Design of an Experiment: Correlation of CO₂ and Global Warming

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Abstract
Carbon dioxide, and other greenhouse gases, are absorbing radiation and raising the average temperature of the Earth’s atmosphere. This Capstone Project is set to quantitatively demonstrate the effect of high carbon dioxide concentrations on the temperature of the Earth’s atmosphere by performing a simple laboratory experiment. An experimental setup has been designed to highlight the difference in cooling rates of a heated object in different gaseous mediums. An electric cartridge heater was chosen to represent Earth, and a large spherical chamber containing gas was chosen to represent the Earth’s atmosphere. The heat transfer within this system is driven by radiation and convection cooling. The cooling rates of an object in air and CO₂ containing environments have been theoretically proven to be different, due to different absorptivities. The experimental setup needs to demonstrate these theoretical results. Some features of the apparatus include: ability to test various gases, an automated data acquisition system, and the ability to change container diameter, which highlights the effect of changing path lengths. All of these features are intended to allow for a variety of tests to be run, as well as for collection of data with minimal inaccuracies. This project has the potential to yield a sufficient amount of data which can empirically support the correlation between rising concentrations of CO₂ in the environment, and rising atmospheric temperatures.

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The Need for Project

Rising concentrations of greenhouse gases have caused a warming effect in Earth’s atmosphere and oceans. The complexity of the global climate drives the need for a demonstration which isolates the effects of specific gases. Global warming is the theory that the average temperatures of Earth's surface, oceans and atmosphere are rising. The scientific consensus is that global warming is due to the increase in concentrations of greenhouse gases in the atmosphere, initiated by human activities through burning fossil fuels or deforestation. The main understanding of global warming is that these greenhouse gases are able to trap irradiative heat from the earth. The increase in human population and activities in the past century (i.e. The Industrial Revolution) has resulted in the emission of more greenhouse gases. The Earth’s surface temperature has been steadily increasing, affecting its environment and the species depending on it. This project is primarily focused on the behavior of carbon dioxide in the atmosphere and on producing empirical data that does or does not support the correlation of rising CO₂ levels and the atmospheric atmosphere.

The Design Project Objectives and Requirements

The terrestrial radiation being absorbed by greenhouse gases is what is driving global warming. The goal of this project is to develop an experiment which compares the cooling rates of a metallic body in the presence of air and CO₂.

Design Objectives

The deliverables for this project include a fully constructed model that simulates terrestrial radiation being absorbed as it passes through Earth’s atmosphere, documented test rules and methods, automated data acquisition system, and a subsequent base of data that shows a statistical comparison of the effects of CO₂ on the earth’s atmospheric temperature. The more data compiled is the cooling rates of the metallic body in an air versus a CO₂ environment.

Design Requirements

The most important objective is to collect enough data to statistically show a difference between cooling times in air and CO₂ to support or not support the correlation between rising CO₂ concentrations in the atmosphere and rising atmospheric temperatures. It is imperative that a difference of cooling times of the metallic body between the control substance (air) and the experimental substance (CO₂) be greater than the error in the temperature measurement device and procedure.
Design Concepts Considered

The main considerations in the design of the model were: simulation of terrestrial radiation, a long path length of the container to amplify the effects of radiative cooling, and a container that allows control over changes in gas concentrations.

General Considerations

There is a host of basic design features that any model constructed would have to incorporate. These included the ability to: integrate an automated data acquisition system, represent terrestrial radiation, implement a standard operating procedure which could be easily reproduced, have the ability to switch between different gases and particulates, be able to conduct the experiment with larger diameter containers to vary the path lengths, and finally, allow a fine control of gas concentrations inside the test chamber.

Simulating Terrestrial Radiation

Solar radiation transmitted from the sun to the Earth’s surface consists of shorter wavelength radiation, ranging from 0.2 to 2µm, while terrestrial radiation is of much longer wavelength, ranging from 2 to 70 µm. The wavelength range where carbon dioxide absorbs overlaps the terrestrial radiation spectrum, in the 10 to 20 µm range. This phenomenon is why solar heating has been eliminated from the design of the model. Now the heat source must be introduced by internally heating a metallic body.

