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Carbon monoxide and carbon dioxide emissions from roasted coffee beans

by

Warner Charles Wilson

Thesis submitted to the Faculty of the
Preventive Medicine and Biostatistics Graduate Program
Uniformed Services University of the Health Sciences
In partial fulfillment of the requirements for the degree of
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Graduate Education Office (A 1045), 4301 Jones Bridge Road, Bethesda, MD 20814



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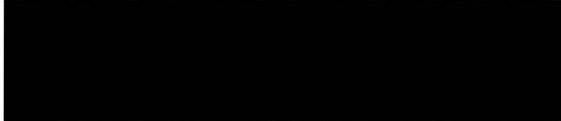
Name of Student: Warner Wilson

Date of Examination: June 25, 2019

Time: 1:30 PM

Place: OEHS Conference Room

DECISION OF EXAMINATION COMMITTEE MEMBERS:

	PASS	FAIL
	<u>X</u>	_____
Dr. Karyn J. Condie DEPARTMENT OF PREVENTIVE MEDICINE & BIOSTATISTICS Committee Chair		
	<u>X</u>	_____
Dr. Alex Stubner DEPARTMENT OF PREVENTIVE MEDICINE & BIOSTATISTICS Thesis Advisor		
	<u>X</u>	_____
Dr. Edward Benchhoff DEPARTMENT OF PREVENTIVE MEDICINE & BIOSTATISTICS Committee Member		
	<u>X</u>	_____
Dr. Cody Schaal DEPARTMENT OF PREVENTIVE MEDICINE & BIOSTATISTICS Committee Member		



UNIFORMED SERVICES UNIVERSITY, SCHOOL OF MEDICINE GRADUATE PROGRAMS
Graduate Education Office (A 1045), 4301 Jones Bridge Road, Bethesda, MD 20814



APPROVAL FOR THE MASTER OF SCIENCE IN PUBLIC HEALTH THESIS IN THE
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Name of Candidate: Warner Wilson
Master of Science in Public Health
June 25, 2019

THESIS AND ABSTRACT APPROVED:

DATE:



25 June 2019

Dr. Karyn J. Condie
DEPARTMENT OF PREVENTIVE MEDICINE & BIostatISTICS
Committee Chair



25 June 2019

Dr. Alex Stubner
DEPARTMENT OF PREVENTIVE MEDICINE & BIostatISTICS
Thesis Advisor



25 June 2019

Dr. Edward Benchoff
DEPARTMENT OF PREVENTIVE MEDICINE & BIostatISTICS
Committee Member



25 JUN 2019

Dr. Cody Schaal
DEPARTMENT OF PREVENTIVE MEDICINE & BIostatISTICS
Committee Member

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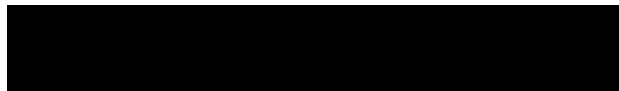
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DEDICATION

This thesis is dedicated to my Judith and Warner Wilson, my mother and father who have stood by me through all my endeavors. Immigrants from Jamaica, they have been married for 35 years and have taught me the importance of hard work and always doing what I perceive to be right. They are the reason that I am the man that I am today and who without this thesis could simply not exist.

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Warner C. Wilson

February 4, 2020

ABSTRACT

Hazardous carbon monoxide and carbon dioxide emissions from roasted coffee beans

LT Warner C. Wilson
Master of Science in Public Health
2019

Thesis directed by: Dr. Alex H. Stubner, Ph.D., Assistant Professor, Department of Preventive Medicine and Biostatistics

Introduction: Navy ships and facilities commonly store large quantities of roasted coffee beans. There have been reports of sailors being adversely affected by carbon monoxide (CO) and carbon dioxide (CO₂) emissions from these beans. This creates a need for guidelines that will abate the risks associated with storage of roasted coffee.

Objective: Determine the emission rate of CO and CO₂ of different roasts of coffee beans at different temperatures, and to construct a model that predicts the amount of CO and CO₂ off-gassing given a known value of mass, roast, time from roast date, and storage temperature.

Methods: Coffee samples varying in mass, roast type, and storage temperature were monitored for 20 days with the Gasmeter DX4040 FTIR (Fourier Transform Infrared Spectroscopy) gas analyzer to quantify the amount of CO and CO₂ generated.

Results: An increase in mass correlated with an increase in CO and CO₂ emissions; emissions ratio trends observed are light roasts emit a larger ratio of CO₂:CO than dark roasts, higher

storage temperature results in a lower emissions ratio of CO₂:CO, increasing mass lowers the emission ratio of CO₂:CO, and the emissions ratio of CO₂:CO slowly decreases overtime; average CO and CO₂ emissions generally increased with an increase in storage temperature; dark roasted coffee beans produce significantly more CO and CO₂ emissions than light roasts;

Conclusion: Further research is needed, but this experiment has collected enough data to conclude that a clear hazard exists and that large quantities of roasted coffee should not be stored in an unventilated and unmonitored storage space.

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CHAPTER 1: Introduction

1.1 Statement of Purpose

“The objective of this study was to determine the emission rate of carbon monoxide (CO) and carbon dioxide (CO₂) of different roasts of coffee beans at different temperatures, and to construct a model that predicts the amount of CO and CO₂ off-gassing given a known value of mass, roast type, time from roast date, and storage temperature.”

1.2 Background

Navy ships and facilities commonly store large quantities of roasted coffee beans with no clear guidelines for the conditions of the storage spaces. After a group of US Navy sailors were adversely affected by CO and CO₂ emissions from stored roasted coffee beans, Navy Supply Systems Command (NAVSUP) released Food Flash 17-01 (Appendix 1), a safety message which recommended transferring all bulk coffee to ventilated storage areas (18). However, this was not a mandatory requirement and the community at large was mostly unaware of the hazard that the large quantities of roasted coffee beans present. The primary purpose of this study is to investigate the emission rates, in mass per unit of time, of CO and CO₂ of roasted of coffee beans, as well as to quantify the effects of different roasts and storage temperatures. Ultimately, the goal of the study is to begin to profile the hazard so that more well-defined safety practices for the storage of roasted coffee beans can be developed.

1.2.1 Carbon Dioxide

CO₂ is a naturally occurring trace gas in our atmosphere consisting of a carbon atom covalently double bonded to two oxygen atoms. Atmospheric concentration of CO₂ has been

monitored and tracked by the Scripps Institution of Oceanography at UC San Diego at their remote facility in Mauna Loa, Hawaii since 1958 (23). Levels of CO₂ are plotted on what is known as the Keeling Curve. Currently, atmospheric concentrations of CO₂ are about 0.0415% (415 ppm) by volume - up from 280 ppm in the 1950s (13).

As described by the Wheeling Jesuit University Center for Educational Technologies 2004 publication, “*Carbon Dioxide: Overview*,” CO₂ is used by plants during photosynthesis and is produced by living creatures during respiration. As the source of available carbon in the carbon cycle, atmospheric CO₂ is the primary carbon source for life. During photosynthesis, plants, algae and cyanobacteria use light, water, and CO₂ from the atmosphere to produce carbon-containing sugars. Animals eat plants to obtain the energy in these carbon-containing sugars. As the animals' bodies break down the carbohydrates in the plant tissue, CO₂ is released to the atmosphere during aerobic respiration. CO₂ is also a product of combustion. When organic materials slowly decay under high pressure and high temperatures, the materials may form pools of energy known as fossil fuels such as coal, oil, and natural gas. People burn fossil fuels, as well as fresh vegetation, to release the energy stored in the fuels releasing CO₂ as a byproduct (31).

CO₂ has a variety of commercial uses and benefits. Some uses include keeping food cold with dry ice and adding carbonation to beverages. It is a common ingredient in fertilizers, plastics, and polymers. In the electronics industry, CO₂ is used in manufacturing applications, including semiconductor device manufacturing, surface cleaning, and circuit board assembly – it is powerful at purging, pressurizing and cooling equipment. Additionally, welders use CO₂ to help prevent impurities, like rust, from forming at welds (2).

According to the Agency for Toxic Substances and Disease Registry (ASTDR), CO₂ at low concentrations (<5%) have few toxicological effects. At concentrations greater than 5% (5000 ppm), CO₂ acts as a simple asphyxiant that displaces oxygen from the air which can lead to a depression of respiration and circulation and may cause convulsions, coma, and death. CO₂ levels of more than 30% (300,000 ppm) can result in loss of consciousness in seconds (24). If high concentrations of CO₂ are to be expected, the exposure should be monitored and controlled if necessary.

1.2.2 Carbon Monoxide

CO is a colorless, odorless, and tasteless gas that is slightly less dense than air. CO consists of one carbon atom and one oxygen atom, connected by a triple covalent bond (11). Atmospheric concentrations of CO are about 80 ppb and it is produced from the partial oxidation of carbon-containing compounds or when there is not enough oxygen to produce CO₂. It is naturally generated from the burning of organic material, released from the Earth's mantle by volcanic eruptions, produced by the oxidation of methane, and from the oxidation of hydrocarbons emitted by vegetation. CO is also generated by human activity as it is a byproduct of incomplete combustion (27).

CO has a variety of commercial uses. It is used in the production of methanol, in the conversion of coal or biomass to diesel, the production of acetic acid, the purifying of nickel and in the production of hydrogen. CO is also used in food packaging systems in the US to keep meat, fish, and pork looking fresh (28). Additionally, it can be used to extract metals from their ores.

CO is a chemical asphyxiant that binds to hemoglobin inhibiting the transportation of oxygen by the circulatory system. As it is an odorless, colorless, and non-irritating gas, it has become known as a silent killer (14). Carbon monoxide poisoning is the leading cause of death due to poisoning in the United States (1). According to the United States Consumer Product Safety Commission, about 170 people die in the United States every year from CO produced by non-automotive consumer products. The Centers for Disease Control and Prevention estimates more than 400 Americans die from unintentional CO poisoning not linked to fires, more than 20,000 visit the emergency room, and more than 4,000 are hospitalized. The health effects of CO depend on a variety of factors such as concentration, length of exposure, as well as the health of the individual exposed. Generally, there will be no negative health effects from prolonged exposure to CO at concentrations below 70 ppm, but as CO exposure concentrations increase above 200 ppm, symptoms become more noticeable and can include headache, fatigue and nausea; at concentrations above 800 ppm, disorientation, unconsciousness, and death are possible (19).

1.2.3 Relevance

The roasting of coffee beans produces CO₂ and CO gas as byproducts of both a chemical reaction between the carbonaceous fuel and oxygen in the air (26) and from many of the non-enzymatic browning reactions that occur during the roasting process (3; 30). A large amount of these gasses remain trapped within the coffee bean matrices and begin emission from the beans after completion of the roasting process – during both bean cooling and storage (3; 30). Degassing from roasted coffee beans is a slow process, and release of CO₂ and CO can continue for more than a month at gradually declining rates (17). Emission of these gases, particularly in

enclosed or poorly ventilated spaces, can lead to airborne concentrations of CO₂ and CO that are dangerous to human health.

Storage of large quantities of roasted coffee beans is a common practice aboard US Navy vessels and in Naval Facilities. These coffee beans are often stored in poorly ventilated spaces for long periods of time, thus potentially resulting in dangerous concentrations of CO₂ and CO which can be dangerous to the health and safety of sailors. Therefore, an understanding of these emissions is imperative for creating safe storage standards.

1.3 Research Question

What is the effect of time, mass, storage temperature, and roast type on CO₂ and CO emission rates from roasted coffee beans?

1.3.1 Specific Aims

- Specific Aim 1:
 - Measure the CO₂ and CO emissions over time for a given mass and roast of Mayorga Organics' Peru COOPARM coffee beans.
 - Investigate the relationship between coffee bean mass and emissions of CO₂ and CO
 - Take samples of 50g, 100g, and 200g of coffee of the same bean type and roast, and observe the CO₂ and CO emissions over time
 - Determine if there is a correlation between coffee beans mass and CO₂ and CO emissions.

- Hypothesis: Increase in the amount (mass) of coffee beans will result in increased CO₂ and CO emissions.
- Specific Aim 2:
 - Determine if there is a ratio between CO₂ and CO emissions.
 - Observe CO₂ and CO emissions and compare the differences.
 - The Command Investigation into incident onboard USS George H.W. Bush stated that Coffee emits CO₂ and CO at a rate of 10:1 (18).
 - Hypothesis: CO₂ and CO will emit at a specific ratio of 10:1 regardless of roast, mass, and storage temperature
- Specific Aim 3:
 - Measure change in emission rates over time after roasting.
 - Investigate the relationship between coffee bean roast date and off gassing of CO₂ and CO
 - Observe CO₂ and CO emission rates over time (20 days)
 - Hypothesis: The rate of CO and CO₂ off gassing will decrease over time
- Specific Aim 4:
 - Measure effects of storage temperature on emissions.
 - Investigate the relationship between coffee bean storage temperature (4°, 25°, 38° C) and emissions of CO₂ and CO
 - Observe CO₂ and CO emissions of coffee beans stored at 3 different temperatures
 - Hypothesis: Higher coffee storage temperatures will result in higher CO₂ and CO off gassing rates

- Specific Aim 5:
 - Measure differences in emissions between light and dark roasts.
 - Investigate the relationship between coffee roasts and off gassing rates of CO₂ and CO
 - Observe differences in CO₂ and CO emissions of light and dark roasts of coffee
 - Hypothesis: Dark roasts will produce more CO₂ and CO emissions than Light Roasts
- Specific Aim 6:
 - Construct a model to predict CO₂ and CO emissions based on mass, roast, and storage temperature.
 - Use all observations to construct a model which can estimate CO₂ and CO off gassing rates using linear regression, when the roast date, mass, roast type, and storage temperature are known

CHAPTER 2: Literature Review

2.1 Coffee

Coffee is one of the most commonly consumed beverages worldwide (25). Green coffee beans were the world's 16th largest legal agricultural export by value in 2016 (9). About 60 tropical and subtropical countries produce coffee extensively and for some it is their main agricultural export product (7).

Coffee is extracted from the fruits of several species of shrub of the genus *Coffea*. Two main species commercially cultivated are *Coffea canephora* (predominantly a form known as 'robusta') and *C. arabica*. The beans are the processed and roasted seeds from a fruit, which is called a coffee cherry. The coffee cherry has a smooth, tough outer skin called the exocarp or pericarp, which is usually green in unripe fruits but often changes color to red, violet, yellow, or orange when ripe. Beneath the pericarp is a thin layer of pulp called the mesocarp. This is followed by a translucent, colorless, thin, viscous and highly hydrated layer of mucilage (also called the pectin layer). The pectin layer is connected to a thin endocarp called parchment, which is yellowish in color. Finally, the silverskin covers each hemisphere of the coffee bean (endosperm). Constitution of the coffee cherry is depicted in Figure 1 (7).

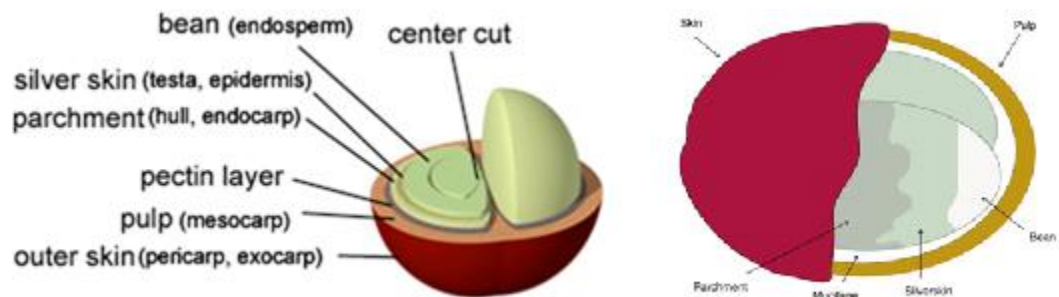


Figure 1: Composition of Coffee Fruit (7; 12)

2.2 Roasting process

The beverage commonly known as coffee is prepared by brewing roasted, ground coffee beans. The beans are prepared from the ripened coffee fruit by removing the pulp, mucilage, parchment, and silverskin, and by drying the left-over seed. The resulting product is a dry green bean that is ready for roasting (7). The roasting process is one of the most complex and important stages of the coffee production chain. During the roasting process, heat will be applied to coffee beans, causing them to undergo chemical and physical changes. The reactions within the bean will modify the sugar, protein, and chemical composition, producing CO₂ and CO in the process. As a result of this transformation, the green coffee beans turn into the familiar, flavorful aromatic brown beans that can be found on store shelves (16).

The general roasting process can be divided into three phases:

1. Initial drying phase: An endothermic or heat absorbing process in which the beans are slowly dried, change color from green to yellow, and give off a bread-like aroma.
2. Browning reactions phase: The chemical composition of the beans is drastically modified and the beans change color to a dark brown. The reaction then becomes an endothermic process as large amounts of CO₂ is released along with other volatiles, including CO. This period is often called first crack as the bean doubles in size and there is an audible crack that sounds like the popping of popcorn with the release of the volatile compounds. If left to continue to roast, this process will repeat itself with another exothermic period, further browning, followed by a second endothermic period, release of more volatiles, and a second audible crack.

3. Bean cooling phase: Using air or water, the beans are rapidly cooled to stop the exothermic release of the roasting operation and to prevent the beans from over roasting or burning (Figure 2).



Figure 2: Roast Color Example (5)

The quantity of heat transferred to the beans is controlled by the roasting temperature and time which is directly correlated to the final roasting temperature: the more heat transferred, the darker the coffee. Essentially, color can be used to define the end of the roasting operation. (4) The degree of roasting is usually described as being 'light', 'medium' or 'dark'. Generally, the definition of the roast degree is made subjectively by masters of roast or by equipment, such as colorimeters and spectrophotometers (16). An example of roast degrees and their general characteristics can be found in Table 1:

Table 1: Coffee Roasts Colors and Characteristics

Roast Degree	Characteristics
Light	Light brown to cinnamon color Low body and light acidity. The beans are dry and there will be no oil on the surface of these beans because they are not roasted long enough for the oils to break through to the surface.
Medium - Light	Medium light brown color. The acidity brightens, the flavor is stronger, and the bean is still dry with no oil on the surface.
Medium	Medium brown color. The acidity continues to increase and the flavor becomes more potent. The bean is mostly dry.
Medium - Dark	Rich dark brown color. Some droplets of oil appear on surface. The acidity is slowly diminished and flavor increases with a slight bittersweet aftertaste.
Dark	Deep brown/black in color. The bean has spots of oil or is completely oily. There is low acidity with a pronounced bitterness.
Very Dark	This roast produces shiny black beans with an oily surface and an increased pronounced bitterness. The darker the roast, the less acidity will be found in the coffee beverage.

Many of the chemical reactions that take place during roasting are not completely understood as they are extremely complex, occur simultaneously, and have wide range of interactions between all the routes involved (4). However, the formation of CO₂ and CO in roasted coffee is attributed to Maillard, Strecker, and pyrolysis reactions (29).

2.3 Health effects

While the amount and rate at which coffee off gasses carbon monoxide and carbon dioxide is not well understood, the health effects of inhaling sufficient quantities of these compounds are.

2.3.1 Health effects of CO

CO poisoning is one of leading causes of morbidity and mortality due to poisoning in the United States. It has been estimated that CO poisoning results in over 50,000 emergency room visits per year in the United States. Inhaled CO is absorbed into blood and distributes throughout the body. The CO binds to hemoglobin, forming carboxyhemoglobin (COHb) which decreases the oxygen carrying capacity of blood. This reduces the oxygen that can be distributed to tissues throughout the body.

The extent of injury from acute CO exposure depends upon the concentration and duration of exposure, as well as the underlying health status of the exposed individual. The severity of CO poisoning is typically categorized as mild, moderate, or severe, based on clinical presentation. Signs and symptoms of mild CO poisoning include headache, nausea, vomiting, dizziness, blurred vision, and occasionally cherry red lips and skin; headache and dizziness are the most commonly reported symptoms. Symptoms associated with moderate CO poisoning may include confusion, loss of consciousness, chest pain, shortness of breath, elevated heart rate, and rapid breathing. Effects of severe poisoning can result in cardiac arrhythmias, heart attack, cardiac arrest, seizures, coma and death. The degree of CO poisoning is determined with a blood test in which COHb levels are measured. Fatalities due to carbon monoxide poisoning have been reported for a wide range of COHb levels (3–70%) with the likelihood of death increasing dramatically when levels of COHb exceed 50% (1).

2.3.2 Health Effects of CO₂

CO₂ exposure is typically not fatal, since it does not chemically adhere to hemoglobin like a chemical asphyxiant such as CO. However, when present in high concentrations, CO₂ can displace oxygen from the environment. As oxygen concentrations in an environment fall below 18%, the human circulatory system will not have enough oxygen available for cellular respiration of all the tissues in the body. As the tissues become oxygen deprived, the symptoms that follow are the same as that of a chemical asphyxiant (8).

2.4 Regulations

Since exposure to certain compounds brings the potential for negative health outcomes, occupational exposure limits have been established to safeguard workers. In the United States the National Institute for Occupational Safety and Health (NIOSH) periodically reviews and evaluates available medical, biological, engineering, chemical, trade, and other information relevant to a given hazard to develop and revise recommended exposure limits (RELs) for hazardous substances or conditions in the workplace. OSHA will then take these recommendations into account when developing their legal standards known as permissible exposure limits (PELs). The RELs and PELs can be listed as a time weighted average (TWA) for typically up to a 10-hour day for RELs and 8-hour work day for PELs during a 40-hour work week. NIOSH also uses the relevant literature to develop a concentration for a hazard that is deemed Immediately Dangerous to Life and Health (IDLH). The IDLH value is the concentration of contaminants that is "likely to cause death or immediate or delayed permanent adverse health effects or prevent escape from such an environment." The NIOSH REL for CO₂ is 5,000 ppm (9,000 mg/m³), the PEL is 5,000 ppm (9,000 mg/m³), and the IDLH concentration is

40,000 ppm (72,000 mg/m³). The NIOSH REL for CO is 35 ppm (40 mg/m³), the PEL is 50 ppm (55 mg/m³), and the IDLH concentration is 1,200 ppm (1375 mg/m³) (20).

2.5 Gaset DX4040

FTIR gas analyzers can both identify and measure gaseous compounds by their absorbance of infrared radiation. According to Gaset and the Institutes of Clean Air Companies' White Papers on FTIR, their FTIR analyzers offer the ability to monitor multiple gases simultaneously, reliably and accurately in a wide variety of applications. Typically, the Gaset DX4040 is used as a direct reading instrument that utilizes a sample probe to actively analyze an atmosphere to identify and quantify the compounds within it. The sample probe collects a sample atmosphere which is then pumped in to a 0.454 L sample cell (Figure 3). The atmosphere inside this cell is energized with an infrared beam. A detector on the other end of the sample cell measures the absorbance of the infrared energy by the atmosphere. By measuring how much light was absorbed at different wavelengths across the infrared spectrum, it can identify the compound.

