# Car Exhaust Pollution Control

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## INTRODUCTION

Pollution, in simple words, relates to our surroundings getting dirtier, unhealthier, and toxic. But in depth, pollution is far more broad than the ordinary term, "dirtiness," which is just a part of it and relates to the materials only, whereas pollution covers both material and non-material aspects and varying amounts of environment constituents in comparison to the state of balance essential for co-existence of life of humans, animals, and plants. Thus, environmental pollution may be defined as unhealthy, imbalanced changes in physical, chemical or biological conditions in the environment affecting the quality of human, animal, and plant life. Environmental pollution has not appeared all of a sudden. It steadily built up with the developments in human civilization; that is, the problem is as old as human life on the earth. As populations grew and cities developed, bringing with them greater water, industrial, and disposal needs, the problem became more apparent.

In the twentieth century, the pollution problem steadily became more widespread. At the turn of the century, ***automobiles*** became the major source of air pollutants.

## OBJECTIVES

The objectives on this interdisciplinary unit are based on Texas Essential Knowledge and Skills (TEKS).

**Texas Essential Knowledge and skills**:

Organize, analyze, evaluate, make inferences, and predict trends from data. (2C)

Describe the connection between Physics and future careers like Engineering. (3D)

The curriculum unit "Car Exhaust Pollution Control" in the seminar *Going Green* will broaden my own knowledge of science and relate science and mathematics to engineering. I can have physics/science and mathematics teachers team up to develop an integrated mathematics and science curriculum to encourage students to take up engineering in their junior and senior years.

## RATIONALE

This interdisciplinary unit will be taught in Madison High School, an inner city school in Houston, Texas. Madison High School is a magnet school for meteorology and space science and is associated with NASA. Students have the privilege to study the dynamics of weather, space exploration, environmental science, geology, oceanography, broadcasting, meteorology, manned space flight, and astronomy.

At Madison, there is an on-site station. It is being used to analyze real-time and historical weather data, to provide Internet access, and most importantly, to facilitate personal contact between students and professionals in the fields of meteorology and space sciences. Also, weather is being reported from school on a local television station.

I teach advanced students in the magnet program. My students deserve an exciting and challenging curriculum, and this interdisciplinary unit on "Car Exhaust Pollution Control" seems like a wonderful opportunity for them to relate mathematics to science and motivate students to pursue science and technology. First of all, my students get a chance to learn about the recent advancements and ongoing research in science and technology. I got the opportunity to relate and connect engineering and engineering terms in a mathematics class. My first order of business will be to have more brain-storming sessions on mathematics and science at the start of a new topic on "Car Exhaust Pollution Control," so my students can have a better background in science like automotive engineering along with mathematics. I will try to relate the topic to students' daily lives to spark their interest in these science and engineering projects. Secondly, I will work with other science teachers in my school so that my students can take the advantage of the school's labs and other facilities.

## UNIT BACKGROUND

### Car Exhaust Pollution

The recent increase in environmental awareness has placed all the factors producing pollutants under increasingly intensive scrutiny. This concern also extends to car exhaust. Automotive exhaust emissions of major concern are unburnt hydrocarbons, oxides of nitrogen, and carbon monoxide. Exhaust pollutants affect human health in many ways. Short-time pollution episodes have numerous acute effects, including discomfort, burning eyes and throat, colds, coughs, and heart attack in extreme cases. Particularly susceptible are children and patients with heart and lung diseases.

Engine modifications alone could not reduce these emissions sufficiently. The solution is the catalytic converter, which abates unburnt hydrocarbons, carbon monoxide, and oxides of nitrogen.

A catalytic converter is a compact unit that fits into the exhaust system. Inside the converter is an auto catalyst, a honeycomb of ceramic, which is chemically treated and coated with small amounts of platinum and rhodium. Platinum oxidizes carbon monoxide and unburnt hydrocarbons to carbon dioxide and water; rhodium reduces oxides of nitrogen to nitrogen.

#### *Statistics of Catalytic Converter*

> Length, area and volume of the ceramic monolithic support are normally 340 mm, 8510.57 $mm^2$ and 1472327.3 $mm^3$ respectively.
>
> Velocity of the exhaust gases and length of the catalytic converter are normally 3458.15 mm per second.
>
> Volume flow rate of exhaust gas analysis is theoretically calculated to be 0.0096 $mm^3$/sec. Thermal shock strength and maximum tensile strength of the ceramic monolithic support are normally 20.6 N/ $mm^2$ and 1.2 N/$mm^2$ respectively. (Harold and Carter, SAE Technical Paper Series 890815)

### Components of a car

- *Engine* - An engine whose purpose is to produce kinetic energy output from a fuel source is called a prime mover; alternatively, a motor is a device which produces kinetic energy from other forms of energy.
- *Transmission* - Using the principle of mechanical advantage, transmissions provide a speed-torque conversion (commonly known as "gear reduction" or "speed reduction") from a higher speed motor to a slower but more forceful output or vice-versa.

