

Reduction of Carbon Monoxide Emission during Idling in 4-stroke Spark-ignition Engine Vehicle Using Scrubber

Narendran G. Musthaq Ahamed P.A¹ and Manokaran K²

*¹B.E. Automobile Engineering B.E. Automobile Engineering
168, Sai Krupa, MTH Road, Chennai - 600049 9/5,
Mandapam St., Dharmapuri – 636702.*

*²B.E. Automobile Engineering, 61, MRP Avenue, Harikrishna Nagar,
Kovilpathagai, Chennai – 600062.*

Abstract

Automobiles have always been a major source of air pollution. The vehicular emission contains several harmful pollutants that affect the surroundings and living beings. This research work concerns the emissive control of carbon monoxide (CO). Mild CO exposure leads to headaches or unconsciousness. Acute poisoning will lead to toxicity of nervous system or heart, resulting in death. CO is mainly generated in the IC engine due to incomplete combustion of the fuel. There are post-combustion emission control devices such as catalytic converters. But the catalytic converter has a drawback - it does not operate efficiently when the engine runs on rich air/fuel mixture. Hence, during idling, CO is not effectively reduced. This results in undesirable consequences, such that when the vehicle is idling at traffic signals or toll booths or garages, a high concentration of CO accumulates around the vehicle. This poses a great danger to those surrounding the vehicle, especially motorists and pedestrians. This research work aims to minimize this hazard. The main intention of this research work is to prevent the aggregation of CO around stationary vehicles. CO mainly affects the people in the vicinity of stationary vehicles, including pedestrians, traffic police, motorists, etc. Hence, it is necessary to avoid the accumulation of CO around static vehicles in traffic signals, traffic jams etc. This will drastically reduce the effects of CO on human health by creating a cleaner commute. To achieve this, we propose to reduce the emission of CO during idling conditions by employing a new post-combustion emission control device called the

scrubber. The scrubber will be used to capture the gaseous CO during idling alone, and later be able to release it under transient conditions. This will prevent the CO from accumulating outside the exhaust during idling.

1. Introduction

Motor vehicles - cars, trucks, and buses are a major source of air pollution. Until the middle of the 20th century, the number of IC engines in the world was small enough that the pollution they emitted was tolerable, and the environment, with the help of sunlight, stayed relatively clean. As world population grew, power plants, factories, and an ever-increasing number of automobiles began to pollute the air to the extent that it was no longer acceptable. The major emissions were carbon dioxide (CO₂), carbon monoxide (CO), hydrocarbons (HC), oxides of nitrogen (NO_x), oxides of sulphur (SO_x) and particulate matter. NO_x includes NO and NO₂. Out of these, HC, CO and NO_x were considered as the most harmful pollutants. Although air pollution is a global problem, some regions of the world still have no emission standards or laws.

Bharat stage emission standards are emission standards instituted by the *Government of India* to regulate the output of air pollutants from internal combustion engine equipment, including motor vehicles. The standards and the timeline for implementation are set by the Central Pollution Control Board under the Ministry of Environment & Forests. The standards, based on European regulations were first introduced in 2000. Progressively stringent norms have been rolled out since then. All new vehicles manufactured after the implementation of the norms have to be compliant with the regulations. Since October 2010, Bharat stage III norms have been enforced across the country. In 13 major cities, Bharat stage IV emission norms have been in place since April 2010.

2. Carbon Monoxide Emissions

CO is a highly toxic, colorless, odorless gas that is dangerous to those who inhale it. When inhaled, it causes severe complications to humans and animals likely. Mild CO exposure leads to headaches or unconsciousness. Acute poisoning will lead to toxicity of nervous system or heart, resulting in death. This is because CO has a high affinity to blood, and when inhaled, it combines with the haemoglobin in blood to produce carboxy haemoglobin, which is an extremely toxic substance. In severe cases, it causes death in around 10-15 minutes of heavy exposure.

There have been numerous improvements and modifications in engine technology in order to lower the emissions substantially. Several pre- and post-combustion emission reduction techniques have been implemented gradually over a long period of time. The following steps give insight of the CO emission control strategies employed in IC engines:

- Catalytic converter
- Charging the engine
- Addition of valves
- Addition of spark plugs
- Fuel injection in SI engines

The most effective after-treatment system for reducing engine emissions is the catalytic converter found on most automobiles and other modern engines of medium or large size. HC and CO can be oxidized to H₂O and CO₂ in exhaust systems and thermal converters if the temperature is held at 600°-700°C. If certain catalysts are present, the temperature needed to sustain these oxidation processes is reduced to 250°-300°C, making for a much more attractive system. A catalyst is a substance that accelerates a chemical reaction by lowering the energy needed for it to proceed. The catalyst is not consumed in the reaction and so functions indefinitely unless degraded by heat, age, contaminants, or other factors. Catalytic converters are chambers mounted in the flow system through which the exhaust gases flow. These chambers contain catalytic material, which promotes the oxidation of the emissions contained in the exhaust flow.