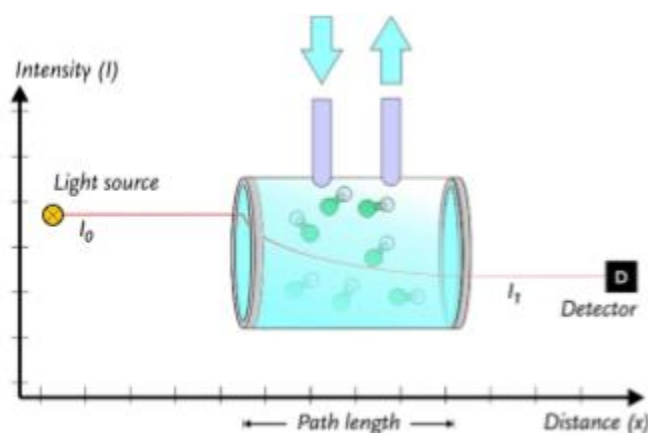


Figure 3: Gaset DX4040 sample cell concept

Every molecular structure has a unique combination of atoms, and therefore produces a unique spectrum when exposed to infrared light. For example, a typical infrared spectrum of CO gas is shown below (Figure 4).

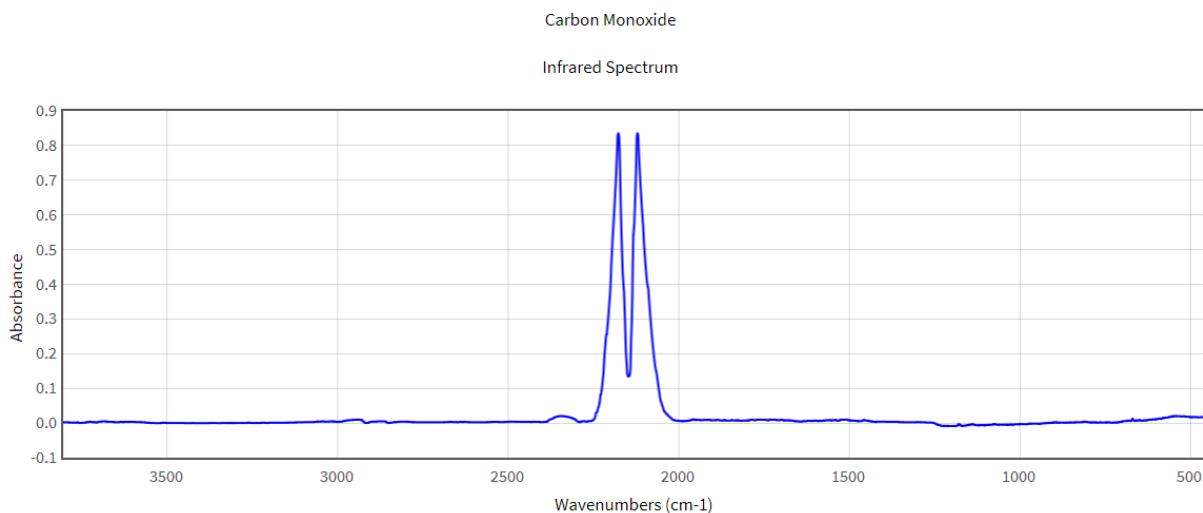


Figure 4: CO Infrared Spectrum

The CO molecules vibrate and rotate as they absorb the IR radiation and produce a corresponding ‘fingerprint’ which is different for the spectra of other gases. The peak heights in absorbance scale are also proportional to gas concentration. When the DX4040 identifies a gas, it compares it to a reference spectrum. The reference spectrum is a spectrum of known concentration of the identified gas and by comparing the peaks the DX4040 can quantify the concentration. For instance, if the absorption due to CO in the sample is 1.2 times that of a 10 ppm CO reference spectrum, the concentration of CO is 12 ppm. The Gasmeter DX4040 gas analyzer collects a complete infrared spectrum 10 times per second (6; 10).

2.6 Case studies

The slow release of CO₂ and CO from fresh roasted coffee beans can lead to an IDLH environment if large enough quantities of coffee are stored in a relatively small unventilated space. The ignorance to this fact has led to multiple accidents, with several resulting in fatalities.

According to Newton J, in 2002, at a coffee roasting plant, a worker entered a coffee roasting holding tank to clean the tank of liquid coffee extract. 18 minutes after entering the employee collapsed and lost consciousness. Two employees were able to remove their collapsed colleague without collapsing themselves and call the fire department. The fire department administered 100% oxygen to the unconscious employee and transported him to the hospital where he was found to have COHb levels of 27.1%. Through the administration of 100% oxygen, the worker was able to reduce his COHb levels and was ultimately saved. OSHA was notified by local fire department of CO poisoning when their gas analysis found the coffee storage tank to have CO in excess concentrations of 1000 ppm. After OSHA conducted their investigation, they concluded that the source of the CO was the roasted coffee beans. Prior to the beginning the inspection, however, they were not able to find any references in literature to support the hypothesis that the coffee roasting process produces carbon monoxide (21).

In 2003, a report by Nishimura F, described a situation involving the fatality of a 23-year-old employee of a coffee roasting plant who collapsed and lost consciousness soon after entering a storage tank (approximately 2 m in diameter and 2.7 m in height) to retrieve a tool. He was found and removed 40 minutes later in a state of cardiopulmonary arrest. Resuscitation attempts, including cardiac compression and administration of 100% oxygen, were unsuccessful. With COHb levels at 26%, the worker died of CO poisoning. Five coworkers were transported to nearby hospitals, three of who had collapsed and lost consciousness when they went inside or

approached the tank. Air samples from within the storage tank were subsequently collected during coffee roasting to determine the levels of CO in the tank. Results indicated that CO levels in the tank were between 10,000 to 100,000 ppm (22).

As described by CDR Morrison, a similar scenario occurred on the USS George H. W. Bush (CVN 77) in 2018. In this case about 200 boxes of coffee totaling 4000 pounds had been stored in a compartment with no mechanical ventilation. The space was 5500 ft³ in volume, but approximately 3125 ft³ of items were in the space displacing 56% of the available air in the compartment. This poorly ventilated space had not been accessed for 48 hours, which allowed high concentrations of CO to accumulate. When a group of 6 Sailors entered the space, some began to feel ill, with several losing consciousness. Later investigation of the space with a multi-gas meter recorded levels of carbon monoxide of at least 1200 ppm, which was the upper limit of detection for the gas analyzing equipment being used (18). It is likely that the levels of CO were far greater than the 1200 ppm maximum concentration that the gas analyzing equipment could reliably detect and quantify.

The specific nature of the hazards of coffee storage are not fully understood, as no literature was found that accurately defines the emission rates of CO₂ and CO (17; 18). The unknown behavior of the emissions of CO and CO₂ from roasted coffee beans and the potential for accumulation of dangerous concentrations of these gasses in confined unventilated spaces are major issues that need to be addressed and further investigated. The intent of this study is to provide initial profiling quantification of the emissions of CO and CO₂ from roasted coffee beans in order to urge the development of safety policies and practices for the storage of this product.

2.7 Other Literature

Anderson's 2003, "Diffusion kinetics of carbon dioxide in fresh roasted and ground coffee," investigated the diffusion kinetics and the specific transport mechanisms of CO₂ from freshly roasted and ground coffee. It was discussed that during the roasting of coffee beans, a large amount (up to 10 ml of carbon dioxide can be produced per gram) of roasted coffee of CO₂ is generated about 87% of gaseous compounds released. The amount of CO₂ produced during roasting depends upon the type of coffee and the roast conditions. The CO₂ is formed as a result of the many reactions that occur including Strecker degradation, pyrolysis of sugars, and the Maillard reaction. The CO₂ formed is trapped in the coffee and slowly diffuses out after roasting. Their results indicated that a darker roast contains more CO₂ initially than does a lighter roast and that coffee stored at higher temperatures off gassed CO₂ at a faster rate than coffee stored at lower temperatures (3).

Xiuju Wang X and Loong-Tak Lim's 2014 article, "Effect of Roasting Conditions on Carbon Dioxide Degassing Behavior in Coffee," and follow on article, "Investigation of CO₂ precursors in roasted coffee" describe how during a typical roasting process, coffee beans swell 40~60% at about 20% roast loss and that the porous structure developed traps CO₂ which is slowly released over time. The studies sought to investigate the CO₂ formation and degassing behaviors and determine the precursors to CO₂ in roasted coffee. Among their findings, it was concluded that the amount of CO₂ retained in the coffee beans after roasting is strongly dependent on the degree of roast, that darker roasts evolved more CO₂ and off gassed at a higher rate relative to lighter roasts of coffee (29; 30).

The technical paper, "Carbon monoxide emission rates from roasted whole bean and ground coffee," by Ryan F. LeBouf and Michael Aldridge in 2018 estimate emission factors

from commercially available whole bean and ground coffee measured in unpackaged, loose form. The study looked at the effects of form (whole or ground), roast (light, medium, dark), and time since opening of package on CO emission rates. The study looked a variety of coffee samples from a variety of manufacturers purchased from local grocery stores and online. The study monitored the CO emissions from the coffee for approximately 1.5 hours and concluded that ground coffee has higher CO emission rates than whole bean coffee and that roast level did not significantly affect emission rates in whole coffee beans (15).

CHAPTER 3: Materials and Methods

3.1 Method Overview

In order to answer all the research questions posed in the current study, a method was developed in order to monitor the emissions of fresh roasted coffee beans over time. Storage of the fresh roasted beans required separate containers whose atmospheres were periodically sampled for change in concentration of CO and CO₂. A local coffee roaster in Rockville Maryland, MAYORGA Organics, roasted a dark and light roast of their Peru COOPARM blend. After the completion of the roasting process, the coffee was transferred and stored in 950cc Amber Wide Mouth Bottles. The tops of the bottles were closed with plastic caps with an attached septum that was ultrasonically welded with a Polytetrafluoroethylene Silicone-liner (J.G. Finneran, Vineland, NJ). These bottles were divided into 21 different groups depicted in Table 2.

Table 2: Coffee Sample Groups

	Low Mass	Medium Mass	High Mass	
Light	Light Roast Low Mass Low Temperature	Light Roast Medium Mass Low Temperature	Light Roast High Mass Low Temperature	Low Temp
Light	Light Roast Low Mass Med Temperature	Light Roast Medium Mass Med Temperature	Light Roast High Mass Med Temperature	Med Temp
Light	Light Roast Low Mass High Temperature	Light Roast Medium Mass High Temperature	Light Roast High Mass High Temperature	High Temp
Dark	Dark Roast Low Mass Low Temperature	Dark Roast Medium Mass Low Temperature	Dark Roast High Mass Low Temperature	Low Temp
Dark	Dark Roast Low Mass Med Temperature	Dark Roast Medium Mass Med Temperature	Dark Roast High Mass Med Temperature	Med Temp
Dark	Dark Roast Low Mass High Temperature	Dark Roast Medium Mass High Temperature	Dark Roast High Mass High Temperature	High Temp

The groups were divided by different mass loads of coffee (low, medium, high), roast level (light dark), and storage temperature (4, 25, 38 degrees Celsius). Three replicates of each group were used for emission sampling in order to observe the variation of readings within each sample group and draw conclusions on the protocols precision and reproducibility. Samples were monitored for 22 days with the Gasmet DX4040 FTIR (Fourier Transform Infrared Spectroscopy) gas analyzer to quantify the mass per volume of CO and CO₂ generated. One-way analysis of variance (ANOVA) was performed to determine if there were significant differences

in the mean emissions due to mass and storage temperature and a t-test was performed to identify if the roast resulted in any significant difference in emissions output.

3.2 Protocol

Each 950cc bottle was labeled to include information about roast (light, or dark), coffee mass (high, medium, and low), and storage temp (cold, ambient, and hot). The label indicated roast level with “light” or “dark.” Bottles labeled “light” contained coffee that had been lightly roasted. Bottles labeled “dark” contained coffee that had been roasted dark. Bottles labeled “low” had the contained mass levels between 15 grams and 50 grams of roasted coffee beans. Bottles labeled “medium” contained mass levels between 70 grams and 100 grams of roasted coffee beans. Bottles labeled “high” contained mass levels of about 200 grams of coffee. Bottles with the labeled “cold” were stored in a refrigerator set at 4° Celsius. Bottles with the labeled “amb” were stored in an incubator set at 25° Celsius. Bottles labeled marked “hot” were stored in an incubator set at 38° Celsius.

Coffee beans were roasted by Mayorga - a local roaster - at their coffee roasting facility. They were transferred and loaded into the amber 950cc bottles the same day of the roasting. The bottles were wrapped with Teflon tape, bottle caps screwed on tightly, and stored in the appropriate refrigerator or incubator as directed by their label to await further gas emission analyzation.

In order to analyze the atmosphere in the 950cc bottles, a closed loop system was created by using $\frac{1}{4}$ in Tygon tubing to connect the inlet and outlet of the DX4040 (Figure 5). Every 48 - 72 hours, Hamilton Gastight syringes were used to withdraw a sample of atmosphere from each bottle and then injected to the Gasmeter DX4040 sample loop system for analysis. Prior to

sampling, the Gaset DX4040 was flushed with 99.9% nitrogen then, bottles were removed from refrigerators and incubators and allowed to adjust to room temperature for at least 20 minutes. Hamilton Gastight syringes were used to withdraw a sample of atmosphere from the containers and injected into the constructed loop. The internal pump in the DX4040 pumps the sample throughout the improvised closed system. At least 30 seconds were given to allow the atmosphere to equilibrate.



Figure 5: Gaset Sample Loop System

During the first week of sampling a 0.005L Hamilton Gastight syringe was used for withdrawing samples. After the first week the 0.005L Gastight syringe was unable to maintain vacuum and was switched out for a 0.000250L Hamilton Gastight syringe. For precise volume sampling, the volume of the ¼ inch tygon tubing was measured by filling it with water and measuring the dispensed volume in a graduated cylinder. To evaluate the accuracy of CO and CO₂ measurements, static atmospheres were created using Tedlar bags, Hamilton Gastight syringes, and 99.9% CO and CO₂. A known volume of CO and CO₂ was injected into the loop and the theoretical and measured value was compared. An average yield (measured value/theoretical value) of over 80% was obtained each day, indicating that the method is adequately accurate capturing CO and CO₂.

3.3 Dilution Calculations

Samples injected into the Gasmeter DX4040 loop system were immediately diluted by the volume of air contained within the Gasmeter sample cell. As a result, the displayed concentration is the concentration inside the loop. The concentration inside the bottles were back calculated using the $C_1V_1 = C_2V_2$ equation.

C_1 = The concentration inside syringe which also equals the concentration inside the bottle

V_1 = The volume of gas in the syringe

C_2 = The concentration in the Gasmeter Loop

V_2 = The volume in the Gasmeter Loop

Chapter 4: Results

4.1 Sampling Results

In this study, the objective was to investigate the effect that mass, storage temperature, and roast type had on emissions of CO₂ and CO from roasted coffee beans. The sealed containers containing the coffee samples had their concentrations of CO and CO₂ and monitored for 22 days. Comparison of the differences of each variable made during this experiment are discussed in the following sections. Extended raw data of each sample day can be found in Appendix 2, extra charts in Appendix 4 and the extended statistical results of this test can be found in Appendix 3.

4.1.2 Effects of Mass on Concentration

To investigate the relationship between coffee mass and the concentration of CO and CO₂, average concentrations of CO and CO₂ for all monitored masses were compared each day after controlling for roast and storage temperature. The differences had an overall trend of an increase in coffee mass correlating with in an increase in average CO and CO₂ concentration which can be seen in Table 3 and 4, confirming the hypothesis that an increase in the amount of coffee beans mass will result in increased CO₂ and CO emissions. More tables and charts of the comparisons can be found in Appendix 4. A one-way ANOVA was performed using IBM's statistical software package, SPSS Version 25. The analysis found that mass had a significant influence on CO and CO₂ concentrations within the sampling containers (89% of comparisons had $p < 0.05$). Meaning the different averages of each triplicate group were unlikely to be the result of chance.

Table 3: Average CO Concentrations over time reported in PPM

Averages of Sample Containers Stored at 4° Celsius									
		Average CO Concentration in PPM per sampling day							
Roast	Target Mass (g)	2	4	6	9	12	15	18	22
Light	50	1.24	56.05	186.84					
Light	100	84.45	112.41	257.37					
Light	200	247.07	322.36	558.04					
Dark	50	3969.37	4528.88	9182.87	9496.53	10550.88	12299.09	12528.00	12651.73
Dark	100	8119.38	11352.69	19715.05	16450.35	19883.88	20886.19	23045.33	22729.81
Dark	200	13773.69	22058.49	15320.97	16555.52	44633.16	45422.51	41227.95	39508.05
Averages of Sample Containers Stored at 25° Celsius									
		Average CO Concentration in PPM per sampling day							
Roast	Target Mass (g)	2	4	6	9	12	15	18	22
Light	25	3.65	69.37	9.28					
Light	75	130.23	321.43	66.20					
Light	200	524.32	517.14	1340.34	810.45	771.12	1781.76	637.23	1398.19
Dark	25	4428.73	5024.65	3408.85	7380.69	6780.96	6069.12	6359.89	6019.63
Dark	75	10455.78	9421.61	16741.12	22117.33	21083.40	23960.96	19896.32	18343.47
Dark	200	25262.33	37667.23	57347.93	67069.65	67228.20	63852.59	59392.00	53922.99
Averages of Sample Containers Stored at 38° Celsius									
		Average CO Concentration in PPM per sampling day							
Roast	Target Mass (g)	2	4	6	9	12	15	18	22
Light	25	163.64	139.97	186.84					
Light	75	336.86	344.66	506.38					
Light	190	954.60	775.72	1435.00	958.93	324.36	1528.11	1076.48	1701.33
Dark	15	4351.39	3403.86	4499.56	3891.41	3580.20	5314.35	4578.13	4602.88
Dark	75	25373.07	19602.21	23289.09	26120.11	32240.16	33265.71	29139.20	27864.75
Dark	200	64109.95	33262.54	51970.17	70113.49	62411.76	64514.56	55958.40	51268.91

Table 4: Average CO₂ Concentrations over time reported in PPM

Averages of Sample Containers Stored at 4° Celsius									
		Average CO ₂ Concentration in PPM per sampling day							
Roast	Mass (g)	2	4	6	9	12	15	18	22
Light	50	6238.63	11612.19	18241.08	42100.27	45961.20	5549.44	50594.56	50712.11
Light	100	16915.58	20181.60	39433.50	72062.29	100937.16	67638.83	93919.79	93530.03
Light	200	38113.58	42929.40	64225.33	111854.93	175576.68	89217.92	190543.15	186738.35
Dark	50	42266.07	42106.62	79379.88	148548.05	155913.12	120893.65	161280.21	152303.36
Dark	100	82798.63	104671.67	159314.71	236615.25	270699.84	250556.29	265179.09	243767.04
Dark	200	137402.77	187127.85	119771.08	217894.40	542482.92	496882.13	452418.56	410411.09
Averages of Sample Containers Stored at 25° Celsius									
		Average CO ₂ Concentration in PPM per sampling day							
Roast	Mass (g)	2	4	6	9	12	15	18	22
Light	25	5228.04	10366.40	8593.90	24629.12	31952.52	22166.83	32133.55	32752.21
Light	75	18445.86	39103.16	19224.76	75687.68	92901.60	76164.05	97143.04	94897.28
Light	200	57472.90	52233.95	120649.28	264578.99	285087.96	68758.61	284784.64	280361.17
Dark	25	38078.93	38387.52	24953.61	138927.79	97020.36	75508.27	70930.13	63506.13
Dark	75	82895.46	69875.66	120422.23	258485.12	250669.08	266187.52	209369.17	175905.49
Dark	200	187609.43	245254.14	340318.02	657797.33	475713.72	45620.48	507319.04	439494.61
Averages of Sample Containers Stored at 38° Celsius									
		Average CO ₂ Concentration in PPM per sampling day							
Roast	Mass (g)	2	4	6	9	12	15	18	22
Light	25	13387.95	13791.93	27850.83	33191.47	26615.88	42836.48	34305.07	31762.35
Light	75	37748.26	34827.90	45223.30	75508.27	151641.36	139150.51	112949.97	114781.23
Light	190	85887.95	66659.47	116733.43	268359.04	177816.60	291732.27	267659.95	241335.68
Dark	15	35799.15	26135.25	37570.08	63722.67	54963.72	63085.44	47847.68	41314.56
Dark	75	188507.73	131249.74	140641.18	260099.84	318815.28	312377.17	229624.32	200936.75
Dark	200	431743.65	192416.96	269823.42	623077.76	523204.92	526188.37	398180.05	327194.24

4.1.3 CO₂ and CO emissions ratio

CO₂ emissions were divided by CO emissions with the results in Tables 5. There is no consistent ratio throughout which rejects the hypothesis that roasted coffee beans off-gas CO₂ and CO in a ratio of 10:1. Trends observed are light roasts emit a larger ratio of CO₂:CO than dark roasts, higher storage temperature results in a lower emissions ratio of CO₂:CO, increasing mass lowers the emission ratio of CO₂:CO, and the emissions ratio of CO₂:CO slowly decreases overtime aside from a jump on day 9. An example of the decrease in emissions ratio of CO₂:CO with increasing temperature can be seen visually in Figure 6 where the quotient of the emissions of CO₂ and CO are plotted over time for 200g of dark roasted coffee beans stored in 4°C, 25°C, and 38°C. More comparison tables and charts can be found in appendix A4.2.

Table 5: CO₂/CO emissions in ppm

Roast	Target Mass	Storage Temp	Day							
			2	4	6	9	12	15	18	22
Light	50	4	5042.00	207.18	97.63					
Light	100	4	200.31	179.54	153.22					
Light	200	4	139.07	133.17	115.09					
Light	25	25	1432.29	149.45	926.07					
Light	75	25	141.64	121.65	290.42					
Light	200	25	109.61	101.00	90.01	326.46	369.71	38.59	446.91	200.52
Light	25	38	81.81	98.54	149.06					
Light	75	38	112.06	101.05	89.31					
Light	190	38	89.97	85.93	81.35	279.85	548.21	190.91	248.64	141.85
Dark	50	4	10.65	9.30	8.64	15.64	14.78	9.83	12.87	12.04
Dark	100	4	10.20	9.22	8.08	14.38	13.61	12.00	11.51	10.72
Dark	200	4	9.98	8.48	7.82	13.16	12.15	10.94	10.97	10.39
Dark	25	25	8.60	7.64	7.32	18.82	14.31	12.44	11.15	10.55
Dark	70	25	7.93	7.42	7.19	11.69	11.89	11.11	10.52	9.59
Dark	200	25	7.43	6.51	5.93	9.81	7.08	0.71	8.54	8.15
Dark	15	38	8.23	7.68	8.35	16.38	15.35	11.87	10.45	8.98
Dark	75	38	7.43	6.70	6.04	9.96	9.89	9.39	7.88	7.21
Dark	200	38	6.73	5.78	5.19	8.89	8.38	8.16	7.12	6.38

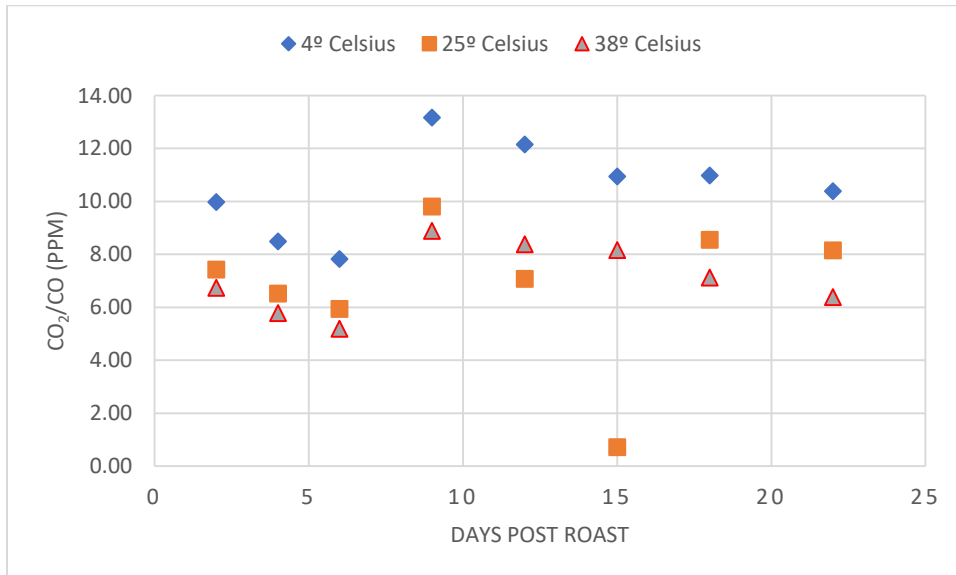


Figure 6: CO₂/CO emissions per day of 200g Dark Coffee Bean Samples

Effect of Storage Temperature on Concentration

To investigate the relationship between storage temperature and the concentration of CO and CO₂, average concentrations of CO and CO₂ for different storage temperatures were compared each day after controlling for roast and mass. A table of the average concentration per day for different temperatures when controlling for mass and roast shown on Table 6.