- *Drive Shaft* - A drive shaft, driving shaft, propeller shaft, or crank shaft is a mechanical component for transmitting torque and rotation, usually used to connect other components of a drive train that cannot be connected directly because of distance or the need to allow for relative movement between them.
- *Frame* - A frame is the main structure of an automobile chassis. All other components fasten to it.
- *Suspension* - Suspension is the term given to the system of springs, shock absorbers and linkages that connect a vehicle to its wheels. Suspension systems serve a dual purpose – contributing to the car's handling and good active safety and driving pleasure, and keeping vehicle occupants comfortable and reasonably well isolated from road noise, bumps, and vibrations.
- *Brakes* - A brake is a device for applying a force against the friction of the road, slowing or stopping the motion of a machine or vehicle, or alternatively a device to restrain it from starting to move again.
- *Wheels* - A wheel is a circular device that is capable of rotating on its axis, facilitating movement or transportation whilst supporting a load, or performing labor in machines.
- *Fuel Injector* - Fuel injection is a system for mixing fuel with air in an internal combustion engine. It has become the primary fuel delivery system used in gasoline automotive engines, having almost completely replaced carburetors in the late 1980s.
- *Fuel Tank* - A fuel tank is safe container for flammable liquids and typically part of an engine system in which the fuel is stored and propelled (fuel pump) or released (pressurized gas) into an engine.
- *Head Gasket* - A head gasket is a gasket that sits between the engine block and cylinder head in an internal combustion engine. Its purpose is to seal the cylinders to ensure maximum compression and avoid leakage of coolant or engine oil into the cylinders.
- *Clutch* - A clutch is a mechanism for transmitting rotation, which can be engaged and disengaged.
- *Alternator* - An alternator is an electromechanical device that converts mechanical energy to alternating current electrical energy.
- *Exhaust* - An exhaust system is used to guide waste exhaust gases away from a controlled combustion inside an engine. The entire system conveys burnt gases from the engine and includes one or more exhaust pipes.
- *Muffler* - A muffler or silencer is a device for reducing the amount of noise emitted by an engine.
- *Catalytic Converter* - A catalytic converter is a device used to reduce the toxicity of emissions from an internal combustion engine. (Nonnernmann, SAE Technical Paper Series 850131)

**Car Exhaust Pollutants and its Impact**

The combustion of fossil fuels releases pollutants with the exhaust gas. The minimization of these pollutants has become a priority objective of environmental policy. The operation of spark-ignition engines gives rise, in particular, to the following pollutants:

- *Carbon monoxide*, as a consequence of incomplete combustion.
- *Nitrogen monoxide*, as a consequence of combustion processes at high temperatures and pressures.

- *Hydrocarbons,* as a consequence of incomplete combustion.
- *Carbon dioxide*, which is directly dependent on the quantity of combusted fuel.

***Carbon Monoxide***

When fuels are burnt in engines, all the carbon is converted to carbon dioxide if combustion is complete. However, in practice combustion is often incomplete, and part of the carbon is oxidized to a poisonous gas, carbon monoxide, which is emitted into the air.

Effects of Carbon Monoxide on the Human Body

The poisonous action of carbon monoxide is harmful to the human body because of its affinity with the hemoglobin in the blood, the substance that combines with oxygen in the lungs and transports it around the body. When carbon monoxide is inhaled it displaces the oxygen in the blood and reduces the amount of oxygen carried to the tissues. An expert committee of the World Health Organization (WHO) has examined the effects of carbon monoxide on health, and on the evidence available to them, concluded that there is an increased risk for patients with cardiovascular disease.

***Nitrogen Oxides***

The major sources of nitrogen oxides are the automotive vehicles. Nitrogen oxides are produced when fuel is burned at very high temperatures. Although there are a number of nitrogen oxides, only nitric oxide and nitrogen dioxide are generally considered to be emitted in sufficient quantities to be regarded as general pollutants. Oxides of nitrogen are formed at relatively high temperatures during combustion. Hence, they are more likely to be emitted from vehicle exhausts.

