Numeric Simulation of the Effect of Varying Velocities on Catalytic Converter and Exhaust Gas Emission

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Abstract. Fossil fuel-powered vehicles are the most significant contributor to air pollution nowadays. They emit substances that are harmful to both human and environment. Carbon monoxide (CO) and Hydrocarbon (HC) is the most common harmful exhaust gases found in the environment. One of the technologies used for reducing CO emissions is catalytic converters. The catalytic converters usually installed in the exhaust system. The numeric study was conducted on the interaction of flow, reaction, and thermal effects in the form of a 2D model of the catalytic converter. Simulation using Fluent software was then used to find out the extent of the catalyst effects on CO gas absorption when velocities were 6.3 m/s, 15 m/s, and 20 m/s. The simulation revealed that CO mass fraction and temperature around the exhaust channel increased as the velocity increased.

1. Introduction
Carbon monoxide (CO) and Hydrocarbon (HC) are pollutants mostly produced by vehicles. The accumulation of CO in the air may cause health problems and even deaths. On the other hand, HC polluted air may trigger cancer cells form in the human body. When pollutant concentration in the air is getting higher, deaths caused by respiratory tract problems or cardiovascular problems increas[1]. Catalytic converters can be a solution to this. When installed in the vehicles exhaust systems, catalytic converters are known to reduce CO and HC emitted by vehicles[2-5].

Uneven flow during cold start of the catalytic converters has a significant effect causing differences in ignition characteristic among channels, particularly in the exhaust channel with lower temperature [6]. G. Bella et al. [7] and M. Badami et al. [8] conducted studies on the effect of uneven flow distributed from oxidation inlet to catalytic converters. By varying catalysts used in catalytic converters such as quartz glass, alumina ceramic, and copper, Junhu Zhou et al. improved micro-combustor that had low stability [9]. The result was that combustion chamber stability increased when those three materials were used as a catalyst. Moreover, the chamber was able to function in extreme equivalence ratio. The other finding was that the use of copper as a catalyst caused lower temperature distribution in the combustion chamber when compared with the other materials [9].

In previous studies, analysis on the effect of the speed of fluid passing through catalytic converters is still rare, so the objective of this study was to find out the result of fluid velocity in catalytic...
converters on gas emission when copper was used as a catalyst. The researcher expected that this study might help in the overcoming of pollution problems.

2. Research Method
In this research, catalytic converters in the vehicle were placed after the exhaust manifold system as an exhaust gas controller (to convert CO and HC into CO₂ and water vapour). The flow inside the catalytic converter was simulated using the Fluent software. The flow inside the catalytic converter was varied in 3 different velocities: 6.3 m/s, 15 m/s, and 20 m/s. The fluid used in this research was carbon monoxide (CO). The other conditions were 300°C inlet temperature condition, 1 atm (atmospheric pressure), 1.1233 kg/m³ density, and 1.75x10⁻⁵ Kg/m.s viscosity.

The catalytic converter geometry in this research is shown in figure 1. Meanwhile, figure 2 shows that the number of cells used was 33,102, the number of faces was 67,095, and the number of nodes was 33,982.

![Figure 1. Catalytic Converter Geometry.](image1)

![Figure 2. Meshing for Catalytic Converter.](image2)

3. Result And Discussion

3.1 Validation
This research result was validated by comparing to the effect of research by Gaurav et al. [10]. The validation was performed for the effect of the 6.3m/s velocity simulation. Table 1 shows that the result of this research was almost similar to that found by Gaurav et al [10]. This research found that the magnitude of velocity in the exhaust area was 1.26x10¹, while in the study conducted by Gaurev et al. was 1.30x10¹. The difference that was only 3.17% (less the 10%) means that the simulation validity was good.
Table 1. Validation.

| Velocity | Present study | Gaurav et. al. | Distance |
|----------|---------------|----------------|----------|
| 6.3 m/s  | $1.26 \times 10^1$ | $1.30 \times 10^1$ | 3.17%    |

3.2 Velocity Contour
The results of the simulation at three different velocities showed that there was a pattern in the magnitude of the velocity. The pattern showed that high recirculation occurred in inlet diffuser, characterised by a flow rotating at the upper part and lower part induced by the existence of sudden area expansion in all 3 inlet velocities as shown in Figure 3. The flow became non-uniform because of this condition.

Transversal velocity component was lower than the axial velocity component at the centre part. This means that the fluid shifted to the upper part and the lower part. Also, the pressure dropped along the channel because of friction. Friction increased drastically because of the inlet velocity within every channel. When the flow speed is high, the friction resistance becomes high as well.

![Figure 3](image)

**Figure 3.** Different contours of the magnitude of the velocity.

3.3 CO Mass Fraction Contour
The analysis result of carbon monoxide fluid showed that mass fraction distributed within the catalytic converter had a high concentration in the centre of the channel. The mass fraction distribution is represented by red colour in Figure 4. Mass fraction decreased while flowing to the outlet channel.

As the velocity was increasing, the area of mass fraction decrease was getting wider and more directed toward the direction of the outlet. This was caused by temperature in the peripheral channel that became lower than that in the centre channel because of the heat loss to the environment.

The flaw of 2D geometric planar was that it could not capture transversal heat shift through the monolithic solid structure. Mass fraction decreased as CO moved to peripheral channel and was multiplied in the last peripheral channel. The initial decrease of CO mass fraction increased as CO flowed further from temperature loss-zone to environment responsible for lower conversion in the previous two channels in the monolithic catalyst. Qualitatively, the same result was observed for other operational conditions and full-scale geometry. This result was obtained for rather simple kinetics for CO oxidation (under low activation energy). For more complex kinetics and higher energy activation, conversion decrease within the peripheral channel is expected to be higher.
3.4 Temperature Contour

Simulation result of temperature contour showed that the temperature around the channel was lower than that in the centre of the channel. As shown in figure 5, this result occurred in all three velocities. As velocity increased, temperature around the channel more significantly decreased. This could be observed from the heat distribution area in various inlet area (red colour) that got narrower when velocity was 20 m/s.

4. Conclusions

The data analysis of the simulation result showed the phenomenon and the flow characteristic of the fluid that flowed through the catalytic converter. The data also the effects of varying velocities. Overall, the conclusions drawn from the study are as the following: Highest CO mass fraction was in the centre of the channel (inlet) for 6.3 m/s velocity. As the velocity increases, the flow in the area where mass fraction decreased was getting wider and going toward the bay. As speed reached 20 m/s, the temperature decrease around the channel became greater. Finally, it is expected that the result of
this research will contribute to any efforts directed toward overcoming pollution, by the use and the
approach of engineering technology.

5. References
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