Table 6: CO and CO₂ Average Concentration in PPM at a given Temperature in °C

		Day							
Average Concentrations from 25g Light Roasted Samples									
Gas	Temperature (°C)	2	4	6	9	12	15	18	22
CO	25	3.65	69.37	9.28					
CO	38	163.64	195.09	186.84					
CO ₂	25	5228.04	10366.40	8593.90	24629.12	31952.52	27246.08	32133.55	32752.21
CO ₂	38	15104.13	16815.36	31796.06	33191.47	26615.88		34305.07	31762.35
Average Concentrations from 75g Light Roasted Samples									
CO	25	130.23	406.90	66.20					
CO	38	336.86	344.66	614.80			1095.04		
CO ₂	25	18445.86	47799.84	19224.76	75687.68	111445.20		97143.04	94897.28
CO ₂	38	33864.11	34827.90	45223.30	97588.48	151641.36	139150.51	112949.97	114781.23
Average Concentrations from 200g Light Roasted Samples									
CO	4	274.07	322.36	679.30					
CO	25	524.32	517.14	1340.34	810.45	771.12	1781.76	637.23	1398.19
CO	38	954.60	775.72	1435.00	1122.88	486.54	1317.76	965.12	1271.36
CO ₂	4	34922.032	42929.4	75219.968	144424.64	175576.68		190543.15	186738.347
CO ₂	25	57472.896	52233.954	120649.28	264578.99	285087.96	68758.613	284784.64	280361.173
CO ₂	38	67119.92	66659.466	116733.43	268359.04	221017.68	291732.27	267659.95	241335.68
Average Concentrations from 75g Dark Roasted Samples									
CO	25	6479.30	9421.61	16741.12	22117.333	21083.4	23960.96	19896.32	18343.47
CO	38	25373.07	19602.21	27369.97	32062.4	32240.16	33265.707	29139.2	29890.88
CO ₂	25	52283.52	69875.66	137112.46	258485.12	250669.08	266187.52	209369.17	175905.49
CO ₂	38	188507.73	131249.74	160081.39	318823.68	318815.28	312377.17	229624.32	200936.75
Average Concentrations from 200g Dark Roasted Samples									
CO	4	13773.69	18821.54	15320.97	21668.80	44633.16	45422.51	41227.95	39508.05
CO	25	25262.33	37667.23	57347.93	67069.65	67228.20	63852.59	59392.00	53922.99
CO	38	72318.11	33262.54	51970.17	70113.49	62411.76	64514.56	55958.40	51268.91
CO ₂	4	137402.77	155428.2	119771.08	217894.4	542482.92	496882.13	452418.56	410411.09
CO ₂	25	187609.43	245254.14	340318.02	712973.12	632401.02		507319.04	439494.61
CO ₂	38	431743.65	211450.62	322017.39	623077.76	523204.92	526188.37	398180.05	327194.24

For the light roasted coffee samples at 25g, all of the average concentrations recorded for CO for the sample containers stored at 38°C were higher each day than the concentrations

recorded for samples stored in 25°C incubators which can be seen in Figure 8. However, after performing an ANOVA only the averages from the first day were significantly different ($p < .05$). The higher p values ($p = 0.480$ for 4 days post roast and $p = 0.116$ for 6 days post roast) for the remaining two days mean differences in the average reading for CO emissions during day 4 and 6 post roast could be due to the result of chance.

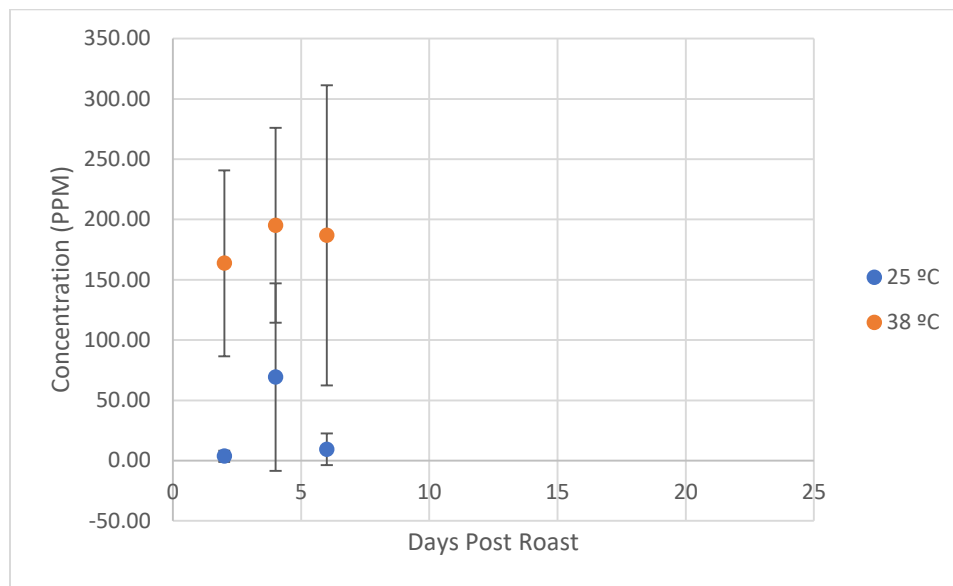


Figure 7: CO Concentrations in 25g Light Roast Coffee Samples at Different Storage

The average concentrations of CO₂ for the samples stored at 38°C were higher for 5 out of the 7 days than the concentrations recorded for samples stored in 25°C incubators which can be seen in Figure 9. The differences were significant on day 2, 6, 9 after roasting all which had a higher concentration for CO₂ for the higher temperature stored samples.

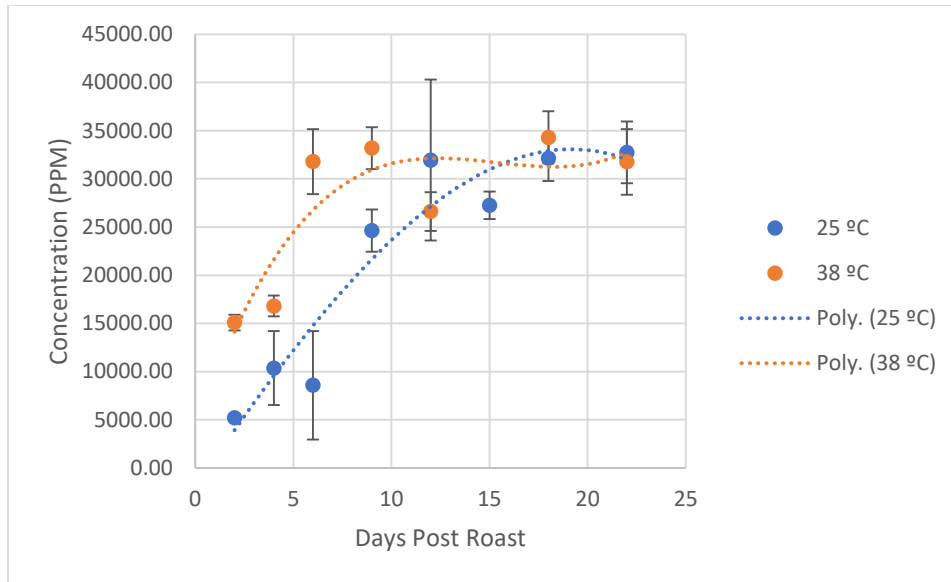


Figure 8: CO₂ Concentrations in 25g Light Roast Coffee Samples at Different Storage

For containers that had 75g of light roasted coffee beans (Figure 10), average sample CO emissions have a positive correlation with increased temperature for 2 out of the 3 days where comparisons could be made; both of which had p-values less than 0.05. On emission samples taken 4 days post roast, average CO concentrations for containers stored in the 25°C and 38°C incubators were about 407ppm and 345ppm respectively. The difference in averages was not significantly different with a p- value = 0.809.

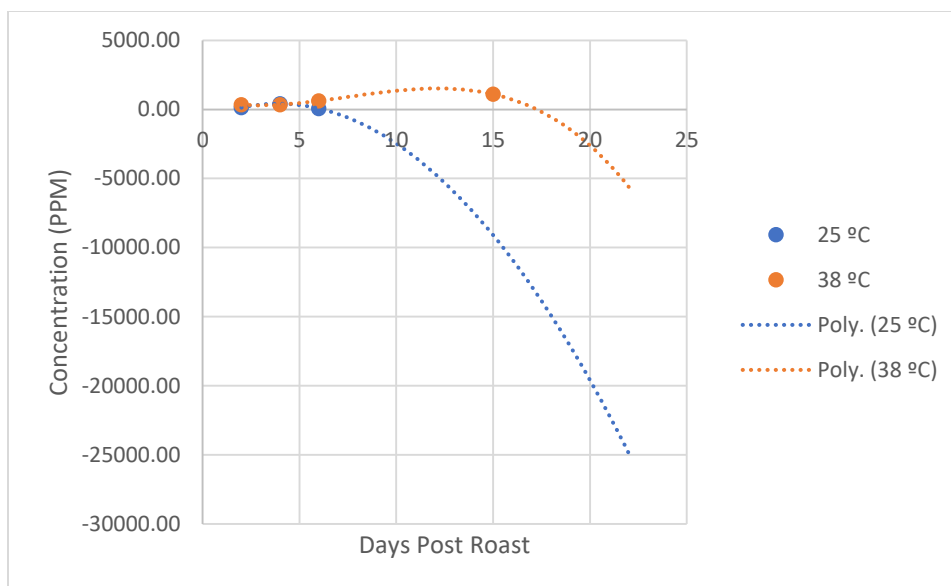


Figure 9: CO Concentrations in 75g Light Roast Coffee Samples at Different Storage

As depicted in Figure 11, average CO₂ emissions in the containers with 75g of light roasted coffee beans had a positive correlation with increased temperature for 5 out of the 7 days where comparisons could be made, one of which was significantly different. Of the 2 days where increased storage temperature had a negative correlation with increased CO₂ emissions, neither of those data sets were statistically different.

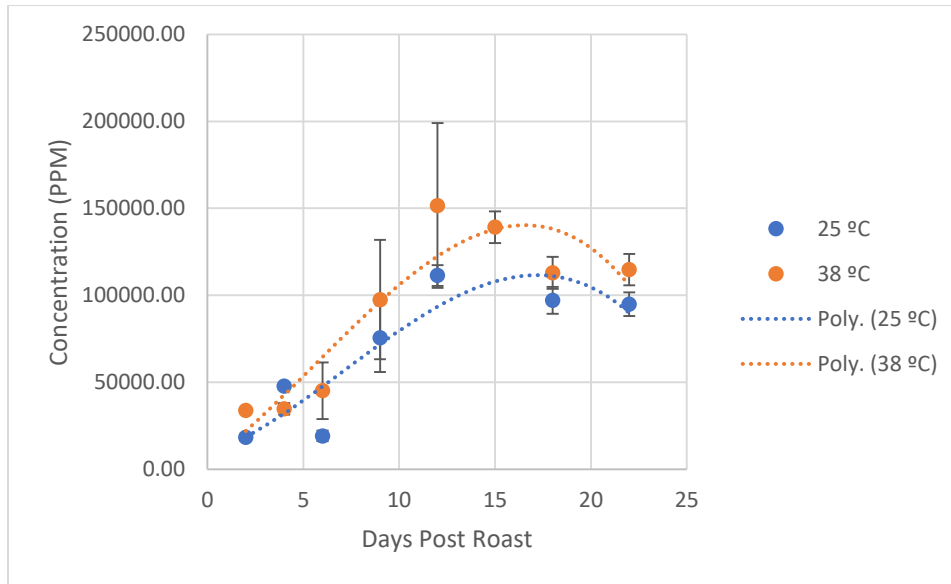


Figure 10: CO₂ Concentrations in 75g Light Roast Coffee Samples at Different Storage

For containers with 75g of dark roasted coffee, temperature had a positive correlation with increased average CO and CO₂ readings for all 8 days as seen in Figure 12 and 13. For CO emissions 6 of 8 days had significantly different averages and for CO₂ emissions 2 of the 8 days had significantly different averages.

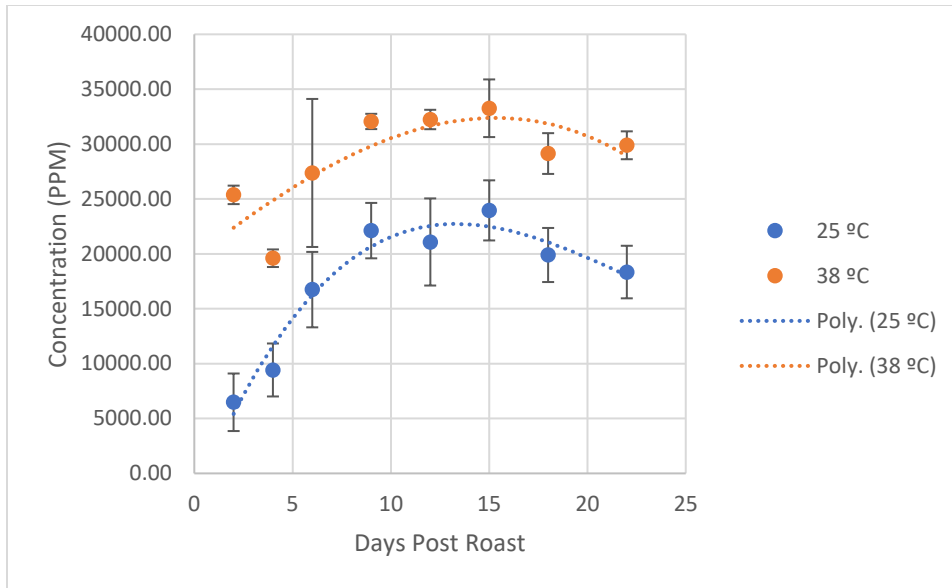


Figure 11: CO Concentrations in 75g Dark Roast Coffee Samples at Different Storage

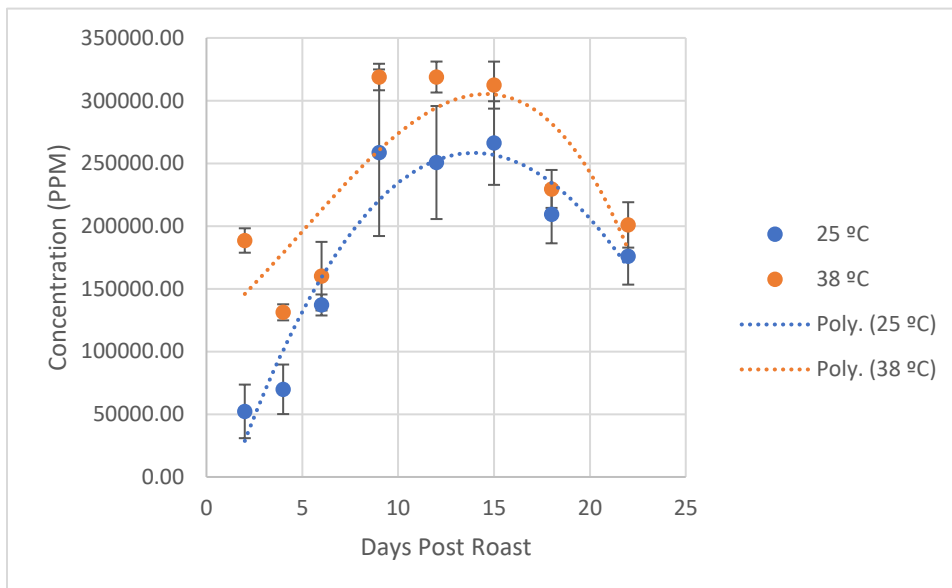


Figure 12: CO₂ Concentrations in 75g Dark Roast Coffee Samples at Different Storage

For containers that had 200g of light roasted coffee beans, average sample CO emissions had a positive correlation with increased temperature for 5 out of the 8 sample days (days 2, 4, 6,

9, 18) as shown in Figure 14. Of which 3 of the differences were significantly different. Of the 3 days where CO emissions had a negative correlation with increased temperature, 2 of those differences were significantly different.

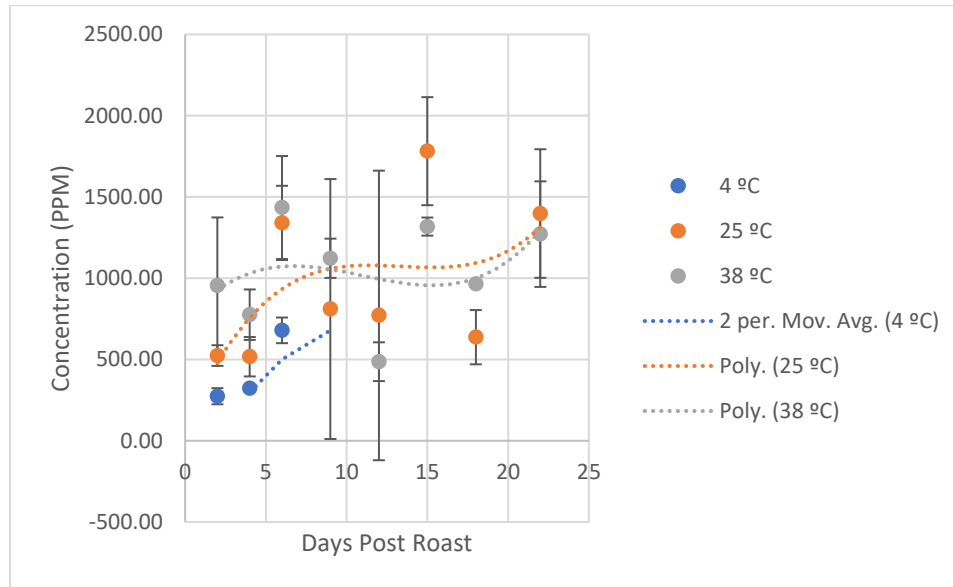


Figure 13: CO Concentrations in 200g Light Roast Coffee Samples at Different Storage

CO₂ emissions were positively correlated with increased storage temperatures for 3 out of the 7 sample days (ignoring day 15) as shown in Figure 15. Of the 3 compared averages where CO₂ emissions were positively correlated with increased storage temperatures 2 were significantly different. There were 4 days where average CO emissions had a negative correlation with increased temperature all of which were significantly different.

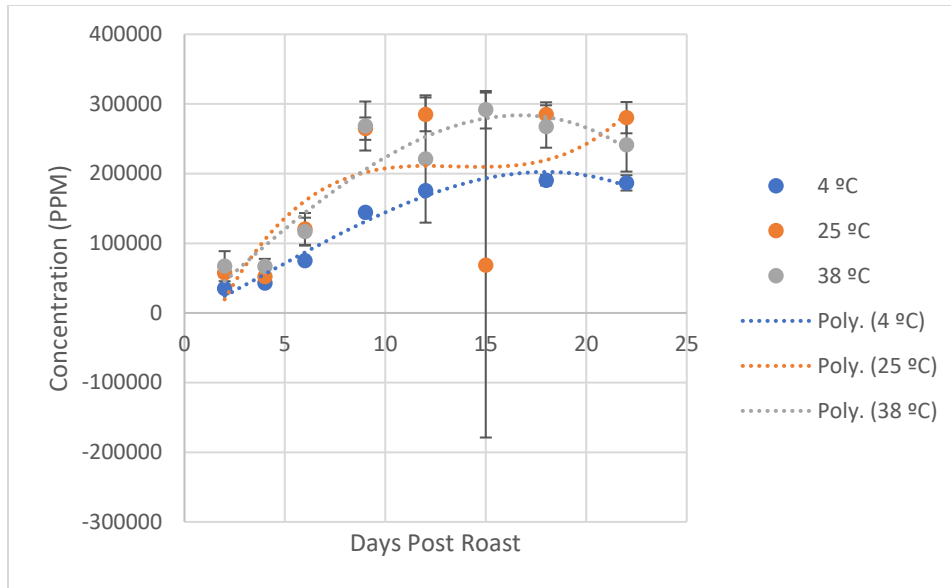


Figure 14: CO₂ Concentrations in 200g Light Roast Coffee Samples at Different Storage

Containers with samples of 200g of dark roasted coffee beans had CO emissions that positively correlated with increased storage temperatures for 3 out of the 8 sample day as can be seen in Figure 16. Of the 2 compared averages where CO emissions were positively correlated with increased storage temperatures were significantly different. There were 5 days where average CO emissions had a negative correlation with increased temperature 1 of which where the differences in averages were significantly different.

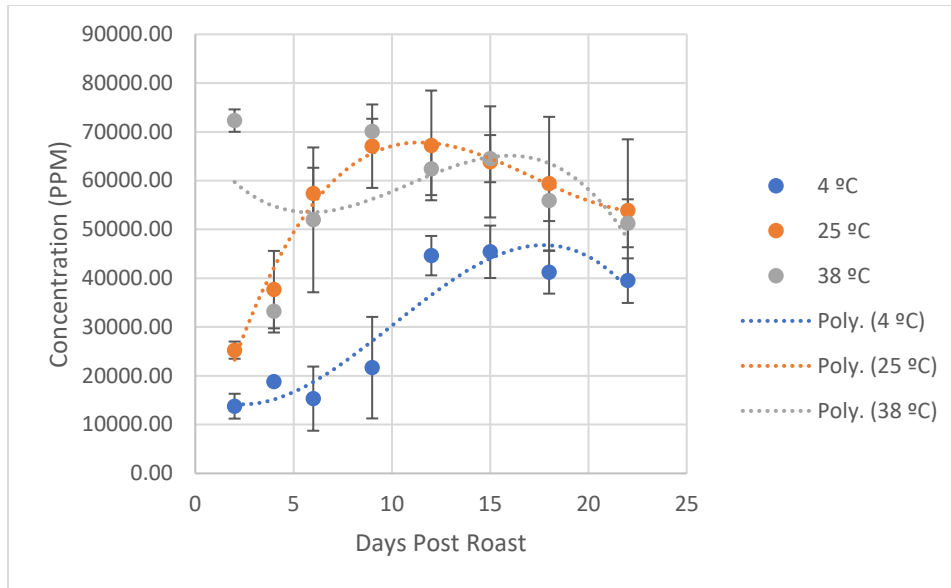


Figure 15: CO Concentrations in 200g Dark Roast Coffee Samples at Different Storage

CO₂ only 3 of the 7 sample periods. CO₂ emissions positively correlated with increased storage temperatures for 1 out of the 7 compared sample days (ignoring day 15) as shown in Figure 17. This difference was significantly different and 2 of the 6 days where the compared averages of CO₂ emissions showed a negative correlation with increase in temperature were significantly different. The variation between the containers stored at 25°C and 38°C just became insignificant.