The general reaction is as follows:

$$N_2 + XO_2 \rightarrow 2NO_X$$

This is a reversible reaction and the particular oxide formed depends on the temperature and the amount of oxygen present.

Nitric oxide is the predominant oxide of nitrogen produced inside the engine cylinders. The principal source of nitric oxide is the oxidation of atmospheric nitrogen. However, if the fuel contains a significant amount of nitrogen, the oxidation of the fuel's nitrogen-containing compounds is an additional source of nitrogen oxide.

Effect of Oxides of Nitrogen on the Human Body

Both nitric oxides and nitrogen dioxides have adverse effects on the human body. Nitrogen oxide reduces the oxygen carrying capacity of the blood. Nitrogen dioxide is more toxic. Nitrogen oxides are harmful for human health and specifically increase susceptibility of children to flu.

***Hydrocarbons***

Hydrocarbons are the name given to an unspecified mixture of hydrocarbon compounds. These arise from gasoline and diesel fuels and their combustion products. These fuels are made up of hundreds of different hydrocarbon compounds. To simplify matters, hydrocarbons are usually reported in terms of a single hydrocarbon compound such as methane, propane, hexane, etc.

***Carbon Dioxide***

Carbon dioxide results from complete combustion and is present in vehicle exhaust gases. Carbon dioxide is estimated to be produced worldwide at about 1.5 times $10^{10}$ tons per year (Nonnernmann, SAE Technical Paper Series 850131).

Effect of Carbon Dioxide on Environment

Although the concentration of carbon dioxide in the air is relatively small, it plays an important role in determining the temperature of the earth. The temperature rises when the amount of carbon dioxide in the atmosphere increases because it absorbs sunlight and infra-red radiation, preventing a portion of the heat from radiating back into space. It is estimated that if the present rate of increase in the amount of carbon dioxide in the air continues, the world temperature would increase by about two degree centigrade by the year 2020 (Nonnernmann, SAE Technical Paper Series 850131).

Green House Effect

There is worry that the total carbon dioxide in the atmosphere may increase, causing an increase in temperature throughout the world because of the "Green House Effect" resulting from the trapping of the sun's energy within the carbon dioxide blanket. Such rises in temperature, if they occur, may cause melting of the glaciers and consequent flooding of low lying areas throughout the world. There is evidence to suggest that the worldwide concentration of carbon dioxide has been increasing for a number of years.

**Controls**

During the combustion process in internal combustion engines, various harmful pollutants are formed. Principle among these pollutants are hydrocarbons, carbon monoxide and oxides of nitrogen. The 1968 model year regulations were established by the US ENVIRONMENTAL PROTECTION AGENCY (EPA) to reduce these emissions from vehicles. Today emissions of hydrocarbons, carbon monoxide, and oxides of nitrogen from new vehicles are at least 90% lower than they were from vehicles built before these regulations were adopted (Nonnenmann, SAE Technical Paper Series 850131).

**Introduction of Catalytic Converters**

Catalytic converters provide most of this reduction. Catalytic converters are installed in the exhaust system where they chemically react with hydrocarbons, carbon monoxide, and nitrogen oxide emissions coming from the engine to form carbon dioxide, water, and nitrogen.

> The typical catalytic converter consists of one or more ceramic monolithic honeycomb substrates impregnated with precious (noble) metals such as platinum, palladium, and rhodium. Some early converters contained loose ceramic pellet catalysts, which were coated with the noble metals. These noble metals promote chemical reactions which would not otherwise occur; hence they are called catalysts. (Harold and Carter, SAE Technical Paper Series 890815)

Unfortunately catalytic converters wear out over time due to several factors. Some of these are normal wear relating to the accumulated miles or years of operation. These normal wear factors include gradual poisoning by lead or other chemicals in the fuel deposits on the ceramic, which restrict the passage of the gasses through the converter or the ability of the gases to reach the surface of the converter, and erosion, which can gradually burn off the noble metals.

Some converters are damaged by conditions which are not normal wear. The ceramic substrate inside a converter can melt if it becomes too hot. This can happen if there is a malfunction in the engine, which causes extra fuel and air to be introduced into the engine. This malfunction includes ignition misfire. Carburetor or fuel injection system problems can cause too much fuel to be added, causing excessively high temperature.

***Types of Catalytic Converter***

There are two types of catalytic converters.

- Two-Way Catalytic converter.
- Three-Way Catalytic converter.