CO is mainly generated in the IC engine due to incomplete combustion of the fuel. This may be due to several reasons, such as rich air/fuel mixture and hurried combustion. It is predominantly formed when the vehicle is idling or operating at high speed, during both of which the engine runs on rich air/fuel mixture. There are post-combustion emission control devices such as catalytic converters that actively serve the purpose of converting CO, HC and NO_x into less degrading gases. But the catalytic converter has a drawback – it does not operate efficiently when the engine runs on rich air/fuel mixture. Hence, during idling, CO is not effectively reduced. This results in undesirable consequences, such that when the vehicle is idling at traffic signals or toll booths or garages, a high concentration of CO accumulates around the vehicle. This poses a great danger to those surrounding the vehicle, especially motorists and pedestrians. This research work aims to minimize this hazard from SI engined vehicles.

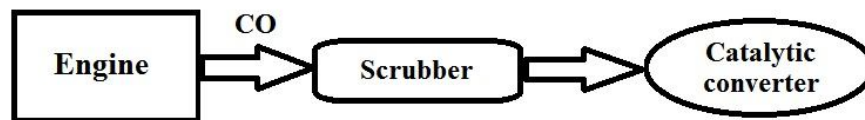
3. Materials and Methods

The main intention of this research work is to prevent the aggregation of CO around stationary vehicles. This enables a safer surrounding in the midst of congested traffic. CO mainly affects the people in the vicinity of stationary vehicles, including pedestrians, traffic police, motorists, etc. Hence, it is necessary to avoid the accumulation of CO around static vehicles in traffic signals, traffic jams, toll-gates, garages, drive-in theatres etc. This will drastically reduce the effects of CO on human health by creating a cleaner commute. Therefore, we propose to reduce the emission of CO during idling conditions by employing a new post-combustion emission control device called the scrubber.

The research work aims to implement a CO absorption mechanism inside the exhaust pipe of vehicle. This absorption device is the CO scrubber (technical term for absorber). The scrubber will be used to capture the gaseous CO during idling alone, and later be able to release it under transient conditions. This will prevent the CO from accumulating outside the exhaust during idling. Later, when the vehicle is running at a higher speed, the CO will be released toward the catalytic converter, which will now efficiently convert this to CO₂. Thus, the hazard of over-exposure is significantly reduced. Moreover, the CO emissions will come down as the converting efficiency of the catalytic converter is higher at greater speeds than at idling.

4. Experimental Setup

The scrubber is a device that absorbs a specific gas or particle when flue gas is passed through it. In this research work, a CO scrubber is being used. This means that when the exhaust gas passes through the scrubber, only the CO gas gets captured by the absorbing material inside the scrubber. There are basically two types of scrubbers – dry and wet scrubbers. Dry scrubbers have a solid absorbent (absorbing compound), while wet scrubbers have fluid absorbents. Scrubbers are popularly used in industries for segregating various materials. CO₂ scrubbers are widely used for separating CO₂ from flue gases. But scrubbers seldom find application in automobiles. By using a CO scrubber in the exhaust system, we aim to solve the problem of inefficient conversion of CO by the catalytic converter. The mechanism is designed such that the exhaust gases are diverted to the scrubber only during idling. Hence, the CO gases are absorbed by the scrubber, while the remaining exhaust makes its way to the catalytic converter. After the idling is over and the vehicle starts to operate at a moderate speed, the exhaust is diverted back directly to the catalytic converter. Meanwhile, the CO from the scrubber is regenerated and passed through the catalytic converter as well. Thus the CO is effectively reduced and also the active build up during idling is prevented.



The scrubber has to contain a sufficient amount of absorbing compound in order to effectively capture CO for a definite time. Based on extensive study and research, we came across several absorbents that have a high affinity to CO. These are inorganic chemicals that can capture several times its own volume of CO. The main necessity of these absorbents is the ability to withstand high temperature characteristic of the exhaust gases, and also have a high absorption capability. The following compounds were found to have excellent absorption rates:

4.1 Metal Carbonyl

The metal atom has the ability to absorb of 5 atoms of the carbon monoxide and forms a metal carbonyl. The metals which are good at absorbing CO are nickel, iron, cobalt etc.

4.2 Cuprous Ammonium Salt

Cuprous ammonium chloride ($\text{Cu}(\text{NH}_4)_2\text{Cl}_4$) has a greater affinity towards carbon monoxide. A single gram of the salt has the ability to absorb 19 grams of carbon monoxide. This absorbent is used in water-gas treatment and for industrial purposes. The cuprous ammonium salt may be acetate, formate, carbonate, nitrate, or ethanalamine nitrate.

After considering all these parameters, the best CO absorbent was found to be pure cobalt metal. Normally metals have π -ligand bond, so another 2 electrons are needed. Mostly transition metals are ready to combine with CO to form a metal carbonyl under specific conditions. The compound formed by cobalt with CO is called Dicobalt octocarbonyl. The conditions such as required pressure and temperature keenly affect the absorption of CO. Cobalt has a melting point of about 1481°C . Moreover, it forms carbonyl only at a pressure of 20-60000 KPa, and the temperature at which it occurs is around $200\text{-}400^\circ\text{C}$. Hence, cobalt can sufficiently react with CO in the exhaust, which may range from $200\text{-}500^\circ\text{C}$ on the test vehicle. Lastly, the carbonyl compound is said to be pyrophoric, which means it instantly disintegrates under room conditions. The setup will be devised by taking this factor into account.