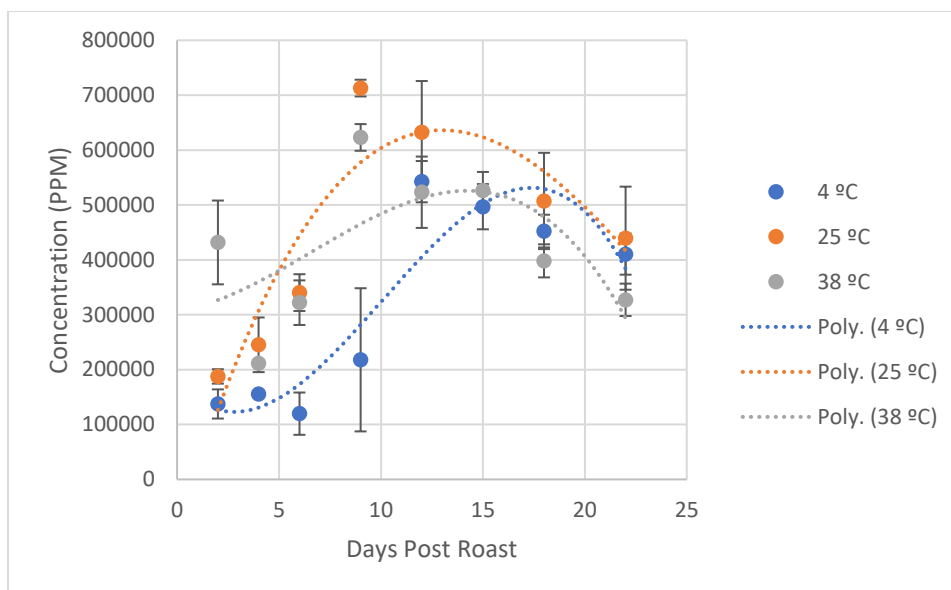


Figure 16: CO₂ Concentrations in 200g Light Roast Coffee Samples at Different Storage

The differences generally showed a trend that increased storage temperature correlated with an increase in average CO and CO₂ emissions. There was much variation in the data especially with respect to CO₂ and differences seemed to get smaller as concentrations appeared to level off in the later sample days. This could be the result of an equilibrium of concentration of CO and CO₂ being reached between the inside and outside of the coffee beans. As this equilibrium is reached and off gassing slows temperature may have little difference in the equilibrium concentration. For CO, 72% of the compared averages suggested that there was a positive correlation between increased storage temperature and increased emissions. That number rises to 82% when looking at statistically significant data. For CO₂ 61% of the compared averages suggested there was a positive correlation between increased storage temperature and increased CO₂ emissions and falls to just 60% when looking only at statistically significant data. This points to an indication that an increase in storage temperature of coffee beans will result in increased CO₂ and CO concentrations, but more testing should be done to

definitively answer the question. Tukey Post Hoc testing results for 200g Dark roast samples are located in Appendix 3.

Effect of Roast on Concentration

To investigate the relationship between roast and concentration, Table 7 and 8 show side by side comparisons between equivalently weighted and stored samples of light and dark roasted coffee beans with a calculated ratio. Comparison plots can also be seen in figures 18-35. A t-test was also performed to confirm that the differences observed were significant. The results indicated that dark roasts produce significantly more CO and CO₂ emissions than light roasts. The full t-test report can be seen in Appendix 3.

Table 7: Comparison between Light and Dark Roasts of CO Concentrations in PPM

Carbon Monoxide				Day							
Roast	Mass	Temp		2	4	6	9	12	15	18	22
Light	50.00g	4 °C		1.24	56.05	186.84	0.00	0.00	0.00	0.00	0.00
Dark	49.87g	4 °C		3969.37	4528.88	9182.87	9496.53	10550.88	12299.09	12528.00	12651.73
			Difference	3968.13	4472.83	8996.03	9496.53	10550.88	12299.09	12528.00	12651.73
			Ratio	3208.00	80.80	49.15					
Light	100.03g	4 °C		84.45	112.41	257.37	0.00	0.00	0.00	0.00	0.00
Dark	100.46g	4 °C		8119.38	11352.69	19715.05	16450.35	19883.88	20886.19	23045.33	22729.81
			Difference	8034.93	11240.28	19457.69	16450.35	19883.88	20886.19	23045.33	22729.81
			Ratio	96.15	100.99	76.60					
Light	199.92g	4 °C		274.07	322.36	558.04	0.00	30.60	0.00	98.99	0.00
Dark	200.90g	4 °C		13773.69	22058.49	15320.97	16555.52	44633.16	45422.51	41227.95	39508.05
			Difference	13499.62	21736.12	14762.93	16555.52	44602.56	45422.51	41128.96	39508.05
			Ratio	50.26	68.43	27.46				416.50	
Light	25.30g	25 °C		3.65	69.37	9.28	0.00	0.00	0.00	0.00	0.00
Dark	24.27g	25 °C		4428.73	5024.65	3408.85	7380.69	6780.96	6069.12	6359.89	6019.63
			Difference	4425.08	4955.29	3399.57	7380.69	6780.96	6069.12	6359.89	6019.63
			Ratio	1213.31	72.44	367.33					
Light	75.22g	25 °C		130.23	321.43	66.20	0.00	0.00	0.00	0.00	0.00

Dark	71.25g	25 °C		10455.78	9421.61	16741.12	22117.33	21083.40	23960.96	19896.32	18343.47
			Difference	10325.55	9100.17	16674.92	22117.33	21083.40	23960.96	19896.32	18343.47
			Ratio	80.29	29.31	252.90					
Light	199.55g	25 °C		524.32	517.14	1340.34	810.45	771.12	1781.76	637.23	1398.19
Dark	200.32g	25 °C		25262.33	37667.23	57347.93	67069.65	67228.20	63852.59	59392.00	53922.99
			Difference	24738.01	37150.09	56007.58	66259.20	66457.08	62070.83	58754.77	52524.80
			Ratio	48.18	72.84	42.79	82.76	87.18	35.84	93.20	38.57
Light	25.77g	38 °C		163.64	139.97	186.84	0.00	0.00	0.00	0.00	0.00
Dark	14.74g	38 °C		4351.39	3403.86	4499.56	3891.41	3580.20	5314.35	4578.13	4602.88
			Difference	4187.75	3263.89	4312.73	3891.41	3580.20	5314.35	4578.13	4602.88
			Ratio	26.59	24.32	24.08					
Light	74.96g	38 °C		336.86	344.66	506.38	0.00	0.00	866.13	0.00	0.00
Dark	75.57g	38 °C		25373.07	19602.21	23289.09	26120.11	32240.16	33265.71	29139.20	27864.75
			Difference	25036.20	19257.55	22782.71	26120.11	32240.16	32399.57	29139.20	27864.75
			Ratio	75.32	56.87	45.99					
Light	189.26g	38 °C		954.60	775.72	1435.00	958.93	324.36	1528.11	1076.48	1701.33
Dark	201.71g	38 °C		64109.95	33262.54	51970.17	70113.49	62411.76	64514.56	55958.40	51268.91
			Difference	63155.35	32486.82	50535.17	69154.56	62087.40	62986.45	54881.92	49567.57
			Ratio	67.16	42.88	36.22	73.12	192.42	42.22	51.98	30.13

Table 8: Comparison between Light and Dark Roasts of CO₂ Concentrations in PPM

Carbon Dioxide				Day							
Roast	Mass	Temp		2	4	6	9	12	15	18	22
Light	50.00g	4 °C		6238.63	11612.19	18241.08	42100.27	45961.20	5549.44	50594.56	50712.11
Dark	49.87g	4 °C		42266.07	42106.62	79379.88	148548.05	155913.12	120893.65	161280.21	152303.36
			Difference	36027.43	30494.43	61138.81	106447.79	109951.92	115344.21	110685.65	101591.25
			Ratio	6.77	3.63	4.35	3.53	3.39	21.78	3.19	3.00
Light	100.03g	4 °C		16915.58	20181.60	39433.50	72062.29	100937.16	67638.83	93919.79	93530.03
Dark	100.46g	4 °C		82798.63	104671.67	159314.71	236615.25	270699.84	250556.29	265179.09	243767.04
			Difference	65883.05	84490.07	119881.21	164552.96	169762.68	182917.46	171259.31	150237.01
			Ratio	4.89	5.19	4.04	3.28	2.68	3.70	2.82	2.61
Light	199.92g	4 °C		38113.58	42929.40	64225.33	111854.93	175576.68	89217.92	190543.15	186738.35
Dark	200.90g	4 °C		137402.77	187127.85	119771.08	217894.40	542482.92	496882.13	452418.56	410411.09
			Difference	99289.19	144198.45	55545.75	106039.47	366906.24	407664.21	261875.41	223672.75
			Ratio	3.61	4.36	1.86	1.95	3.09	5.57	2.37	2.20
Light	25.30g	25 °C		5228.04	10366.40	8593.90	24629.12	31952.52	22166.83	32133.55	32752.21
Dark	24.27g	25 °C		38078.93	38387.52	24953.61	138927.79	97020.36	75508.27	70930.13	63506.13
			Difference	32850.89	28021.12	16359.71	114298.67	65067.84	53341.44	38796.59	30753.92
			Ratio	7.28	3.70	2.90	5.64	3.04	3.41	2.21	1.94

Light	75.22g	25 °C		18445.86	39103.16	19224.76	75687.68	92901.60	76164.05	97143.04	94897.28
Dark	71.25g	25 °C		82895.46	69875.66	120422.23	258485.12	250669.08	266187.52	209369.17	175905.49
			Difference	64449.60	30772.51	101197.47	182797.44	157767.48	190023.47	112226.13	81008.21
			Ratio	4.49	1.79	6.26	3.42	2.70	3.49	2.16	1.85
Light	199.55g	25 °C		57472.90	52233.95	120649.28	264578.99	285087.96	68758.61	284784.64	280361.17
Dark	200.32g	25 °C		187609.43	245254.14	340318.02	657797.33	475713.72	45620.48	507319.04	439494.61
			Difference	130136.53	193020.19	219668.74	393218.35	190625.76	-23138.13	222534.40	159133.44
			Ratio	3.26	4.70	2.82	2.49	1.67	0.66	1.78	1.57
Light	25.77g	38 °C		13387.95	13791.93	27850.83	33191.47	26615.88	42836.48	34305.07	31762.35
Dark	14.74g	38 °C		35799.15	26135.25	37570.08	63722.67	54963.72	63085.44	47847.68	41314.56
			Difference	22411.20	12343.31	9719.25	30531.20	28347.84	20248.96	13542.61	9552.21
			Ratio	2.67	1.89	1.35	1.92	2.07	1.47	1.39	1.30
Light	74.96g	38 °C		37748.26	34827.90	45223.30	75508.27	151641.36	139150.51	112949.97	114781.23
Dark	75.57g	38 °C		188507.73	131249.74	140641.18	260099.84	318815.28	312377.17	229624.32	200936.75
			Difference	150759.48	96421.84	95417.89	184591.57	167173.92	173226.67	116674.35	86155.52
			Ratio	4.99	3.77	3.11	3.44	2.10	2.24	2.03	1.75
Light	189.26g	38 °C		85887.95	66659.47	116733.43	268359.04	177816.60	291732.27	267659.95	241335.68
Dark	201.71g	38 °C		431743.65	192416.96	269823.42	623077.76	523204.92	526188.37	398180.05	327194.24
			Difference	345855.70	125757.49	153089.99	354718.72	345388.32	234456.11	130520.11	85858.56
			Ratio	5.03	2.89	2.31	2.32	2.94	1.80	1.49	1.36

Figure 18 compares average concentration measurements of CO for light and dark roasts of 50g of coffee beans stored at 4°C. All dark roast average concentration measurements are larger than light roast average concentration measurements with a minimum difference of about 4000 ppm and all average dark roast concentrations being at least 50 times greater than light roast concentrations.

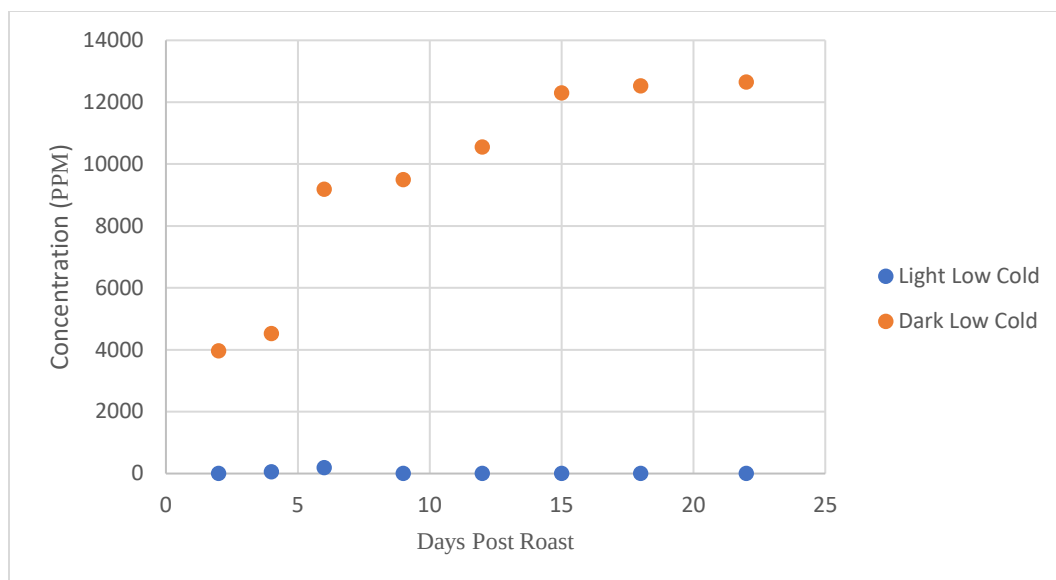


Figure 17: Concentration of CO of 50g of Light and Dark Coffee stored at 4°C

Figure 19 compares average concentration measurements of CO₂ for light and dark roasts of 50g of coffee beans stored at 4°C. All dark roast average concentration measurements are at least 3 times larger than light roast average concentration measurements with a minimum difference of over 30,000ppm. Day 15 shows the expected dip in CO₂ concentration readings due to the instrument error on that day.

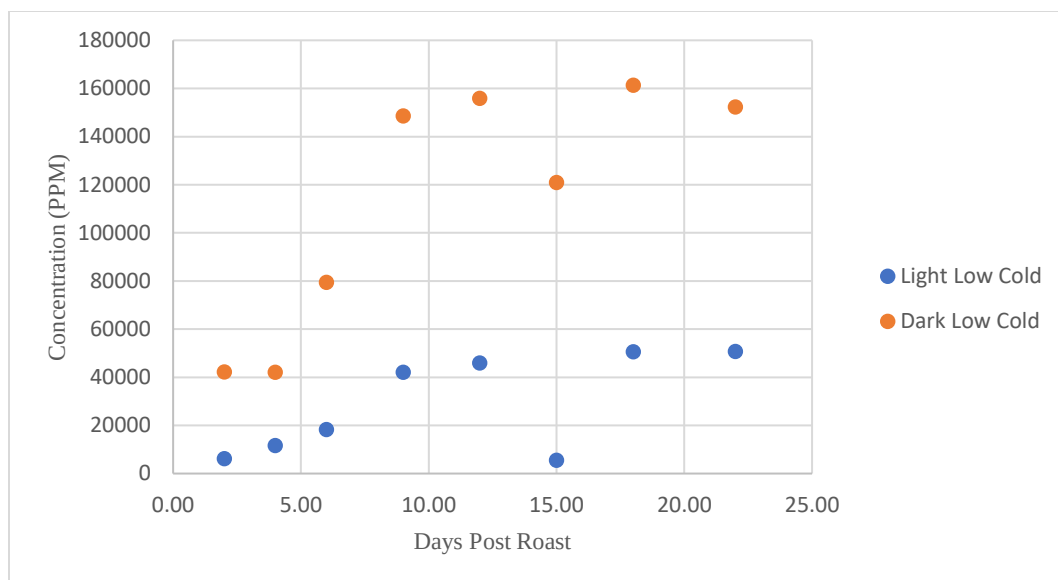


Figure 18: Concentration of CO₂ of 50g of Light and Dark Coffee stored at 4°C

Figure 20 compares average concentration measurements of CO for light and dark roasts of 100g of coffee beans stored at 4°C. All dark roast average concentration measurements are at least 75 times larger than light roast average concentration measurements with a minimum difference of about 8000 ppm.

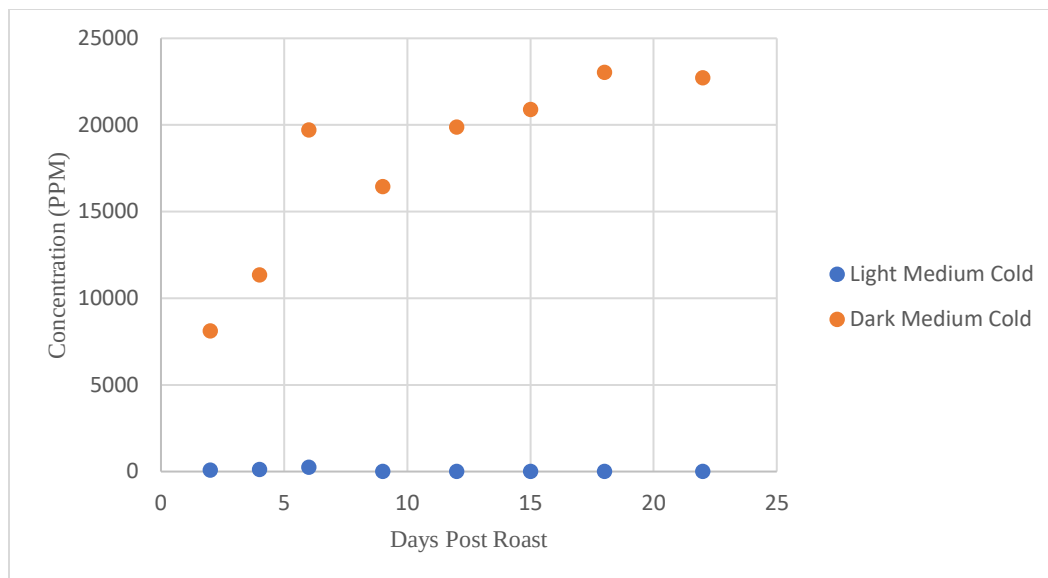


Figure 19: Concentration of CO of 100g of Light and Dark Coffee stored at 4°C

Figure 21 compares average concentration measurements of CO₂ for light and dark roasts of 100g of coffee beans stored at 4°C. All dark roast average concentration measurements are at least 2.5 times larger than light roast average concentration measurements with a minimum difference of over 65,000ppm. Day 15 shows the expected dip in CO₂ concentration readings due to the instrument error on that day.

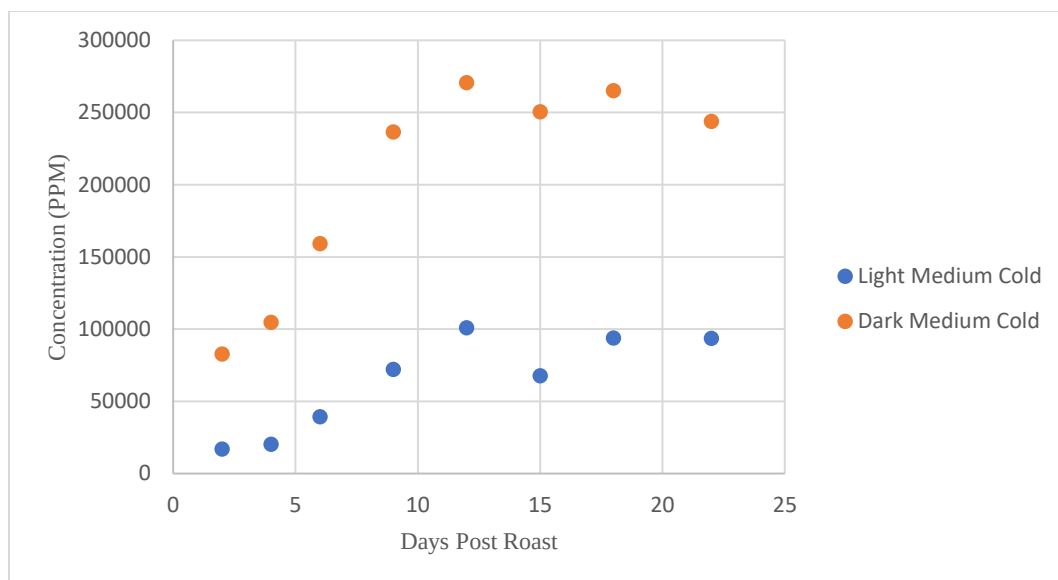


Figure 20: Concentration of CO₂ of 100g of Light and Dark Coffee stored at 4°C

Figure 22 compares average concentration measurements of CO for light and dark roasts of 200g of coffee beans stored at 4°C. All dark roast average concentration measurements are at least 25 times larger than light roast average concentration measurements with a minimum difference of about 13000 ppm.