***Two-Way Catalytic Converter***

The term two-way catalytic converter implies oxidation of the two constituents in the exhaust, hydrocarbons and carbon monoxide, to form carbon dioxide and water as shown in the figure of a catalytic converter.

A two-way catalytic converter is also sometimes called an oxidation type converter. Oxidation type converters contain platinum and/or palladium to catalyze the oxidation of hydrocarbons and carbon monoxide. Oxidation converters do not function properly unless a pump supplies enough oxygen. The air is injected in front of the converter, usually at the exhaust manifold.

> The function of an oxidation catalyst is to oxidize carbon monoxide and hydrocarbons to carbons to carbon dioxide and water in an exhaust gas stream which typically contains 12% carbon dioxide and water, 100 to 2000 ppm nitric oxide, 20 ppm sulphur dioxide, 1 to 5% oxygen and 0.2 to 5 % carbon monoxide, often with the small amounts of lead and phosphorus. (Harold and Carter, SAE Technical Paper Series 890815)

About half the hydrocarbons emitted by the spark ignition engine are unburned fuel compounds. The saturated hydrocarbons are most difficult to oxidize. Sufficient oxygen must be present to oxidize the hydrocarbons and carbon monoxide.

At high enough temperatures, the steady-state conversion efficiencies of a new oxidation catalyst are typically 98 to 99 % for carbon monoxide and 95% or above for hydrocarbons. However, the catalyst is ineffective until its temperature has risen above 250 to 300 degrees centigrade. The term light-off temperature is often used to describe the temperature at which the catalyst becomes more than 50% effective (Harold and Carter, SAE Technical Paper Series 890815).

***Reactions Occurring in Two-way Catalytic Converter***

$2CO+O_2 \rightarrow 2CO_2$

$4HC+5O_2 \rightarrow 4CO_2+2H_2O$

***Automotive Catalyst***

An automotive catalyst is a substance which promotes a chemical reaction but remains unaffected by that reaction. Any reaction which is possible thermodynamically takes place at a rate dependent upon the temperature of the reactants. In general, the higher the temperature, the greater the rate of reaction. In engine exhaust, gas phase reactions normally proceed at a very slow rate. On the catalyst, however, the rate is fast enough to be of practical value for controlling emissions (Harold and Carter, SAE Technical Paper Series 890815).

An automotive catalyst converts harmful gases, such as hydrocarbons (unburnt fuel), carbon monoxide, and oxides of nitrogen, to harmless emissions: carbon dioxide, water, and nitrogen.

There are three important parts of an automotive catalyst: substrate, wash coat, and catalyst material.

Substrate

This is the component on which the catalyst material is supported. There are two main types of substrates: ceramic monolithic support and metal support. The substrate is an integral part of the catalytic system. Its primary function is to bring the active catalytic materials into maximum effective exposure with the exhaust gases.

The substrate has to withstand a variety of severe operating conditions. It has to survive rapid changes in temperature, vibrations from the road, and engine pulses associated with rapid changes in operating conditions, i.e., accelerations and decelerations.

A variety of potential ceramic bodies were available for the automotive application. Two types were eventually chosen:

- Alumina Pellets is made up of both cylindrical and spherical geometry.
- Honeycomb Monolith is composed of the ceramic material Cordierite (Cordierite is a Magnesium Aluminum Silicate).

Wash coat

This is a material applied to the substrate to provide a very high surface area for the catalyst material.

Catalyst Material

Three catalytic materials are used in automotive catalysts: platinum, palladium, and rhodium. An exhaust gas catalyst designed for reducing the amounts of pollutants emitted from motor vehicles consists essentially of a catalytically effective substance, such as platinum, rhodium etc., embedded in a wash coat having a specific surface area and applied to a support. This support determines the basic design of the catalyst: mechanical characteristics, geometric surface area, and catalytic action.

***Metal Supports***

In developing metal supports for vehicles, three major problems had to be solved:

- Selecting suitable steel alloys and rolling sufficiently thin steel strip stock.
- Finding a reliable, economically viable method of shaping the steel strips into a honeycomb coil and then forming a monolith block. After initial attempts to strengthen the substrate mechanically, development went from electron beam welding to present-day brazing technology.
- Coating the metallic surfaces with a wash coat and catalyzing materials. Effectiveness and reliability of a metallic catalyst depend largely on good adhesion of the wash coat to the metal surface.