After due consideration, the cobalt metal was purchased in the form of fine powder. This enables better utilization of metal for flexible purposes.

5. Scrubber

The scrubber had to be designed such that the absorption occurs with maximum efficiency. Considering the peril of squandering the already expensive cobalt metal, the powder should be strongly embedded inside the scrubber with minimum risk of liberation. Also, the surface area of exposure of CO to the metal powder must be high enough such that the maximum CO is scrubbed. The design focuses on increasing surface area of contact to enable effective CO absorption. The scrubber is a hollow chamber with several 'baffles' that obstruct the path of exhaust flow. These baffles are coated with cobalt powder strongly. When the exhaust flows through the scrubber, it is forced to undulate by the baffles. This makes sure that the CO impinges on the cobalt surfaces and thus causing the reaction resulting in formation of dicobalt octocarbonyl. The cobalt will then regenerate under ideal conditions. Meanwhile, the free flowing

nature of exhaust will prevent rise in back pressure. The cobalt has to be coated firmly on the baffle boards.

Considering the efficiency and disbursement of these processes, simple adhesion and moulding were chosen viable choices for the coating process. Adhesion can be done by means of temperature resistant mucilage (adhesive). Moulding is another option where the cobalt is applied over the baffles in molten state and later condensed.

5.1 Test Vehicle

The test vehicle was chosen with respect to ease of implementation and practicality. The vehicle used was a 2003 TVS Scooty Pep model which has a 4-stroke single cylinder engine with a displacement of 74.6cc and an idling speed of 1400 ± 100 rpm.

6. Result and Discussions

Initially, the CO emission of the test vehicle had to be ascertained. According to norms, a normal 2-wheeler of 75cc-100cc can emit about 2.3-3.56 g/km of CO. The test vehicle is equipped with a 75cc four-stroke SI engine. The actual CO emission without using the scrubber was determined as 1.37% by volume of the engine exhaust. This reading was recorded under the idle bar test. It signifies the emission standard conformity of the vehicle. The testing was done using a Netel multi-gas analyzer. This analyzer can measure the CO₂, CO, HC and NO_x emissions. The CO reading was recorded with an accuracy of 0.01%.

6.1 Netel Gas Analyzer:

Multi-gas Analyzer – Model: NPM – MGA-2

The scrubber was fitted to the vehicle using a flange and secured. The vehicle was operated under different conditions to test the scrubber's effect on the performance. After finalizing, the vehicle was again tested at the same emission testing centre for measuring CO emission with the scrubber intact. It was found that during idling, the CO levels were drastically reduced. Now the reading recorded was 0.83% of the engine exhaust. This is considerably lower than the previous reading of 1.37% taken without the scrubber. This assures the ideal operation of the scrubber.

The tests clearly indicate the reduction in CO emissions after the usage of scrubber in the vehicle. This authenticates the viability of the scrubber and the absorption capability of cobalt. Hence, the scrubber's functionality is confirmed. It was noted that there was no abnormal emission characteristics while the scrubber was under operation during idling. Moreover, no physical variations were seen.

6.2 Results

Table 1: CO readings (in %) with and without scrubber.

CO (% by vol.)	Without scrubber	With scrubber
Hot idling	1.37	0.83
Cold idling	1.46	1.17

7. Conclusion

The scrubber clearly overcomes the drawbacks of the existing control techniques. The fact that it aids in reducing exposure to CO during idling is highly benefitting. The scrubber is a cheap, effective way to lower idling CO emissions. It can be employed in any kind of vehicle irrespective of its engine. To improve the effectiveness of the scrubber, we are researching on newer potentials and options regarding the absorbent and scrubber principle. Further, we desire to improve the absorption of CO by utilizing alternatives for cobalt. To successfully implement this research work in the industry, efforts are being taken to make people acknowledge this concept.

References

- [1] Davis W.T. (2000), *Air Pollution Engineering Manual*, John Wiley & Sons, Inc.
- [2] Richards J. R., *Control of Gaseous Emissions*, U.S. Environmental Protection Agency.
- [3] Kirk-Othmer (1999), *Encyclopedia of Chemical Technology*, John Wiley and Sons.
- [4] John Moore (2002), *Encyclopedia of Chemical Physics and Physical Chemistry*, Taylor & Francis, UK
- [5] Eran Sher (1998), *Handbook of Air Pollution from Internal Combustion Engines*, Academic Press, London.
- [6] John B. Heywood (1988), *Internal Combustion Engine Fundamentals*, Massachusetts Institute of Technology, USA
- [7] Gerald T. Joseph & David S. Beachler, *Scrubber Systems Operation Review*, DMG Environmental Inc.

