 100-300 ppm for untreated catco in exhaust emission system. Lower engine load with constant speed will produce lower NOx emission as well. In line with that, speed increased as NOx emission increased as well in constant engine load. Therefore, the lowest NOx emission at engine load 10% and speed of 1000 rpm as well as the highest NOx emission at engine load of 3000 rpm and speed of 30%. NOx emission inlet is higher than outlet metallic catco where the highest value reached of 604.67 ppm and the lowest NOx emission reached of 39.47 ppm.

![Figure 8. NOx emission of metallic catco fuelled by RON 95](image)

### 3.1.3 HC emission analysis

HC emission inlet and outlet conventional ceramic and metallic catco are shown in Figure 9 and Figure 10. Standard of HC emission level between 500-1000 ppm. For ceramic catco shows that the HC emission in the range of 114 to 316.77 ppm for HC inlet ceramic catco and outlet ceramic catco of 2.67 to 290.67 ppm. It means that HC emission of inlet ceramic catco is lower than outlet ceramic catco. It may caused by chemical reaction between HC and O₂ inside ceramic catco which led to transformation into CO₂ and H₂O forms [26]. The lowest HC emission at speed of 1000 rpm and engine load of 10% for 114 ppm and 2.67 ppm. Meanwhile, the highest HC emission at speed of 3000 rpm and engine load of 30% for 316.77 ppm and 290.67 ppm. From the Figure 9 that engine load increased in constant speed as HC emission increased as well. In addition, speed increased as HC emission increased as well. However, in speed of 1000 rpm and engine load of 30% has higher
HC emission as compared to speed of 2000 rpm and engine load 30% for 13.53%. It may caused by complete burned of HC emission on 2000 rpm (30%).

![Figure 9. HC emission of ceramic catco fuelled by RON 95](image)

Table 4 shows the effect of engine load and speed on HC emission inlet and outlet conventional ceramic catco. Ceramic catco shows the lower HC emission as compared to metallic catco in both of inlet and outlet catco. The highest percentage of ceramic catco in converting HC is at speed of 1000 rpm and engine load of 10% for 97.66%.

| Speed  | Ceramic catco RON95 | Metallic catco RON95 |
|--------|---------------------|----------------------|
| Load   | HC emission (ppm)  |
|        | 1000 (rpm)/inlet   | 2000 (rpm)/inlet     | 3000 (rpm)/inlet | 1000 (rpm)/outlet | 2000 (rpm)/outlet | 3000 (rpm)/outlet |
| 10%    | 114                  | 223.07               | 273.73           | 2.67              | 155.00             | 234.67             |
| 20%    | 143.73               | 224.07               | 310.93           | 4.6               | 196.6              | 278.4              |
| 30%    | 277.33               | 239.8                | 316.77           | 237.53            | 212                | 290.67             |
| 10%    | 77.87                | 156.4                | 283.73           | 15.4              | 103.8              | 230.13             |
| 20%    | 327.67               | 316.33               | 364.73           | 271.07            | 282.6              | 305.73             |
| 30%    | 391.87               | 466.53               | 698.67           | 315.47            | 320.2              | 350.67             |

In line pattern of metallic catco with ceramic catco in HC emission inlet and outlet that engine load and speed increased as HC emission increased as well. However, it shows higher HC emission up to 381.9 ppm which at inlet ceramic and metallic catco with engine load of 30% and speed of 3000 rpm. The highest and the lowest HC emission is shown by 3000 rpm (30%) and 1000 rpm (10%), respectively with the value of 698.67 ppm, 350.67 ppm and 15.4 ppm, 77.87 ppm. Lower and higher speed and engine load will be effect to the higher and lower axial energy of crankshaft which released higher and lower energy of the engine and automatically will effect to the fuel consumption and torque [3]. Lower HC emission may be caused by oxidation process for CO and HC inside catco which can obtain CO₂ and H₂O forms [1].
4. Conclusion
Comparison of existing metallic and ceramic catalytic converter in terms of exhaust gas emission were successfully conducted by gasoline engine fuelled by RON 95. Exhaust gas emission of CO shows that the ceramic catco has more conversion efficient as compared to metallic catco with the highest conversion efficiency is 96.88% which at engine load of 10% and speed of 1000 rpm. In addition, for NOx emission shows that metallic catco has higher NOx conversion efficient as compared to ceramic catco. The lowest NOx emission of metallic catco is shown by speed 1000 rpm and engine load 10% for 2.07%. Moreover, for HC emission shows the ceramic catco has more efficient as compared to metallic catco where the highest number of conversion efficiency of ceramic catco is at speed of 1000 rpm and engine load of 10% for 97.66%.

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