Varying Path Lengths

The absorptivity, $\alpha$, of any gas is mathematically dependent on the path length radiation needs to travel to the final surface boundary. The dependence can be thought of physically by seeing that for any given density of gas or substance, more of it is encountered over a much longer path. In this test, the path length is the diameter of the spherical container. This is used to simulate the atmosphere. Because air is considered to be a transparent gas, its absorptivity is 0. By increasing the size of the spherical container, the amount of heat absorbed through radiation will increase. As more radiation is absorbed, the difference in cooling rates should increase. The use of a 3ft diameter sphere versus a 6.5ft sphere would increase the absorptivity of CO$_2$ gas 17.6%. A 6.5ft sphere is not readily available, so a 3ft environment is being used to validate the theoretical data. The choice of a flexible container also allows for more control over gas concentrations. The entire container can be drained without need to apply a vacuum pressure, and a new gas can be introduced and maintained at a 100% concentration.

Repeatable Test Plan
Many tests must be conducted in order to accurately and statistically conclude that there is a difference in the time it takes to cool a metallic body in air and CO₂. The variables introduced are kept to a minimum by keeping the range the metallic body is cooled to the range of 100°F to 70°F, heating the body for a constant time, and keeping the amount of gas present constant throughout each run. The design of the experiment keeps all of these variables in mind.

**Recommended Experiment Concept**

A spherical container surrounding a small, internally heated metal body was used to replicate Earth’s environment without solar heating. All gas is expelled between tests control gas concentration, and change mediums.

**Design Description**

A flexible, spherical container is mounted in the middle of a wooden platform. The hardware is suspended in the chamber, utilizing the existing hole, originally intended for inflation and deflation. The heater itself is wired back to a 120v outlet, controlled by a potentiometer. The potentiometer is used to control the upper temperature limit of the heater. A thermocouple has been epoxied to the surface of the heated, metal body to record the temperature of our simulated “Earth.” Another thermocouple is suspended inside the chamber to monitor ambient temperature. A third thermocouple sits on the wooden stand, monitoring the room temperature. The three thermocouples are wired back to a DAQ from Omega, and records data through the user interface supplied by Omega (tracerDAQ.) A 120 volt vacuum-pump is used to inflate the container for air tests, and fully deflate the container when switching between gases. Two 50lb capacity, industrial CO₂ tanks, controlled with a pressure regulator, are used to fill the container for CO₂ tests. As data is collected, the spherical container can be swapped out for containers with a higher and higher path length to increase the effects of CO₂ absorption.

**Analytical Investigation**

In depth heat transfer analysis was performed to address several concerns during the design phase. The metal body needed to be shock heated to prevent heating of the air inside the chamber. Simple conduction with no loss due to convection showed that heating in less than 30 seconds should be expected. It was also a concern, that once the metal body reached its equilibrium temperature, it would have raised the temperature inside the container. Equilibrium calculations,
assuming the mass of gas and the metal body were isolated in contact, show a rise of one degree Fahrenheit when used with the smallest container (three foot diameter.) Theoretical cooling curves were modeled with convection and radiation. MATLAB was used to solve the equations, but a difference 5 minutes between cooling times should be seen during testing.

Experimental Investigation

Results indicate a difference of four minutes between cooling times from 100 °F to 70 °F. This difference can be amplified with a higher path length, which would increase absorptivity. Also, conducting more tests would make this data statistically significant. At this time, no conclusions can be drawn; even though a correlation between CO₂ and increased cooling times is seen in Figure 5 where the cooling curve for the air test is shown and labeled in red, while the cooling curve of the air environment is shown and labeled in blue.

Financial Issues

The apparatus had to be constructed of materials that were easily obtained, could be machined in house, and were not price prohibitive. The cost of the device was kept down by machining and assembling all parts of the apparatus in house. Much of the apparatus is constructed of commonly found materials that are available in large enough quantities that the cost is minimal. It is worth noting that a 6.5 foot diameter container would cost between $300-$500.

Recommended Improvements

The apparatus is ready for tests with various other gases, as well as testing with spheres which could increase the path length. Improvements for this apparatus include the introduction of other gases, particulates, aerosols, and vapors all present in greenhouse gases. Testing with such could yield results allowing for a much better understanding of the causes, and their direct effects with respect to temperature change, of global warming.