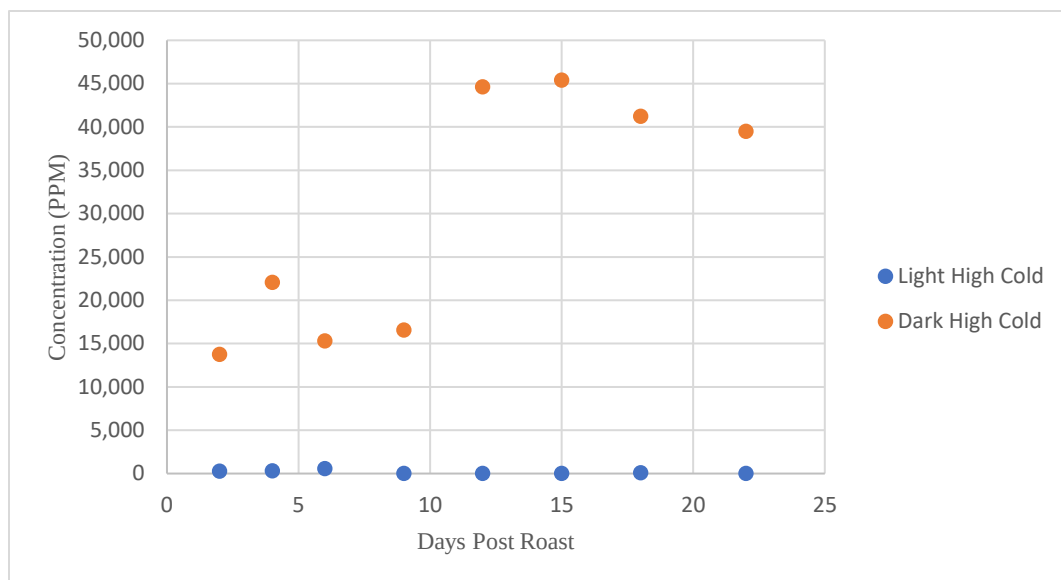


Figure 21: Concentration of CO of 200g of Light and Dark Coffee stored at 4°C

Figure 23 compares average concentration measurements of CO₂ for light and dark roasts of 200g of coffee beans stored at 4°C. All dark roast average concentration measurements are at larger than light roast average concentration measurements with a minimum difference of over 50,000ppm. Day 15 shows the expected dip in CO₂ concentration readings due to the instrument error on that day.

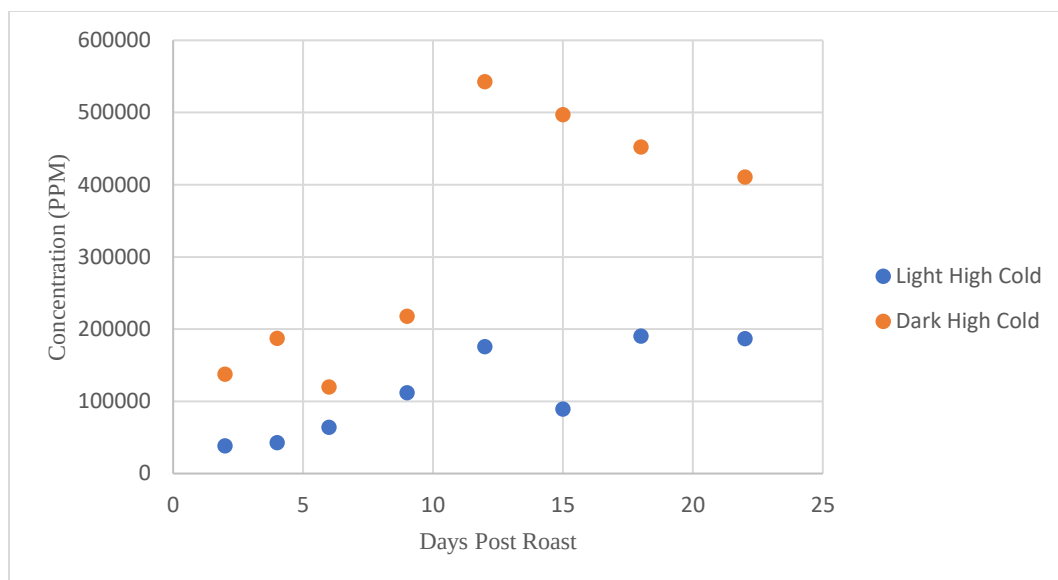


Figure 22: Concentration of CO₂ of 200g of Light and Dark Coffee stored at 4°C

Figure 24 compares average concentration measurements of CO for light and dark roasts of 25g of coffee beans stored at 25°C. All dark roast average concentration measurements are larger than light roast average concentration measurements with a minimum difference of over 3000 ppm.

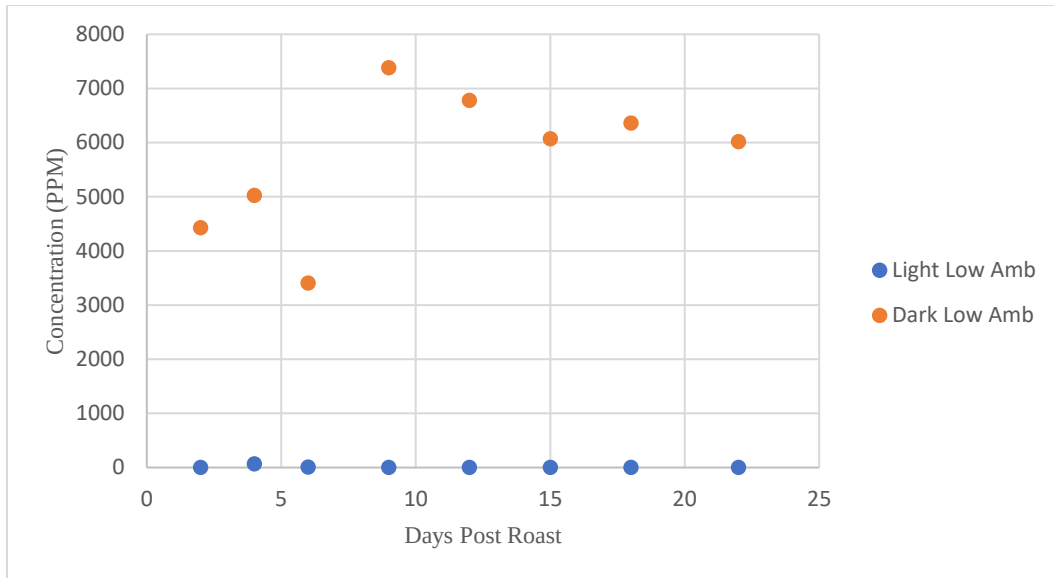


Figure 23: Concentration of CO of 25g of Light and Dark Coffee stored at 25°C

Figure 25 compares average concentration measurements of CO₂ for light and dark roasts of 25 of coffee beans stored at 25°C. All dark roast average concentration measurements are at least twice as large as light roast average concentration measurements with a minimum difference of over 16,000ppm. Day 15 shows the expected dip in CO₂ concentration readings due to the instrument error on that day.

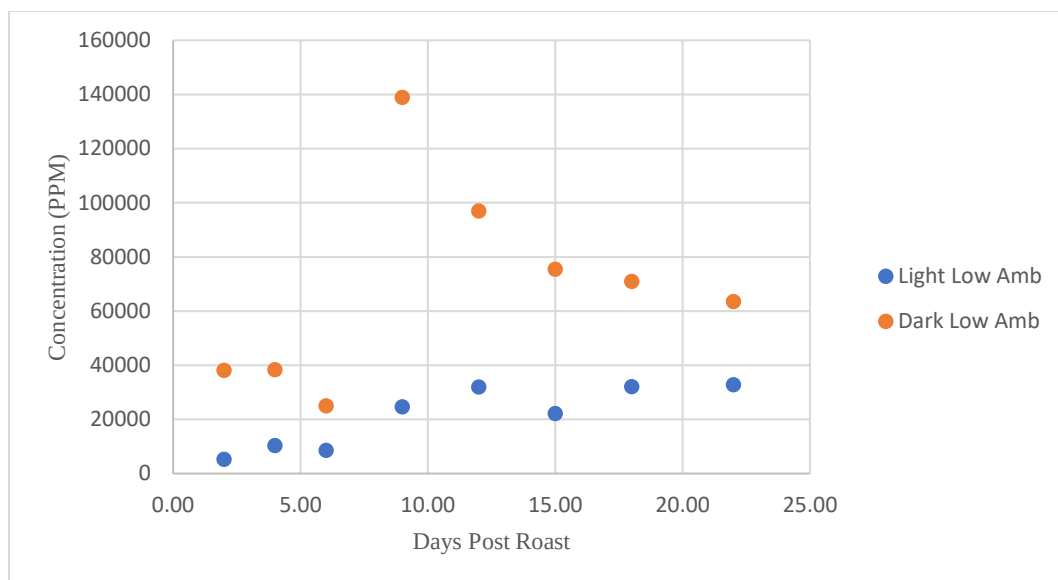


Figure 24: Concentration of CO₂ of 25g of Light and Dark Coffee stored at 25°C

Figure 26 compares average concentration measurements of CO for light and dark roasts of 75g of coffee beans stored at 25°C. All dark roast average concentration measurements are larger than light roast average concentration measurements with a minimum difference of over 24,000 ppm.

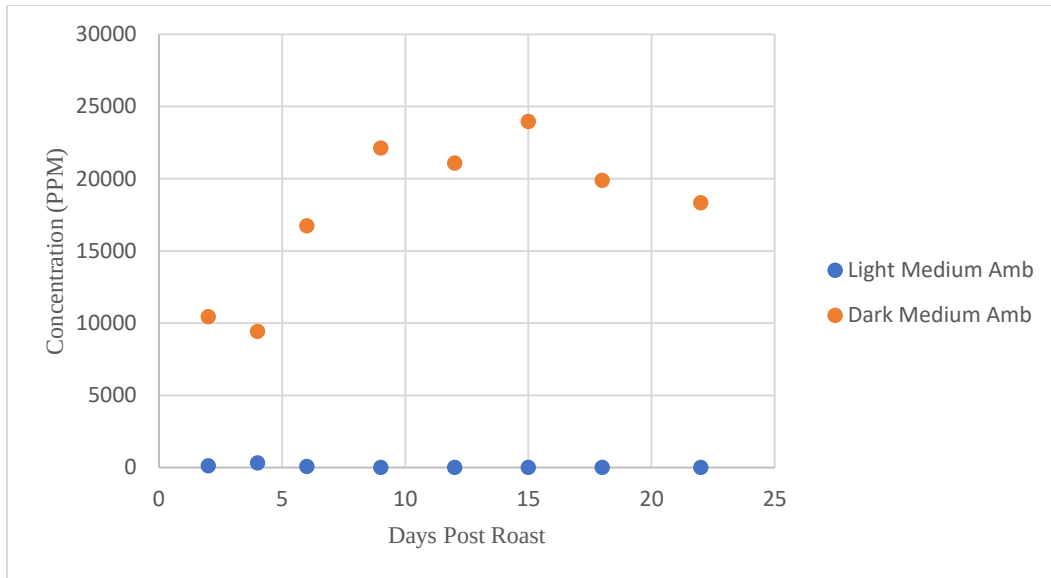


Figure 25: Concentration of CO of 75g of Light and Dark Coffee stored at 25°C

Figure 27 compares average concentration measurements of CO₂ for light and dark roasts of 75g of coffee beans stored at 25°C. All dark roast average concentration measurements are larger than light roast average concentration measurements with a minimum difference of over 30,000ppm.

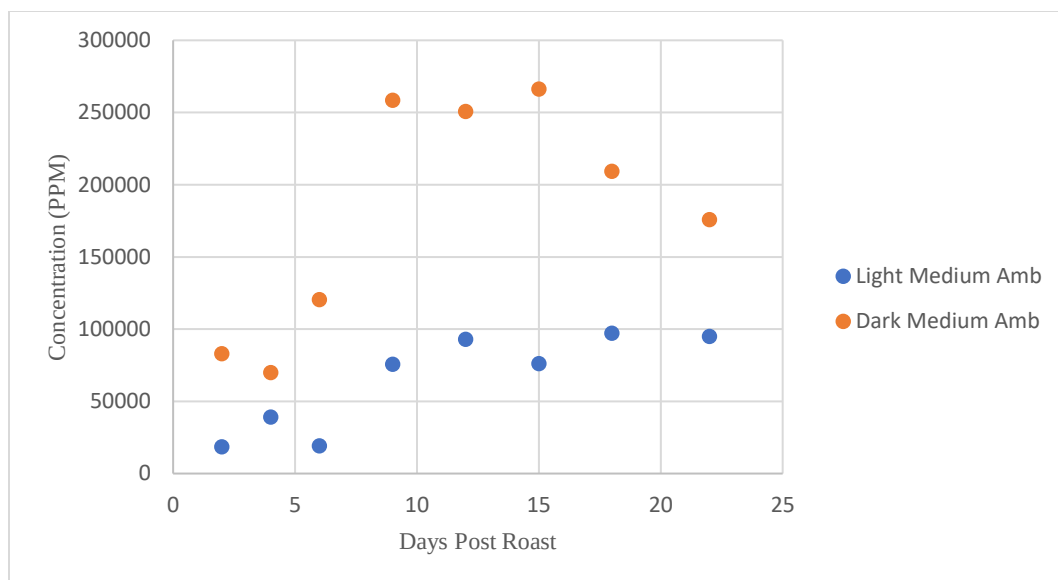


Figure 26: Concentration of CO₂ of 75g of Light and Dark Coffee stored at 25°C

Figure 28 compares average concentration measurements of CO for light and dark roasts of 200g of coffee beans stored at 25°C. All dark roast average concentration measurements are at least 38 times larger than light roast average concentration measurements with a minimum difference of over 24000 ppm.

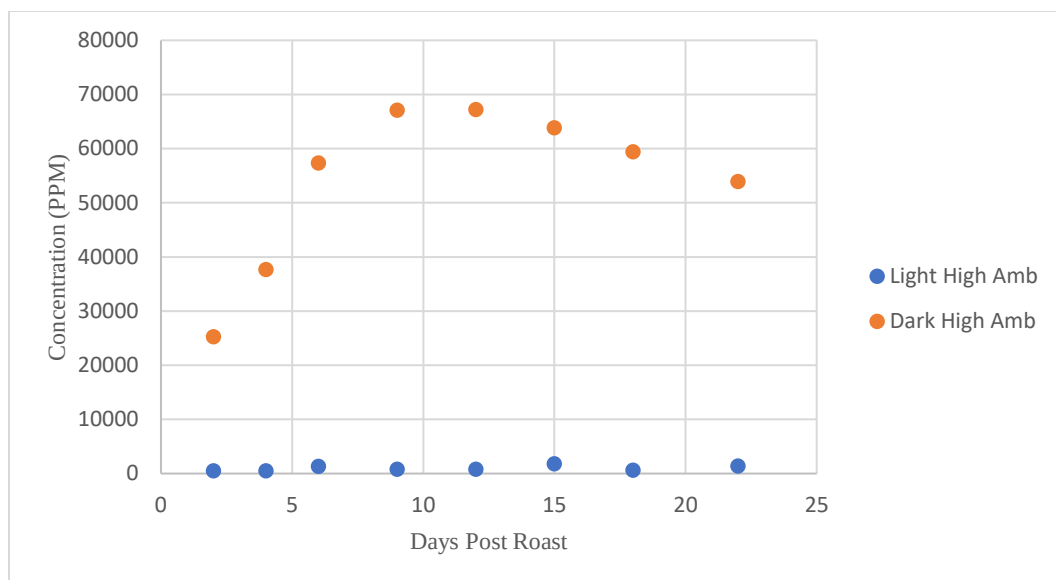


Figure 27: Concentration of CO of 200g of Light and Dark Coffee stored at 25°C

Figure 29 compares average concentration measurements of CO₂ for light and dark roasts of 200g of coffee beans stored at 25°C. Excluding the data from 15 days post roast, all dark roast average concentration measurements are at least 3 times larger than light roast average concentration measurements with a minimum difference of over 130,000ppm. On Day 15 post roast, the Gasmeter DX4040 was not able to measure CO₂ accurately. This can account for the low concentration readings of CO₂ and explain why dark average concentration of CO₂ appears to be lower on that day.

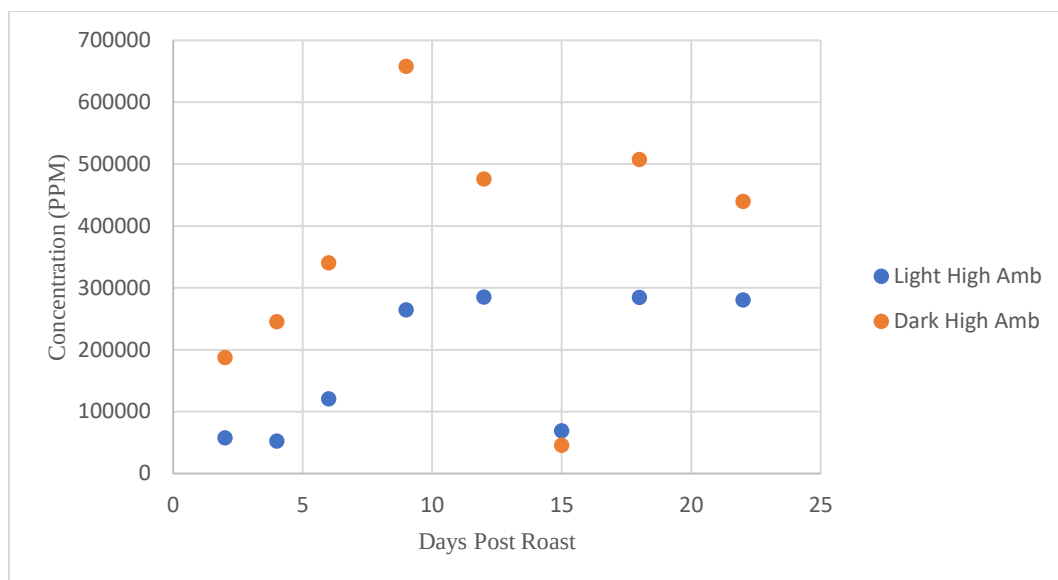


Figure 28: Concentration of CO₂ of 200g of Light and Dark Coffee stored at 25°C

Figure 30 compares average CO concentrations of 25g of light and 14g of dark Coffee stored at 38°C. All dark roast average concentration measurements are larger than light roast average concentration measurements with a minimum difference of over 3000 ppm.

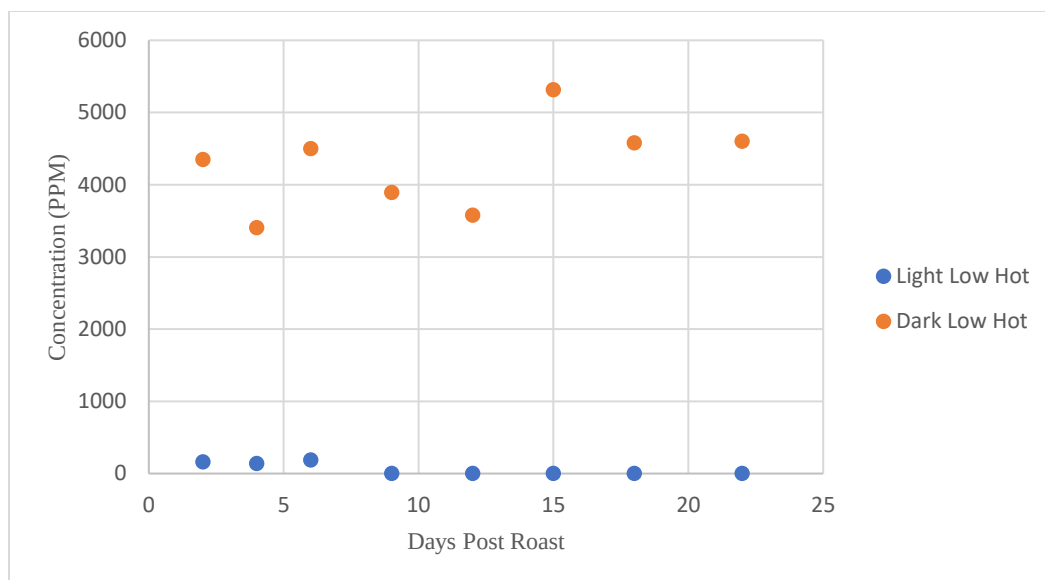


Figure 29: Concentration of CO of 25g of Light and 14g of Dark Coffee stored at 38°C

Figure 31 compares average concentration measurements of CO₂ for 25g of light roasted coffee beans and 14g of dark roasted coffee beans stored at 38°C. Even with 11g less of coffee for the dark roasted samples, all dark roast average concentration measurements were larger than light roast average concentration measurements with a minimum difference of over 9,000ppm.

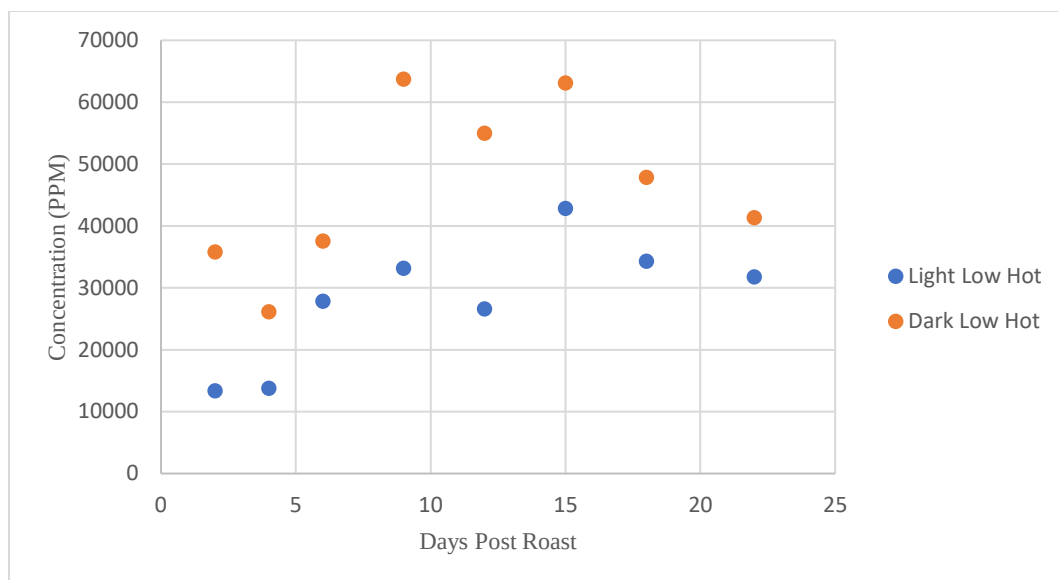


Figure 30: Concentration of CO₂ of 25g of Light and 14g Dark Coffee stored at 38°C

Figure 32 compares average concentration measurements of CO for light and dark roasts of 75g of coffee beans stored at 38°C. All dark roast average concentration measurements are larger than light roast average concentration measurements with a minimum difference of over 19000 ppm.

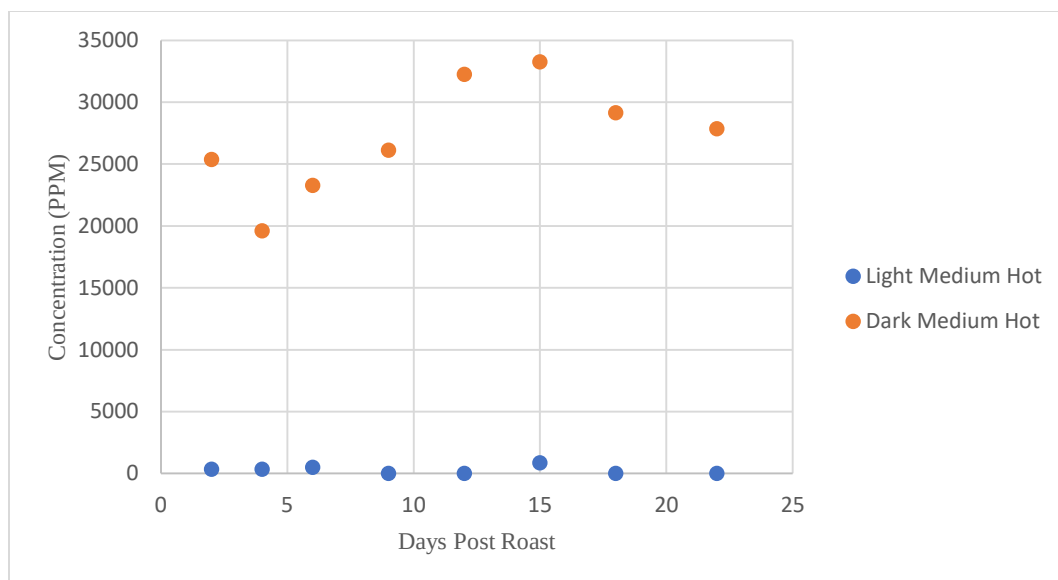


Figure 31: Concentration of CO of 75g of Light and Dark Coffee stored at 38°C

Figure 33 compares average concentration measurements of CO₂ for light and dark roasts of 75g of coffee beans stored at 38°C. All dark roast average concentration measurements are larger than light roast average concentration measurements with a minimum difference of over 85,000ppm.