***Requirements of Catalyst Supports***

A catalyst support is expected to meet following high demands such as:

- Large surface area.
- Low volume.
- Low mass.
- Good coating adhesion.
- Low exhausts backpressure.

- High thermal shock resistant.
- High mechanical strength.
- High corrosion resistance.
- Low heat capacity.
- Low cost.

**LESSON PLANS**

**Lesson Plan One**

***Objective***

Students will be learning and exploring about car exhaust pollution.

***Introduction***

Car exhaust pollution is the process when the combustion of fossil fuels releases pollutants with the exhaust gas.

***Concept Development***

Automotive exhaust emissions of major concern are unburnt hydrocarbons, oxide of nitrogen, and carbon monoxide. Engine modifications could not reduce these emissions sufficiently.

***Student Practice***

Students will explore different types of cars to study car exhaust pollutions. Students will understand how exhaust from the car contributes to air pollution.

***Assessment***

Assessment will be graded on a class presentation made by student's car exhaust pollution. Students will be assessed on the analysis when they work on the experiment on car .

***Resources***

James E. Duffy, *Modern Automotive Mechanics*
Edward F. Obert., *Internal Combustion Engines*
Martin T. Stockel, *Auto Mechanics Fundamentals*

**Lesson Plan Two**

***Objective***

Students will be learning about and exploring components of a car.

***Introduction***

Components of a car are all the parts that help in the manufacturing of a car.

***Concept Development***

Components of a car include several major parts like engine, transmission, drive shaft, frame, suspension, brakes, exhaust system, catalytic converter, etc. It is very important to understand all the components of a car in order to understand the mechanism and the operating cycle of the car.

***Assessment***

Students will be graded on a class presentation on components of a car. Students will be assessed on the analysis when they work on the mapping of the components of a car.

***Student Practice***

Students will explore different types of cars. Students will understand how the components of a car are related to each other

***Resources***

James E. Duffy, *Modern Automotive Mechanics*
Edward F. Obert., *Internal Combustion Engines*
Martin T. Stockel, *Auto Mechanics Fundamentals*

**Lesson Plan Three**

***Objective***

Students will be learning about and exploring the impact of exhaust pollution.

***Introduction***

The recent increase in environmental awareness has placed all the factors under vigilance, which also includes car exhaust pollution. Automotive exhaust emissions of major concern are unburnt hydrocarbons, oxide of nitrogen, and carbon monoxide. These emissions are harmful to human health and can affect health in several ways.

***Concept Development***

When fuels are burned in the engines, all the carbon is converted to carbon dioxide if combustion is complete. However, in practice combustion is often incomplete, and part of the carbon is oxidized to a poisonous gas called carbon monoxide, which is emitted into the air.

Similarly, the major source of nitrogen oxides is also the exhaust from the automotive vehicles.

***Student Practice***

Students will explore different types of cars to study car exhaust pollutions. Students will analyze and evaluate how exhaust from the car contributes to air pollution.

***Assessment***

Students will be assessed on the analysis and experiment when they work on different ways to reduce car exhaust pollution.

***Resources***

James E. Duffy, *Modern Automotive Mechanics*
Edward F. Obert., *Internal Combustion Engines*
Martin T. Stockel, *Auto Mechanics Fundamentals*

**Lesson Plan Four**

***Objective***

Students will be learning about and exploring about the Car Exhaust Pollution Control and the catalytic converter

***Introduction***

**Concept Development**

Automotive exhaust emissions of major concern are unburnt hydrocarbons, oxide of nitrogen and carbon monoxide. Engine modifications could not reduce these emissions sufficiently. Therefore, the solution is the catalytic converter, which abates unburnt hydrocarbons, carbon monoxide and oxides of nitrogen.

A catalytic converter is a compact unit that fits into the exhaust system. Inside the converter is an auto catalyst, a honeycomb of ceramic, which is chemically treated and coated with small amounts of platinum and rhodium. Platinum oxidizes carbon monoxide and unburnt hydro carbons to carbon dioxide and water while rhodium reduces oxides of nitrogen to nitrogen.

***Assessment***

Students will be graded on a class presentation on different types of catalytic converters. Students will also be assessed on their analysis of the car exhaust system.

***Student Practice***

Students will explore different types of catalytic converters to study car exhaust pollution control. Students will understand how the catalytic converter converts harmful emissions to harmless emissions.

***Resources***

James E. Duffy, *Modern Automotive Mechanics*
Edward F. Obert, *Internal Combustion Engines*
Martin T. Stockel, *Auto Mechanics Fundamentals*

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