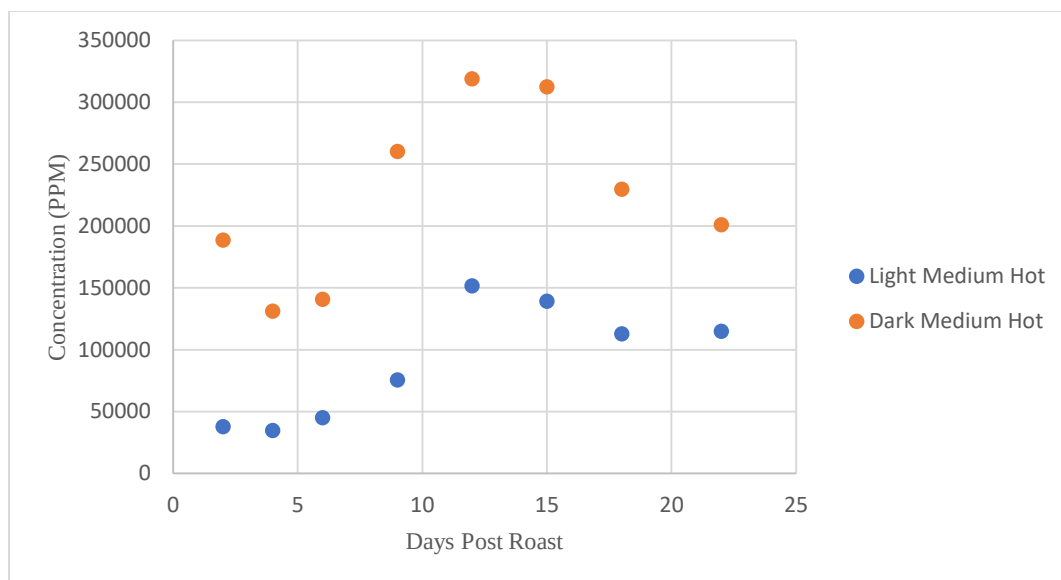


Figure 32: Concentration of CO₂ of 75g of Light and Dark Coffee stored at 38°C

Figure 34 compares average concentration measurements of CO for light and dark roasts of 200g of coffee beans stored at 38°C. All dark roast average concentration measurements are at least 30 times larger than light roast average concentration measurements with a minimum difference of over 49,000 ppm.

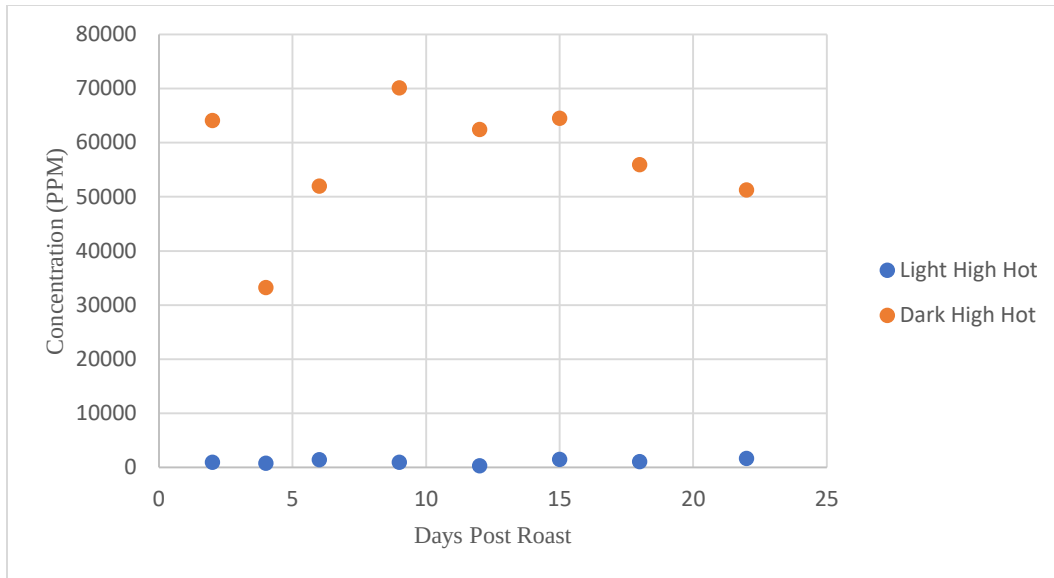


Figure 33: Concentration of CO of 200g of Light and Dark Coffee stored at 38°C

Figure 35 compares average concentration measurements of CO₂ for light and dark roasts of 200g of coffee beans stored at 38°C. All dark roast average concentration measurements are larger than light roast average concentration measurements with a minimum difference of over 85,000ppm.

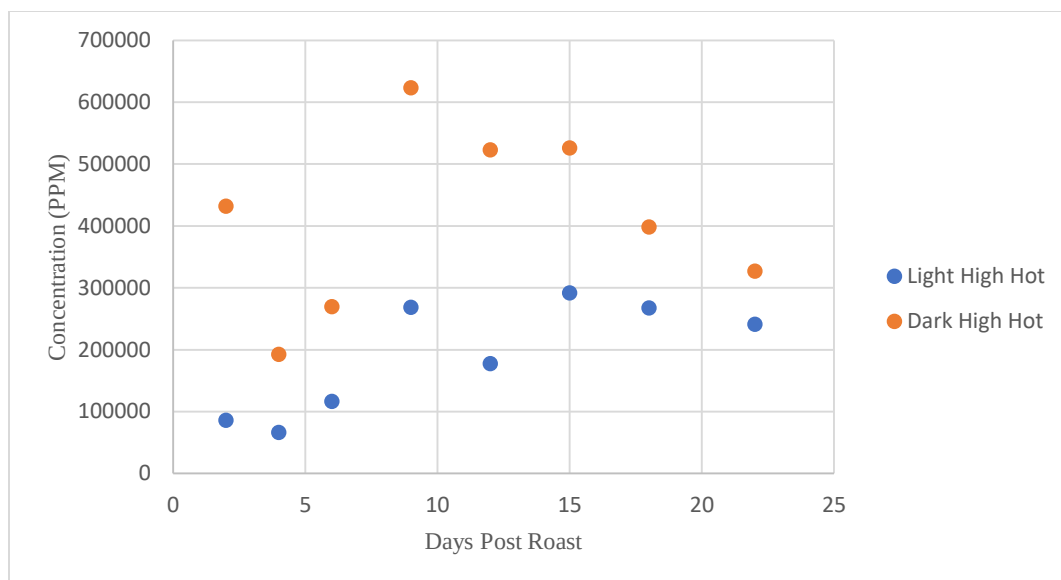


Figure 34: Concentration of CO₂ of 200g of Light and Dark Coffee stored at 38°C

Chapter 5: Discussion

In this study, concentrations of CO₂ and CO emissions from roasted coffee beans were monitored in order to investigate the effect that mass, storage temperature, and roast type would have on these emissions. By controlling for variables and comparing concentrations, conclusions were able to be drawn about the effect and significance of mass, temperature, and roast.

5.1 Mass Effect

An increase in mass correlated with an increase in CO and CO₂ emissions for all cases as depicted in Tables 3, 4 and in the charts and tables in section 4.3 of Appendix 4. This is in agreement with all relating literature and to be expected. On days 2, 4 and 6 a 5 mL gastight syringe was being used to transfer gas from the sample containers to the Gasmeter sample loop. The plunger on this 5 mL syringe was not consistently maintaining its vacuum and therefore not withdrawing an accurate volume from the sample container. The 5mL syringe was changed out for a .250mL (250µl) syringe on day 9. On day 15 the Gasmeter was not accurately responding to CO₂ and the concentrations for CO₂ that day are not reliable. These equipment malfunctions explain some of the variations and low reading on the first three sample days (2,4,6) and the unusually low readings for CO₂ on day 15. The change in syringe also resulted in a loss of resolution and a higher limit of detection for sample days 9 -22 resulting in many of CO concentrations in the light roasts falling below the limit of detection.

5.2 CO₂ and CO emissions ratio

The literature states that about 90% of all emissions from roasted coffee beans is CO₂ (3; 29; 30). In CDR James Morrison's report on the incident aboard CVN 77, it is stated that CO₂ and CO off gas from coffee beans in a ratio of about 10 to 1. The data in this report found the emissions ratio was dependent on roast, storage temperature, mass, and day after roast.

Dark roasted coffee beans on average released a mass of 1 to 2 orders of magnitude higher of CO than light roasts. Therefore, light roasted coffee beans released much more CO₂ relative to CO than dark roasts which results in light roasted coffee beans having a much higher emissions ratio than dark roasted coffee beans

As temperature increased the emissions ratio for CO₂:CO decreased which can be seen in Table 5 and is even more clearly presented in Table 25 of Appendix 4. While this experiment provides no clear insight into the diffusion kinetics of CO or CO₂, it was observed that raising the storage temperature more rapidly increased the release of CO than CO₂

As mass and time increased, the ratio for CO₂ and CO decreased. One possible factor contributing to this is the static container inhibiting the rate of emissions. As coffee mass increases, the available headspace decreases resulting in less CO and CO₂ required to raise the partial pressure of CO and CO₂ in that headspace space that would result in an equilibrium condition. As more CO and CO₂ fill the headspace, the concentration gradient is reduced lowering the rate of diffusion. This would continue to happen day after day until the concentration of CO and CO₂ matches the concentration within the coffee bean in which an equilibrium state is reached ultimately resulting in no net diffusion of CO and CO₂ in either direction.

It must also be considered that different coffee beans have different make ups of macronutrients which affect the production of CO and CO₂ during the roasting process (3). This means that bean type also likely has an effect on the CO CO₂ emissions ratio.

5.2 Temperature Effect

Temperature had the least significant effect on CO and CO₂ emissions. There was a difference in average CO and CO₂ emissions with respect to temperature with the average emissions generally increasing with an increase in storage temperature, but the increase was small making it possible that the difference was due to chance. A follow-on experiment with a larger sample size and wider disparities in temperature may better elucidate the effect coffee bean storage temperature has on the emissions of CO and CO₂.

5.3 Roast Effect

Dark roasted coffee beans produce significantly more CO and CO₂ emissions than light roasts. Dark roasted coffee beans have more heat transferred to them relative to light roasted coffee beans. This additional energy allows for more Maillard reactions to take place and for the volume of the bean to increase which also increases the storage capacity for gasses of the bean to increase. An increase in the amount of CO and CO₂ being produced and stored results in an increase being released.

5.4 Static vs Dynamic Flow Chamber

In a static container, as the concentration in the container's headspace increases, the concentration gradient decreases, reducing the rate of diffusion into the headspace of the container. This can be mitigated by using a headspace so relatively large that the emissions have

little impact on the concentration gradient or by using a dynamic flow chamber. A dynamic flow chamber is constantly is purged with clean air, removing the emitted gas and maintaining a sufficient concentration gradient to enable uninhibited diffusion.

5.5 Incorrect Coffee Mass

Due to pyrolysis reactions during roasting, the weight of dry mass also decreases which results in a decreased bean solids density process (3; 30). During the roasting process a coffee roaster has to estimate how much coffee to start with in order to get a specific mass of coffee. The roast master at Mayorga Organics roasted 8.5 pounds of dry green beans with the intention of producing 7 pounds of roasted coffee beans but instead produced 6 pounds of roasted coffee beans. Being a pound short of coffee, adjustments had to be made with respect to the mass contained in each group which resulted in a wide range for the low and medium labeled masses. This resulted in it being more difficult to control for mass when investigating the effects of temperature and roast on coffee emissions.

5.6 Leaks

The incubators and refrigerator had a notable coffee aroma in them indicating that containers may be leaking. The 5mL syringe was changed out for a 250 μ l syringe due to the 5 mL syringe not maintaining a consistent vacuum. The seal of the Gasmeter sample loop was not perfect and resulted in measured concentrations slowly and consistently decreasing. Perforations made by the gastight syringe's sample injections only compound this problem.

5.7 Model

Due to a variety of factors such as using containers that leaked, not being able to monitor the pressure within the containers, and the fact that the experiment was using a static container in

which a specific concentration gradient could not be maintained, a model to predict CO₂ and CO emissions based on mass, roast, and storage temperature based on the collected data would have little utility and the decision was made to not do so. Further studies that addresses these problems are necessary for assembling an accurate prediction model for these emissions.

5.8 Emission Rate Over Time

One of the specific aims of this project was to measure change in emission rates over time after roasting. This could be done by looking at the change in concentration between each sample period, however this was not done as the measurement would not be accurate. For one it was determined fairly early on that the sample containers were slowly leaking and there was no way to determine how much gas was leaking out of the sample containers. Furthermore, a static container is not ideal for this type of analysis. In a static container as the concentration in the container increases, the concentration gradient decreases, limiting diffusion into the headspace of the container. A test in a dynamic flow chamber would be much more appropriate for this type of analysis as the chamber is constantly is purged with clean air, removing the emitted gas and maintaining a sufficient concentration gradient to enable uninhibited or accelerated diffusion.

5.9 Other Literature

Xiuju Wang X and Loong-Tak Lim's results in the 2014 article, Effect of Roasting Conditions on Carbon Dioxide Degassing Behavior in Coffee, concurred with this study as in both studies, an increase in roast temperature correlated with an increase in CO₂ emissions. Their results also a large drop in the rate of CO₂ emissions around day 10 which matched the results in this study. The diffusion kinetics of carbon dioxide in fresh roasted and ground coffee also

agreed with this study in that increased storage temperature increased the rate of diffusion of CO₂

Ryan F. LeBouf and Michael Aldridge's technical paper, "Carbon monoxide emission rates from roasted whole bean and ground coffee," concluded that roast level had no significant effect on CO emissions from roasted coffee beans which differs from the conclusion of this study. This may be due to the fact that this particular study did not control for roast date and only monitored CO emissions for approximately 1.5 hours.

5.10 Future Research

Xiuju Wang X and Loong-Tak Lim's 2014 article, Effect of Roasting Conditions on Carbon Dioxide Degassing Behavior in Coffee, took a look at how CO₂ rates of off gassing were affected by the temperature and duration of the roast process. This study did not look at that, but it would be interesting and useful to know if the rate CO off gassing is affected in the same way.

As mentioned in a previous section, using a static container for this type of analysis can have the drawback of creating a sliding concentration gradient which can create the illusion of a decreasing rate of emissions when slowdown of off gassing may just be due to increased concentration in the headspace that is slowing the rate of diffusion. One solution would be to use a much larger volume of headspace per mass, but this could result in the need for very large container. Another approach would be to design a test that would measure the rate of CO and CO₂ emissions in a dynamic flow chamber. As the chamber continuously purges itself with clean air diffusion of CO and CO₂ would no longer be inhibited by a large concentration of the gasses in the headspace.

This test monitored off gassing of coffee beans open to the atmosphere. However, coffee is usually not stored out in the open, but it is instead packaged in container that keep most of the volatiles within the package. The coffee on the USS Bush were packaged in foil bags with an integrated gas relief valve designed to allow the burping of gasses once a specific internal bag pressure is reached to prevent damage to the bag from gas expansion, and prevent oxygen from entering in order to preserve freshness. It would be interesting to measure the rate of emissions from a full bag of coffee that periodically releases CO and CO₂ to relieve the internal pressure built up inside the bag. This would give much more practical data to any group or individual that is storing a large amount of coffee bags in one place as these parties would have little interest in the amount of CO and CO₂ that is inside the bags, but would be more interested in how much CO and CO₂ the bags could expect to release.

Also, it will be important for future studies to look at different coffee beans. The diffusion kinetics of carbon dioxide in fresh roasted and ground coffee showed that different beans are composed of different amounts of carbohydrates and sucrose which have an effect on the production of volatiles.

Chapter 6: Conclusion

CO and CO₂ are produced during the coffee roasting process, stored within the beans, and slowly released over time. There are already documented exposures have been associated with fatalities and near-fatalities in the coffee industry and aboard US Navy Vessels. Coffee will continue be an inhalation hazard anywhere large quantities of coffee are stored. This experiment was conducted to get a better understanding of the emissions of CO and CO₂ to drive better policy and guidelines for the storage and transport of roasted coffee beans.

Data showed that most of the CO and CO₂ was released in the first 10 days after roasting. If coffee was allowed to off-gas for two weeks before packaging or if received coffee packages were allowed to vent for two weeks and then purged with nitrogen before storage this could sufficiently mitigate the hazard. Another solution is to favor ground coffee over whole beans as the store volatiles diffuse out of ground coffee faster than from whole beans (3; 29) due to the disruption of the micropores in the coffee bean during the grinding process.

Though more research is needed, this experiment has collected enough data to conclude that a clear hazard exists and that large quantities of roasted coffee should not be stored in an unventilated storage space. Coffee storage rooms should also be monitored for CO and CO₂ to avoid entering such a space with high concentrations of these gasses.

Appendix 1: Food Flash 17-01



FOOD FLASH 17-01

07 February 2017

Attention: Supply Officer/Food Service Officer/Leading Culinary Specialist

Purpose: TO PROVIDE INFORMATION FOR COFFEE STOWAGE

Discussion: Recently, two ships have reported increased concentrations of Carbon Monoxide (CO) in stowage spaces used to store large quantities of bulk whole bean and ground coffee. While the root cause(s) of CO emissions experienced in the Fleet is under investigation, it is advisable to take these extra safety measures:

1. Relocate the coffee beans to a ventilated space/storeroom after the Gas Free Engineer has certified the current storeroom "safe for entry". Storing coffee beans at room temperature is preferred. If relocation is not operationally feasible, please inform your TYCOM.
2. Request assistance from the Chief Engineer to have storerooms where coffee beans are located, certified "safe for entry" by a Gas Free Engineer before entering the storeroom for any reason.
3. Request the original storeroom location, if coffee beans were moved, certified "safe for entry" prior to entering that space if other supplies are stored in that location.
4. Work with the Safety Officer to conduct CO monitoring on an as needed basis for storerooms exceeding the established safety threshold.
5. Inspect coffee packaging on a routine basis to ensure packaging is intact and free of any signs of leakage, cans are not bloated, and packages are not ripped or torn.
6. As space permits, utilize distributive stowage versus concentrating stock in a single location.
7. Review coffee demand/stockage levels to prevent excess inventory and utilize First-in/First-Out (FIFO) breakout process.

8. If you have questions related to extending the shelf life of coffee or any other provisions you are encouraged to seek the professional expertise of your local Army Veterinarian and/or Medical personnel.

For additional guidance, reach out to your local TYCOM/Regional Directors, Afloat Training Groups and/or Navy Food Management Teams.


KEITH A. CAPPER
CDR, SC, USN
Director, Navy Food Service

Please Expedite Routing to:
Supply Officer
Food Service Officer
Leading Culinary Specialist

APPENDIX 2: Raw Coffee Data in ppm

May 3rd	Day 2												
System Conditions													
Loop Size	0.464	L											
Syringe Volume	0.005	L											
Container Volume	0.95	L											
Sample Name	Roast	Mass	Storage Temp	Loop CO Background	Loop CO Concentration	Net Loop CO Concentration	Calculated Container CO Concentration	Loop CO2 Background	Loop CO2 Concentration	Net Loop CO2 Concentration	Calculated Container CO2 Concentration	Sample Loop Pressure	Sample Loop
Light Low Cold - 1	Light	49.96	4	0	0	0	0	480.17	517.46	37.29	3460.512	1002	25
Light Low Cold - 2	Light	50.07	4	0	0.04	0.04	3.712	455.71	543.25	87.54	8123.712	1002	25
Light Low Cold - 3	Light	49.97	4	0	0	0	0	476.4	553.25	76.85	7131.68	1002	25
Dark Low Cold - 1	Dark	51.1	4	0	45.11	45.11	4186.208	485.79	972.62	486.83	45177.824	1002	25
Dark Low Cold - 2	Dark	47.25	4	0	43.65	43.65	4050.72	478.78	919.17	440.39	40868.192	1002	25
Dark Low Cold - 3	Dark	51.25	4	0	39.56	39.56	3671.168	476.11	915.25	439.14	40752.192	1002	24
Light Medium Cold - 1	Light	99.97	4	0	1.3	1.3	120.64	471.36	708.69	237.33	22024.224	1002	25
Light Medium Cold - 2	Light	100.07	4	0	0.48	0.48	44.544	479.26	610.82	131.56	12208.768	1002	25
Light Medium Cold - 3	Light	100.05	4	0	0.95	0.95	88.16	474.25	652.2	177.95	16513.76	1002	25
Dark Medium Cold - 1	Dark	99.24	4	0	88.83	88.83	8243.424	480.28	1347.48	867.2	80476.16	1001	25
Dark Medium Cold - 2	Dark	101.29	4	0	75.17	75.17	6975.776	470.42	1255.71	785.29	72874.912	1002	25
Dark Medium Cold - 3	Dark	100.84	4	0	98.48	98.48	9138.944	471.65	1495.84	1024.19	95044.832	1002	24
Light High Cold - 1	Light	200.02	4	0	2.38	2.38	220.864	475.37	844.89	369.52	34291.456	1002	25
Light High Cold - 2	Light	200.08	4	0	3.67	3.67	340.576	471.14	950.63	479.49	44496.672	1002	25
Light High Cold - 3	Light	199.67	4	0	2.81	2.81	260.768	479.19	862.3	383.11	35552.608	1001	25
Dark High Cold - 1	Dark	201.22	4	0	114.39	114.39	10615.392	469.62	1580.9	1111.28	103126.784	1002	25
Dark High Cold - 2	Dark	199.95	4	0	149.21	149.21	13846.688	469.18	1991.07	1521.89	141231.392	1002	25
Dark High Cold - 3	Dark	201.54	4	0	181.67	181.67	16858.976	475.32	2284.05	1808.73	167850.144	1002	25
Light Low Amb - 1	Light	25.61	25	0	0.008	0.008	0.7424	464.57	523.27	58.7	5447.36	1002	25
Light Low Amb - 2	Light	25.12	25	0	0	0	0	472.63	530.77	58.14	5395.392	1002	25
Light Low Amb - 3	Light	25.16	25	0	0.11	0.11	10.208	463.21	515.38	52.17	4841.376	1002	25

Dark Low Amb - 1	Dark	25.72	25	0	58.71	58.71	5448.288	465.94	943.34	477.4	44302.72	1002	25
Dark Low Amb - 2	Dark	25.3	25	0	42.6	42.6	3953.28	479.74	826.96	347.22	32222.016	1002	25
Dark Low Amb - 3	Dark	21.79	25	0	41.86	41.86	3884.608	450.53	856.91	406.38	37712.064	1002	24
Light Medium Amb - 1	Light	75.56	25	0	1.02	1.02	94.656	458.97	633.08	174.11	16157.408	1002	25
Light Medium Amb - 2	Light	75.04	25	0	2.07	2.07	192.096	467.56	693.05	225.49	20925.472	1002	25
Light Medium Amb - 3	Light	75.05	25	0	1.12	1.12	103.936	462.25	658.96	196.71	18254.688	1002	24
Dark Medium Amb - 1	Dark	73.7	25	0	198.37	198.37	18408.736	465.48	2018.49	1553.01	144119.328	1002	24
Dark Medium Amb - 2	Dark	64.59	25	0	98.07	98.07	9100.896	460.42	1253.89	793.47	73634.016	1002	25
Dark Medium Amb - 3	Dark	75.45	25	0	41.57	41.57	3857.696	463.21	796.54	333.33	30933.024	1002	25
Light High Amb - 1	Light	199.53	25	0	5.65	5.65	524.32	456.92	1084.54	627.62	58243.136	1002	24
Light High Amb - 2	Light	199.39	25	0	6.49	6.49	602.272	445.79	1136.28	690.49	64077.472	1002	25
Light High Amb - 3	Light	199.74	25	0	4.81	4.81	446.368	459.74	999.59	539.85	50098.08	1002	24
Dark High Amb - 1	Dark	201.61	25	0	258.28	258.28	23968.384	473.47	2376.52	1903.05	176603.04	1002	25
Dark High Amb - 2	Dark	200.05	25	0	299.02	299.02	27749.056	480.44	2700.59	2220.15	206029.92	1002	25
Dark High Amb - 3	Dark	199.29	25	0	259.37	259.37	24069.536	469.51	2411.27	1941.76	180195.328	1002	25
Light Low Hot - 1	Light	25.03	38	0	1.3	1.3	120.64	506	660	154	14291.2	1001	26
Light Low Hot - 2	Light	25.04	38	0	2.93	2.93	271.904	474.78	646.3	171.52	15917.056	1001	26
Light Low Hot - 3	Light	27.24	38	0	1.06	1.06	98.368	487.95	595.23	107.28	9955.584	1001	25
Dark Low Hot - 1	Dark	13.67	38	0	47.25	47.25	4384.8	517.85	928.88	411.03	38143.584	1001	26
Dark Low Hot - 2	Dark	15.5	38	0	36.47	36.47	3384.416	488.03	786.69	298.66	27715.648	1001	25
Dark Low Hot - 3	Dark	15.04	38	0	56.95	56.95	5284.96	487	934.61	447.61	41538.208	1001	26
Light Medium Hot - 1	Light	75.07	38	0	3.13	3.13	290.464	486	847.62	361.62	33558.336	1001	26
Light Medium Hot - 2	Light	74.91	38	0	4.56	4.56	423.168	494.49	984.97	490.48	45516.544	1001	26
Light Medium Hot - 3	Light	74.89	38	0	3.2	3.2	296.96	490	858.21	368.21	34169.888	1001	26
Dark Medium Hot - 1	Dark	76.06	38	0	275.56	275.56	25571.968	503.62	2632.05	2128.43	197518.304	1001	25
Dark Medium Hot - 2	Dark	75.64	38	0	283.3	283.3	26290.24	485.21	2565.11	2079.9	193014.72	1001	25
Dark Medium Hot - 3	Dark	75	38	0	261.39	261.39	24256.992	489.97	2375.64	1885.67	174990.176	1001	25
Light High Hot - 1	Light	190.19	38	0	15.91	15.91	1476.448	490	1820	1330	123424	1001	27
Light High Hot - 2	Light	189	38	0	4.84	4.84	449.152	485	975.51	490.51	45519.328	1001	26
Light High Hot - 3	Light	188.6	38	0	10.11	10.11	938.208	475.79	1431.83	956.04	88720.512	1001	25
Dark High Hot - 1	Dark	202.91	38	0	804.02	804.02	74613.056	495.65	5850.2	5354.55	496902.24	1001	25

Dark High Hot - 2	Dark	200.68	38	0	513.94	513.94	47693.632	482.51	3980.42	3497.91	324606.048	1001	25
Dark High Hot - 3	Dark	201.53	38	0	754.56	754.56	70023.168	464	5568.77	5104.77	473722.656	1001	25

May 5th	Day 4												
System Conditions													
Loop Size	0.4645	L											
Syringe Volume	0.005	L											
Container Volume	0.95	L											
Sample Name	Roast	Mass	Storage Temp	Loop CO Background	Loop CO Concentration	Net Loop CO Concentration	Calculated Container CO Concentration	Loop CO2 Background	Loop CO2 Concentration	Net Loop CO2 Concentration	Calculated Container CO2 Concentration	Sample Loop Pressure	Sample Loop
Light Low Cold - 1	Light	49.96	4	0	0.81	0.81	75.249	460.98	575.44	114.46	10633.334	1002	24
Light Low Cold - 2	Light	50.07	4	0	0.21	0.21	19.509	465.98	561.7	95.72	8892.388	1002	24
Light Low Cold - 3	Light	49.97	4	0	0.79	0.79	73.391	465.1	629.91	164.81	15310.849	1002	24
Dark Low Cold - 1	Dark	51.1	4	0	52.13	52.13	4842.877	461.55	952.08	490.53	45570.237	1002	24
Dark Low Cold - 2	Dark	47.25	4	0	47.9	47.9	4449.91	451.75	886.06	434.31	40347.399	1002	24
Dark Low Cold - 3	Dark	51.25	4	0	46.22	46.22	4293.838	468.83	903.73	434.9	40402.21	1002	24
Light Medium Cold - 1	Light	99.97	4	0	0.8	0.8	74.32	464.77	630.98	166.21	15440.909	1002	24
Light Medium Cold - 2	Light	100.07	4	0	1.23	1.23	114.267	464.41	697.01	232.6	21608.54	1002	24
Light Medium Cold - 3	Light	100.05	4	0	1.6	1.6	148.64	471.3	724.21	252.91	23495.339	1002	24
Dark Medium Cold - 1	Dark	99.24	4	0	119.79	119.79	11128.491	465.9	1539.55	1073.65	99742.085	1002	24
Dark Medium Cold - 2	Dark	101.29	4	0	125.92	125.92	11697.968	461.59	1640.5	1178.91	109520.739	1002	24
Dark Medium Cold - 3	Dark	100.84	4	0	120.9	120.9	11231.61	464.95	1592.53	1127.58	104752.182	1002	24
Light High Cold - 1	Light	200.02	4	0	3.66	3.66	340.014	459.16	918.55	459.39	42677.331	1002	24
Light High Cold - 2	Light	200.08	4	0	3.2	3.2	297.28	462.06	916.39	454.33	42207.257	1002	24
Light High Cold - 3	Light	199.67	4	0	3.55	3.55	329.795	469.58	942.17	472.59	43903.611	1002	24
Dark High Cold - 1	Dark	201.22	4	0	201.34	201.34	18704.486	461.62	2116.4	1654.78	153729.062	1002	24
Dark High Cold - 2	Dark	199.95	4	0	307.13	307.13	28532.377	458.31	3155.05	2696.74	250527.146	1002	24

Dark High Cold - 3	Dark	201.54	4	0	203.86	203.86	18938.594	460.96	2152.32	1691.36	157127.344	1002	24
Light Low Amb - 1	Light	25.61	25	0	1.93	1.93	179.297	471.99	641.85	169.86	15779.994	1002	24
Light Low Amb - 2	Light	25.12	25	0	0.19	0.19	17.651	457.9	544.17	86.27	8014.483	1002	24
Light Low Amb - 3	Light	25.16	25	0	0.12	0.12	11.148	458.91	537.54	78.63	7304.727	1002	24
Dark Low Amb - 1	Dark	25.72	25	0	60.61	60.61	5630.669	458.55	919.99	461.44	42867.776	1002	24
Dark Low Amb - 2	Dark	25.3	25	0	52.97	52.97	4920.913	463.83	865.31	401.48	37297.492	1002	24
Dark Low Amb - 3	Dark	21.79	25	0	48.68	48.68	4522.372	462.04	838.76	376.72	34997.288	1002	24
Light Medium Amb - 1	Light	75.56	25	0	4.57	4.57	424.553	459.52	977	517.48	48073.892	1003	24
Light Medium Amb - 2	Light	75.04	25	0	4.19	4.19	389.251	462.97	974.55	511.58	47525.782	1003	24
Light Medium Amb - 3	Light	75.05	25	0	1.62	1.62	150.498	465.72	699.41	233.69	21709.801	1003	24
Dark Medium Amb - 1	Dark	73.7	25	0	97.15	97.15	9025.235	453.88	1152.43	698.55	64895.295	1003	24
Dark Medium Amb - 2	Dark	64.59	25	0	135.16	135.16	12556.364	455.7	1490.89	1035.19	96169.151	1003	24
Dark Medium Amb - 3	Dark	75.45	25	0	71.94	71.94	6683.226	466.41	989.15	522.74	48562.546	1003	24
Light High Amb - 1	Light	199.53	25	0	6.02	6.02	559.258	464.31	1057.17	592.86	55076.694	1003	24
Light High Amb - 2	Light	199.39	25	0	6.89	6.89	640.081	463.07	1147.78	684.71	63609.559	1003	24
Light High Amb - 3	Light	199.74	25	0	3.79	3.79	352.091	473.13	882.34	409.21	38015.609	1003	24
Dark High Amb - 1	Dark	201.61	25	0	323.61	323.61	30063.369	466.03	2542.21	2076.18	192877.122	1003	24
Dark High Amb - 2	Dark	200.05	25	0	369.39	369.39	34316.331	471.57	2954.33	2482.76	230648.404	1003	24
Dark High Amb - 3	Dark	199.29	25	0	523.38	523.38	48622.002	474.76	3835.76	3361	312236.9	1003	24
Light Low Hot - 1	Light	25.03	38	0	2.97	2.97	275.913	469.38	661.88	192.5	17883.25	1003	24
Light Low Hot - 2	Light	25.04	38	0	1.23	1.23	114.267	483.93	653.44	169.51	15747.479	1003	24
Light Low Hot - 3	Light	27.24	38	0	0.32	0.32	29.728	475.5	558.87	83.37	7745.073	1003	24
Dark Low Hot - 1	Dark	13.67	38	0	35.85	35.85	3330.465	469.69	759.57	289.88	26929.852	1003	24
Dark Low Hot - 2	Dark	15.5	38	0	41.09	41.09	3817.261	473.8	782.03	308.23	28634.567	1003	24
Dark Low Hot - 3	Dark	15.04	38	0	32.98	32.98	3063.842	475.88	721.75	245.87	22841.323	1003	24
Light Medium Hot - 1	Light	75.07	38	0	3.45	3.45	320.505	477.93	817.46	339.53	31542.337	1003	25
Light Medium Hot - 2	Light	74.91	38	0	4.26	4.26	395.754	474.69	898.28	423.59	39351.511	1003	25
Light Medium Hot - 3	Light	74.89	38	0	3.42	3.42	317.718	475.58	837.15	361.57	33589.853	1003	25
Dark Medium Hot - 1	Dark	76.06	38	0	209.58	209.58	19469.982	491.64	1942.62	1450.98	134796.042	1004	25
Dark Medium Hot - 2	Dark	75.64	38	0	222.21	222.21	20643.309	478.91	1950.16	1471.25	136679.125	1003	24
Dark Medium Hot - 3	Dark	75	38	0	201.22	201.22	18693.338	473.64	1789.83	1316.19	122274.051	1003	24

Light High Hot - 1	Light	190.19	38	0	10.44	10.44	969.876	470.31	1333.06	862.75	80149.475	1003	24
Light High Hot - 2	Light	189	38	0	6.35	6.35	589.915	482.42	1054.92	572.5	53185.25	1003	24
Light High Hot - 3	Light	188.6	38	0	8.26	8.26	767.354	501.26	1218.63	717.37	66643.673	1004	24
Dark High Hot - 1	Dark	202.91	38	0	291.27	291.27	27058.983	465.04	2126.5	1661.46	154349.634	1004	24
Dark High Hot - 2	Dark	200.68	38	0	388.2	388.2	36063.78	461.65	2731.65	2270	210883	1004	25
Dark High Hot - 3	Dark	201.53	38	0	394.67	394.67	36664.843	463.82	2746.04	2282.22	212018.238	1004	24

May 7th	Day 6												
System Conditions													
Loop Size	0.464	L											
Syringe Volume	0.005	L											
Container Volume	0.95	L											
Sample Name	Roast	Mass	Storage Temp	Loop CO Background	Loop CO Concentration	Net Loop CO Concentration	Calculated Container CO Concentration	Loop CO2 Background	Loop CO2 Concentration	Net Loop CO2 Concentration	Calculated Container CO2 Concentration	Sample Loop Pressure	Sample Loop
Light Low Cold - 1	Light	49.96	4	0	2.84	2.84	263.552	435.85	655.59	219.74	20391.872	1009	26
Light Low Cold - 2	Light	50.07	4	0	1.5	1.5	139.2	433.81	602.3	168.49	15635.872	1009	26
Light Low Cold - 3	Light	49.97	4	0	1.7	1.7	157.76	432.87	634.33	201.46	18695.488	1009	26
Dark Low Cold - 1	Dark	51.1	4	0	104.39	104.39	9687.392	390.96	1291.45	900.49	83565.472	1009	26
Dark Low Cold - 2	Dark	47.25	4	0	99.31	99.31	9215.968	402.66	1258.71	856.05	79441.44	1009	26
Dark Low Cold - 3	Dark	51.25	4	0	93.16	93.16	8645.248	427.35	1236.97	809.62	75132.736	1009	25
Light Medium Cold - 1	Light	99.97	4	0	3.77	3.77	349.856	452.75	924.27	471.52	43757.056	1009	25
Light Medium Cold - 2	Light	100.07	4	0	0.75	0.75	69.6	430.21	742.9	312.69	29017.632	1009	25
Light Medium Cold - 3	Light	100.05	4	0	3.8	3.8	352.64	432.78	923.36	490.58	45525.824	1009	25
Dark Medium Cold - 1	Dark	99.24	4	0	220	220	20416	412.88	2153.37	1740.49	161517.472	1009	25
Dark Medium Cold - 2	Dark	101.29	4	0	222.36	222.36	20635.008	418.26	2199.9	1781.64	165336.192	1009	25
Dark Medium Cold - 3	Dark	100.84	4	0	194.98	194.98	18094.144	408.34	2036.47	1628.13	151090.464	1009	25
Light High Cold - 1	Light	200.02	4	0	8.17	8.17	758.176	433.24	1279.08	845.84	78493.952	1009	25
Light High Cold - 2	Light	200.08	4	0	6.47	6.47	600.416	434.08	1209.36	775.28	71945.984	1009	25
Light High Cold - 3	Light	199.67	4	0	3.4	3.4	315.52	440.53	895.66	455.13	42236.064	1009	25
Dark High Cold - 1	Dark	201.22	4	0	131.97	131.97	12246.816	432.3	1520.81	1088.51	101013.728	1010	25

Dark High Cold - 2	Dark	199.95	4	0	99.76	99.76	9257.728	427.03	1341.31	914.28	84845.184	1010	25
Dark High Cold - 3	Dark	201.54	4	0	263.56	263.56	24458.368	447.48	2316.6	1869.12	173454.336	1009	25
Light Low Amb - 1	Light	25.61	25	0	0	0	0	446.29	469.17	22.88	2123.264	1010	25
Light Low Amb - 2	Light	25.12	25	0	0	0	0	468.88	553.02	84.14	7808.192	1010	25
Light Low Amb - 3	Light	25.16	25	0	0.3	0.3	27.84	466.32	637.12	170.8	15850.24	1010	25
Dark Low Amb - 1	Dark	25.72	25	0	55.59	55.59	5158.752	474.74	862.19	387.45	35955.36	1010	25
Dark Low Amb - 2	Dark	25.3	25	0	12.83	12.83	1190.624	471.12	627.57	156.45	14518.56	1010	25
Dark Low Amb - 3	Dark	21.79	25	0	41.78	41.78	3877.184	467.94	730.73	262.79	24386.912	1010	26
Light Medium Amb - 1	Light	75.56	25	0	0.79	0.79	73.312	436.9	607.38	170.48	15820.544	1010	26
Light Medium Amb - 2	Light	75.04	25	0	0.5	0.5	46.4	460.25	661.56	201.31	18681.568	1010	26
Light Medium Amb - 3	Light	75.05	25	0	0.85	0.85	78.88	446.1	695.8	249.7	23172.16	1010	26
Dark Medium Amb - 1	Dark	73.7	25	0	133.27	133.27	12367.456	439.75	1377.7	937.95	87041.76	1010	25
Dark Medium Amb - 2	Dark	64.59	25	0	223.74	223.74	20763.072	446.67	2014.46	1567.79	145490.912	1010	25
Dark Medium Amb - 3	Dark	75.45	25	0	184.19	184.19	17092.832	439.09	1826.31	1387.22	128734.016	1010	25
Light High Amb - 1	Light	199.53	25	0	11.07	11.07	1027.296	427.62	1387.32	959.7	89060.16	1010	25
Light High Amb - 2	Light	199.39	25	0	15.39	15.39	1428.192	426.18	1835.77	1409.59	130809.952	1010	25
Light High Amb - 3	Light	199.74	25	0	16.87	16.87	1565.536	428.23	1959.24	1531.01	142077.728	1010	25
Dark High Amb - 1	Dark	201.61	25	0	690.55	690.55	64083.04	443.15	4462.8	4019.65	373023.52	1010	25
Dark High Amb - 2	Dark	200.05	25	0	612.41	612.41	56831.648	425.23	4236.59	3811.36	353694.208	1010	25
Dark High Amb - 3	Dark	199.29	25	0	550.96	550.96	51129.088	423.45	3594.1	3170.65	294236.32	1010	25
Light Low Hot - 1	Light	25.03	38	0	3.88	3.88	360.064	443.06	822.01	378.95	35166.56	1009	25
Light Low Hot - 2	Light	25.04	38	0	0.78	0.78	72.384	447.55	662.64	215.09	19960.352	1009	25
Light Low Hot - 3	Light	27.24	38	0	1.38	1.38	128.064	452.92	759.23	306.31	28425.568	1009	25
Dark Low Hot - 1	Dark	13.67	38	0	30.98	30.98	2874.944	435.36	852.82	417.46	38740.288	1009	25
Dark Low Hot - 2	Dark	15.5	38	0	57.41	57.41	5327.648	438.3	846.17	407.87	37850.336	1009	25
Dark Low Hot - 3	Dark	15.04	38	0	57.07	57.07	5296.096	446.26	835.48	389.22	36119.616	1009	25
Light Medium Hot - 1	Light	75.07	38	0	7.44	7.44	690.432	446.84	1102.22	655.38	60819.264	1009	25
Light Medium Hot - 2	Light	74.91	38	0	5.81	5.81	539.168	449.17	1010.94	561.77	52132.256	1009	25
Light Medium Hot - 3	Light	74.89	38	0	3.12	3.12	289.536	463.79	708.6	244.81	22718.368	1009	25
Dark Medium Hot - 1	Dark	76.06	38	0	163.01	163.01	15127.328	446.05	1542.61	1096.56	101760.768	1009	25
Dark Medium Hot - 2	Dark	75.64	38	0	222.27	222.27	20626.656	441.65	1872.08	1430.43	132743.904	1009	25

Dark Medium Hot - 3	Dark	75	38	0	367.6	367.6	34113.28	449.53	2469.13	2019.6	187418.88	1009	25
Light High Hot - 1	Light	190.19	38	0	20	20	1856	458.98	1970.76	1511.78	140293.184	1009	25
Light High Hot - 2	Light	189	38	0	11.76	11.76	1091.328	448.04	1431.89	983.85	91301.28	1009	25
Light High Hot - 3	Light	188.6	38	0	14.63	14.63	1357.664	462.74	1740.82	1278.08	118605.824	1009	25
Dark High Hot - 1	Dark	202.91	38	0	355.79	355.79	33017.312	452.84	2235.55	1782.71	165435.488	1009	25
Dark High Hot - 2	Dark	200.68	38	0	746.36	746.36	69262.208	446.79	4354.86	3908.07	362668.896	1009	26
Dark High Hot - 3	Dark	201.53	38	0	577.92	577.92	53630.976	443.81	3475.77	3031.96	281365.888	1009	26

May 10th	Day 9												
System Conditions													
Loop Size	0.464	L											
Syringe Volume	0.00025	L											
Container Volume	0.95	L											
Sample Name	Roast	Mass	Storage Temp	Loop CO Background	Loop CO Concentration	Net Loop CO Concentration	Calculated Container CO Concentration	Loop CO2 Background	Loop CO2 Concentration	Net Loop CO2 Concentration	Calculated Container CO2 Concentration	Sample Loop Pressure	Sample Loop
Light Low Cold - 1	Light	49.96	4	0	0	0	0	391.53	417.91	26.38	48961.28	27	1004
Light Low Cold - 2	Light	50.07	4	0	0	0	0	433.38	456.35	22.97	42632.32	27	1004
Light Low Cold - 3	Light	49.97	4	0	0	0	0	456.35	475.05	18.7	34707.2	27	1004
Dark Low Cold - 1	Dark	51.1	4	0	5.4	5.4	10022.4	474.12	558.66	84.54	156906.24	27	1004
Dark Low Cold - 2	Dark	47.25	4	0	4.9	4.9	9094.4	430.99	509.35	78.36	145436.16	27	1004
Dark Low Cold - 3	Dark	51.25	4	0	5.05	5.05	9372.8	444.62	521.83	77.21	143301.76	28	1004
Light Medium Cold - 1	Light	99.97	4	0	0	0	0	445.15	487.62	42.47	78824.32	27	1004
Light Medium Cold - 2	Light	100.07	4	0	0	0	0	485.44	520.22	34.78	64551.68	28	1004
Light Medium Cold - 3	Light	100.05	4	0	0	0	0	519.26	558.49	39.23	72810.88	28	1004
Dark Medium Cold - 1	Dark	99.24	4	0	9.08	9.08	16852.48	437.87	571.89	134.02	248741.12	28	1004
Dark Medium Cold - 2	Dark	101.29	4	0	7.34	7.34	13623.04	461.75	572.06	110.31	204735.36	28	1004
Dark Medium Cold - 3	Dark	100.84	4	0	10.17	10.17	18875.52	486.73	624.86	138.13	256369.28	28	1004
Light High Cold - 1	Light	200.02	4	0	0	0	0	441.06	518.5	77.44	143728.64	28	1004
Light High Cold - 2	Light	200.08	4	0	0	0	0	517.63	595.82	78.19	145120.64	27	1004

Light High Cold - 3	Light	199.67	4	0	0	0	0	450.16	475.33	25.17	46715.52	27	1004
Dark High Cold - 1	Dark	201.22	4	0	17.28	17.28	32071.68	437.1	652.29	215.19	399392.64	28	1004
Dark High Cold - 2	Dark	199.95	4	0	6.07	6.07	11265.92	475.77	559.67	83.9	155718.4	27	1004
Dark High Cold - 3	Dark	201.54	4	0	3.41	3.41	6328.96	450.94	504.05	53.11	98572.16	27	1004
Light Low Amb - 1	Light	25.61	25	0	0	0	0	471.79	486.56	14.77	27413.12	26	1005
Light Low Amb - 2	Light	25.12	25	0	0	0	0	480.99	494.14	13.15	24406.4	26	1005
Light Low Amb - 3	Light	25.16	25	0	0	0	0	491.52	503.41	11.89	22067.84	27	1005
Dark Low Amb - 1	Dark	25.72	25	0	4.85	4.85	9001.6	479.78	538.2	58.42	108427.52	27	1005
Dark Low Amb - 2	Dark	25.3	25	0	4.15	4.15	7702.4	377	434.97	57.97	107592.32	26	1005
Dark Low Amb - 3	Dark	21.79	25	0	2.93	2.93	5438.08	445.44	553.61	108.17	200763.52	26	1006
Light Medium Amb - 1	Light	75.56	25	0	0	0	0	508.85	536.08	27.23	50538.88	26	1006
Light Medium Amb - 2	Light	75.04	25	0	0	0	0	532.61	585.75	53.14	98627.84	26	1006
Light Medium Amb - 3	Light	75.05	25	0	0	0	0	574.72	616.69	41.97	77896.32	26	1006
Dark Medium Amb - 1	Dark	73.7	25	0	12.41	12.41	23032.96	478	580.96	102.96	191093.76	26	1006
Dark Medium Amb - 2	Dark	64.59	25	0	13.28	13.28	24647.68	478	665.95	187.95	348835.2	26	1006
Dark Medium Amb - 3	Dark	75.45	25	0	10.06	10.06	18671.36	398.89	525.79	126.9	235526.4	25	1006
Light High Amb - 1	Light	199.53	25	0	0.02	0.02	37.12	396.93	531.67	134.74	250077.44	25	1006
Light High Amb - 2	Light	199.39	25	0	1.03	1.03	1911.68	529.58	684.2	154.62	286974.72	25	1006
Light High Amb - 3	Light	199.74	25	0	0.26	0.26	482.56	492.15	630.45	138.3	256684.8	25	1006
Dark High Amb - 1	Dark	201.61	25	0	38.75	38.75	71920	416.77	792.69	375.92	697707.52	25	1006
Dark High Amb - 2	Dark	200.05	25	0	40	40	74240	424.63	817	392.37	728238.72	25	1005
Dark High Amb - 3	Dark	199.29	25	0	29.66	29.66	55048.96	426.64	721.6	294.96	547445.76	26	1006
Light Low Hot - 1	Light	25.03	38	0	0	0	0	424.35	442.85	18.5	34336	26	1006
Light Low Hot - 2	Light	25.04	38	0	0	0	0	440.76	459.66	18.9	35078.4	26	1006
Light Low Hot - 3	Light	27.24	38	0	0	0	0	457.34	473.59	16.25	30160	26	1006
Dark Low Hot - 1	Dark	13.67	38	0	1.46	1.46	2709.76	412	447	35	64960	26	1006
Dark Low Hot - 2	Dark	15.5	38	0	2.35	2.35	4361.6	414.3	452.9	38.6	71641.6	26	1006
Dark Low Hot - 3	Dark	15.04	38	0	2.48	2.48	4602.88	415.35	444.75	29.4	54566.4	26	1006
Light Medium Hot - 1	Light	75.07	38	0	0	0	0	415.01	486.03	71.02	131813.12	26	1006
Light Medium Hot - 2	Light	74.91	38	0	0	0	0	479.79	496.68	16.89	31347.84	26	1006
Light Medium Hot - 3	Light	74.89	38	0	0	0	0	493.28	527.42	34.14	63363.84	26	1006

Dark Medium Hot - 1	Dark	76.06	38	0	7.67	7.67	14235.52	417	493.86	76.86	142652.16	26	1006
Dark Medium Hot - 2	Dark	75.64	38	0	16.9	16.9	31366.4	409.98	576.07	166.09	308263.04	26	1006
Dark Medium Hot - 3	Dark	75	38	0	17.65	17.65	32758.4	437.16	614.63	177.47	329384.32	26	1006
Light High Hot - 1	Light	190.19	38	0	0.34	0.34	631.04	430.22	587.82	157.6	292505.6	26	1006
Light High Hot - 2	Light	189	38	0	0.54	0.54	1002.24	500.24	618	117.76	218562.56	26	1006
Light High Hot - 3	Light	188.6	38	0	0.67	0.67	1243.52	479.17	637.58	158.41	294008.96	26	1006
Dark High Hot - 1	Dark	202.91	38	0	37.99	37.99	70509.44	426.57	759.42	332.85	617769.6	26	1006
Dark High Hot - 2	Dark	200.68	38	0	35.98	35.98	66778.88	426.07	747.36	321.29	596314.24	26	1006
Dark High Hot - 3	Dark	201.53	38	0	39.36	39.36	73052.16	439.6	792.59	352.99	655149.44	26	1006

May 13th	Day 12												
System Conditions													
Loop Size	0.459	L											
Syringe Volume	0.00025	L											
Container Volume	0.95	L											
Sample Name	Roast	Mass	Storage Temp	Loop CO Background	Loop CO Concentration	Net Loop CO Concentration	Calculated Container CO Concentration	Loop CO2 Background	Loop CO2 Concentration	Net Loop CO2 Concentration	Calculated Container CO2 Concentration	Sample Loop Pressure	Sample Loop
Light Low Cold - 1	Light	49.96	4	0	0	0	0	528.26	560	31.74	58274.64	1000	23
Light Low Cold - 2	Light	50.07	4	0	0	0	0	558.31	588.26	29.95	54988.2	1000	23
Light Low Cold - 3	Light	49.97	4	0	0	0	0	587.91	601.32	13.41	24620.76	1000	23
Dark Low Cold - 1	Dark	51.1	4	0	5.13	5.13	9418.68	550	620.83	70.83	130043.88	1000	23
Dark Low Cold - 2	Dark	47.25	4	0	6.02	6.02	11052.72	551.17	642.7	91.53	168049.08	1000	23
Dark Low Cold - 3	Dark	51.25	4	0	6.09	6.09	11181.24	547.67	640.07	92.4	169646.4	1000	23
Light Medium Cold - 1	Light	99.97	4	0	0	0	0	597.82	652.91	55.09	101145.24	1000	23
Light Medium Cold - 2	Light	100.07	4	0	0	0	0	650	709.28	59.28	108838.08	1000	24
Light Medium Cold - 3	Light	100.05	4	0	0	0	0	705	755.56	50.56	92828.16	1000	24
Dark Medium Cold - 1	Dark	99.24	4	0	8.49	8.49	15587.64	557.37	675.06	117.69	216078.84	1000	23
Dark Medium Cold - 2	Dark	101.29	4	0	12.1	12.1	22215.6	503.83	669.21	165.38	303637.68	1000	23
Dark Medium Cold - 3	Dark	100.84	4	0	11.9	11.9	21848.4	503.69	662.94	159.25	292383	1000	24

Light High Cold - 1	Light	200.02	4	0	0	0	0	474.43	572.46	98.03	179983.08	1000	24
Light High Cold - 2	Light	200.08	4	0	0.05	0.05	91.8	572.46	666.92	94.46	173428.56	1000	24
Light High Cold - 3	Light	199.67	4	0	0	0	0	514.73	609.13	94.4	173318.4	1000	24
Dark High Cold - 1	Dark	201.22	4	0	26.49	26.49	48635.64	608.44	926.42	317.98	583811.28	1000	24
Dark High Cold - 2	Dark	199.95	4	0	21.3	21.3	39106.8	495.69	764.14	268.45	492874.2	1000	24
Dark High Cold - 3	Dark	201.54	4	0	25.14	25.14	46157.04	505.12	805.1	299.98	550763.28	1000	24
Light Low Amb - 1	Light	25.61	25	0	0	0	0	487.75	507.36	19.61	36003.96	1000	24
Light Low Amb - 2	Light	25.12	25	0	0	0	0	508.94	520	11.06	20306.16	1000	24
Light Low Amb - 3	Light	25.16	25	0	0	0	0	517.23	538.77	21.54	39547.44	1000	24
Dark Low Amb - 1	Dark	25.72	25	0	4.03	4.03	7399.08	542.41	600.96	58.55	107497.8	1000	24
Dark Low Amb - 2	Dark	25.3	25	0	4.35	4.35	7986.6	538.94	598.79	59.85	109884.6	1000	24
Dark Low Amb - 3	Dark	21.79	25	0	2.7	2.7	4957.2	532.77	572.9	40.13	73678.68	1000	24
Light Medium Amb - 1	Light	75.56	25	0	0	0	0	598.43	655.89	57.46	105496.56	1000	24
Light Medium Amb - 2	Light	75.04	25	0	0	0	0	654	717.94	63.94	117393.84	1000	24
Light Medium Amb - 3	Light	75.05	25	0	0	0	0	714.19	744.59	30.4	55814.4	1000	24
Dark Medium Amb - 1	Dark	73.7	25	0	9.19	9.19	16872.84	496.67	604.99	108.32	198875.52	1000	24
Dark Medium Amb - 2	Dark	64.59	25	0	14.38	14.38	26401.68	530.51	698.66	168.15	308723.4	1000	24
Dark Medium Amb - 3	Dark	75.45	25	0	10.88	10.88	19975.68	509	642.12	133.12	244408.32	1000	24
Light High Amb - 1	Light	199.53	25	0	0	0	0	543.85	680.51	136.66	250907.76	1000	24
Light High Amb - 2	Light	199.39	25	0	1.1	1.1	2019.6	680	845.93	165.93	304647.48	1000	24
Light High Amb - 3	Light	199.74	25	0	0.16	0.16	293.76	492.46	655.7	163.24	299708.64	1000	24
Dark High Amb - 1	Dark	201.61	25	0	39.45	39.45	72430.2	602	690.42	88.42	162339.12	1000	24
Dark High Amb - 2	Dark	200.05	25	0	28.11	28.11	51609.96	508.18	801.72	293.54	538939.44	1000	24
Dark High Amb - 3	Dark	199.29	25	0	42.29	42.29	77644.44	485.77	881.12	395.35	725862.6	1000	24
Light Low Hot - 1	Light	25.03	38	0	0	0	0	452.88	468.86	15.98	29339.28	1000	24
Light Low Hot - 2	Light	25.04	38	0	0	0	0	468	482.13	14.13	25942.68	1000	24
Light Low Hot - 3	Light	27.24	38	0	0	0	0	482.13	495.51	13.38	24565.68	1000	24
Dark Low Hot - 1	Dark	13.67	38	0	1.47	1.47	2698.92	490.4	516.22	25.82	47405.52	1000	24
Dark Low Hot - 2	Dark	15.5	38	0	1.85	1.85	3396.6	471.27	499.86	28.59	52491.24	1000	24
Dark Low Hot - 3	Dark	15.04	38	0	2.53	2.53	4645.08	492.87	528.27	35.4	64994.4	1000	24
Light Medium Hot - 1	Light	75.07	38	0	0	0	0	493.41	610.9	117.49	215711.64	1000	24

Light Medium Hot - 2	Light	74.91	38	0	0	0	0	484.83	558.99	74.16	136157.76	1000	24
Light Medium Hot - 3	Light	74.89	38	0	0	0	0	557.95	614.08	56.13	103054.68	1000	24
Dark Medium Hot - 1	Dark	76.06	38	0	17.24	17.24	31652.64	612.03	790.77	178.74	328166.64	1000	24
Dark Medium Hot - 2	Dark	75.64	38	0	17.2	17.2	31579.2	507.09	671.24	164.15	301379.4	1000	24
Dark Medium Hot - 3	Dark	75	38	0	18.24	18.24	33488.64	535.51	713.56	178.05	326899.8	1000	24
Light High Hot - 1	Light	190.19	38	0	0	0	0	534.16	604.77	70.61	129639.96	1000	24
Light High Hot - 2	Light	189	38	0	0.2	0.2	367.2	604.58	654.37	49.79	91414.44	1000	24
Light High Hot - 3	Light	188.6	38	0	0.33	0.33	605.88	468.46	638.61	170.15	312395.4	1000	24
Dark High Hot - 1	Dark	202.91	38	0	29.91	29.91	54914.76	478.17	716.13	237.96	436894.56	1000	24
Dark High Hot - 2	Dark	200.68	38	0	36.61	36.61	67215.96	656.97	980.32	323.35	593670.6	1000	24
Dark High Hot - 3	Dark	201.53	38	0	35.46	35.46	65104.56	487	780.6	293.6	539049.6	1000	24

May 16th	Day 15												
System Conditions													
Loop Size	0.464	L											
Syringe Volume	0.00025	L											
Container Volume	0.95	L											
Sample Name	Roast	Mass	Storage Temp	Loop CO Background	Loop CO Concentration	Net Loop CO Concentration	Calculated Container CO Concentration	Loop CO2 Background	Loop CO2 Concentration	Net Loop CO2 Concentration	Calculated Container CO2 Concentration	Sample Loop Pressure	Sample Loop
Light Low Cold - 1	Light	49.96	4	0	0	0	0	1.04	3.32	2.28	4231.68	1001	23
Light Low Cold - 2	Light	50.07	4	0	0	0	0	3.14	7.05	3.91	7256.96	1001	24
Light Low Cold - 3	Light	49.97	4	0	0	0	0	7	9.78	2.78	5159.68	1001	24
Dark Low Cold - 1	Dark	51.1	4	0	6.98	6.98	12954.88	9.68	33.93	24.25	45008	1001	24
Dark Low Cold - 2	Dark	47.25	4	0	6.28	6.28	11655.68	407.41	488.75	81.34	150967.04	1001	24
Dark Low Cold - 3	Dark	51.25	4	0	6.62	6.62	12286.72	470.98	560.8	89.82	166705.92	1001	24
Light Medium Cold - 1	Light	99.97	4	0	0	0	0	411.91	428.39	16.48	30586.88	1001	25
Light Medium Cold - 2	Light	100.07	4	0	0	0	0	427.83	475.48	47.65	88438.4	1001	24
Light Medium Cold - 3	Light	100.05	4	0	0	0	0	475.03	520.23	45.2	83891.2	1001	25
Dark Medium Cold - 1	Dark	99.24	4	0	9.31	9.31	17279.36	517.53	631.87	114.34	212215.04	1001	25

Dark Medium Cold - 2	Dark	101.29	4	0	12.7	12.7	23571.2	411.656	561.27	149.614	277683.584	1001	25
Dark Medium Cold - 3	Dark	100.84	4	0	11.75	11.75	21808	399.21	540.25	141.04	261770.24	1001	25
Light High Cold - 1	Light	200.02	4	0	0	0	0	420.06	450.22	30.16	55976.96	1001	25
Light High Cold - 2	Light	200.08	4	0	0	0	0	514.55	531.49	16.94	31440.64	1001	25
Light High Cold - 3	Light	199.67	4	0	0	0	0	417.47	514.58	97.11	180236.16	1001	25
Dark High Cold - 1	Dark	201.22	4	0	27.25	27.25	50576	456.37	748.14	291.77	541525.12	1001	26
Dark High Cold - 2	Dark	199.95	4	0	20.48	20.48	38010.88	445.44	683.65	238.21	442117.76	1001	25
Dark High Cold - 3	Dark	201.54	4	0	25.69	25.69	47680.64	421.53	694.7	273.17	507003.52	1001	26
Light Low Amb - 1	Light	25.61	25	0	0	0	0	409.61	416.08	6.47	12008.32	1001	26
Light Low Amb - 2	Light	25.12	25	0	0	0	0	412.92	428.37	15.45	28675.2	1001	26
Light Low Amb - 3	Light	25.16	25	0	0	0	0	428.82	442.73	13.91	25816.96	1001	26
Dark Low Amb - 1	Dark	25.72	25	0	3.66	3.66	6792.96	441.87	485.59	43.72	81144.32	1001	26
Dark Low Amb - 2	Dark	25.3	25	0	3.44	3.44	6384.64	507.25	547.3	40.05	74332.8	1001	26
Dark Low Amb - 3	Dark	21.79	25	0	2.71	2.71	5029.76	451.63	489.91	38.28	71047.68	1001	26
Light Medium Amb - 1	Light	75.56	25	0	0	0	0	436.69	484.01	47.32	87825.92	1001	26
Light Medium Amb - 2	Light	75.04	25	0	0	0	0	484.24	522.3	38.06	70639.36	1001	26
Light Medium Amb - 3	Light	75.05	25	0	0	0	0	447.93	485.66	37.73	70026.88	1001	26
Dark Medium Amb - 1	Dark	73.7	25	0	12.49	12.49	23181.44	445.05	575.76	130.71	242597.76	1001	20
Dark Medium Amb - 2	Dark	64.59	25	0	14.89	14.89	27635.84	625.76	794.58	168.82	313329.92	1001	22
Dark Medium Amb - 3	Dark	75.45	25	0	11.35	11.35	21065.6	608.82	739.55	130.73	242634.88	1002	22
Light High Amb - 1	Light	199.53	25	0	0.87	0.87	1614.72	666.6	843.17	176.57	327713.92	1002	22
Light High Amb - 2	Light	199.39	25	0.83	2.04	1.21	2245.76	842.67	699.95	-142.72	-264888.32	1002	22
Light High Amb - 3	Light	199.74	25	2.05	2.85	0.8	1484.8	700.06	777.35	77.29	143450.24	1002	22
Dark High Amb - 1	Dark	201.61	25	0	33.62	33.62	62398.72	692.91	703.17	10.26	19042.56	1002	22
Dark High Amb - 2	Dark	200.05	25	0	27.31	27.31	50687.36	714	700.22	-13.78	-25575.68	1002	22
Dark High Amb - 3	Dark	199.29	25	0	42.28	42.28	78471.68	641.48	718.74	77.26	143394.56	1002	23
Light Low Hot - 1	Light	25.03	38	0	0	0	0	648.81	672.99	24.18	44878.08	1002	23
Light Low Hot - 2	Light	25.04	38	0	0	0	0	670.2	690.36	20.16	37416.96	1002	23
Light Low Hot - 3	Light	27.24	38	0	0	0	0	688.14	713.04	24.9	46214.4	1002	23
Dark Low Hot - 1	Dark	13.67	38	0	2.29	2.29	4250.24	680.6	709	28.4	52710.4	1002	23
Dark Low Hot - 2	Dark	15.5	38	0	3.07	3.07	5697.92	667.69	706.39	38.7	71827.2	1002	23

Dark Low Hot - 3	Dark	15.04	38	0	3.23	3.23	5994.88	666.3	701.17	34.87	64718.72	1002	23
Light Medium Hot - 1	Light	75.07	38	0	0.22	0.22	408.32	642.33	723.36	81.03	150391.68	1002	23
Light Medium Hot - 2	Light	74.91	38	0.21	0.76	0.55	1020.8	721.1	790.16	69.06	128175.36	1002	23
Light Medium Hot - 3	Light	74.89	38	0.7	1.33	0.63	1169.28	788.05	862.88	74.83	138884.48	1001	24
Dark Medium Hot - 1	Dark	76.06	38	0	16.04	16.04	29770.24	670.69	825.23	154.54	286826.24	1001	24
Dark Medium Hot - 2	Dark	75.64	38	0	18.28	18.28	33927.68	641.58	813.48	171.9	319046.4	1001	24
Dark Medium Hot - 3	Dark	75	38	0	19.45	19.45	36099.2	626.28	804.76	178.48	331258.88	1001	24
Light High Hot - 1	Light	190.19	38	0	0.68	0.68	1262.08	634.37	777.91	143.54	266410.24	1001	24
Light High Hot - 2	Light	189	38	0	0.74	0.74	1373.44	652.59	803.34	150.75	279792	1001	24
Light High Hot - 3	Light	188.6	38	0	1.05	1.05	1948.8	670.7	847.96	177.26	328994.56	1001	24
Dark High Hot - 1	Dark	202.91	38	0	33.02	33.02	61285.12	644.01	913.29	269.28	499783.68	1001	24
Dark High Hot - 2	Dark	200.68	38	0	38.44	38.44	71344.64	571.42	880.8	309.38	574209.28	1002	24
Dark High Hot - 3	Dark	201.53	38	0	32.82	32.82	60913.92	631.92	903.78	271.86	504572.16	1002	24

May 19th	Day 18												
System Conditions													
Loop Size	0.464	L											
Syringe Volume	0.00025	L											
Container Volume	0.95	L											
Sample Name	Roast	Mass	Storage Temp	Loop CO Background	Loop CO Concentration	Net Loop CO Concentration	Calculated Container CO Concentration	Loop CO2 Background	Loop CO2 Concentration	Net Loop CO2 Concentration	Calculated Container CO2 Concentration	Sample Loop Pressure	Sample Loop
Light Low Cold - 1	Light	49.96	4	0	0	0	0	425.06	458.26	33.2	61619.2	1002	27
Light Low Cold - 2	Light	50.07	4	0	0	0	0	456.55	482.21	25.66	47624.96	1002	27
Light Low Cold - 3	Light	49.97	4	0	0	0	0	482.21	505.13	22.92	42539.52	1002	27
Dark Low Cold - 1	Dark	51.1	4	0	7.89	7.89	14643.84	504.4	600.3	95.9	177990.4	1002	27
Dark Low Cold - 2	Dark	47.25	4	0	5.93	5.93	11006.08	417.87	500.36	82.49	153101.44	1002	27
Dark Low Cold - 3	Dark	51.25	4	0	6.43	6.43	11934.08	428.84	511.14	82.3	152748.8	1002	27
Light Medium Cold - 1	Light	99.97	4	0	0	0	0	437.35	488.48	51.13	94897.28	1002	28
Light Medium Cold - 2	Light	100.07	4	0	0	0	0	488.48	541.78	53.3	98924.8	1002	27
Light Medium Cold - 3	Light	100.05	4	0	0	0	0	435.33	482.71	47.38	87937.28	1002	27

Dark Medium Cold - 1	Dark	99.24	4	0	13.23	13.23	24554.88	481.18	631.06	149.88	278177.28	1002	28
Dark Medium Cold - 2	Dark	101.29	4	0	12.29	12.29	22810.24	422.7	564.04	141.34	262327.04	1002	27
Dark Medium Cold - 3	Dark	100.84	4	0	11.73	11.73	21770.88	432.99	570.4	137.41	255032.96	1002	27
Light High Cold - 1	Light	200.02	4	0	0.16	0.16	296.96	444.47	550.37	105.9	196550.4	1002	27
Light High Cold - 2	Light	200.08	4	0	0	0	0	498.89	604.04	105.15	195158.4	1002	27
Light High Cold - 3	Light	199.67	4	0	0	0	0	456.9	553.84	96.94	179920.64	1002	28
Dark High Cold - 1	Dark	201.22	4	0	24.04	24.04	44618.24	437.95	689.04	251.09	466023.04	1002	27
Dark High Cold - 2	Dark	199.95	4	0	18.88	18.88	35041.28	469.3	690.79	221.49	411085.44	1002	28
Dark High Cold - 3	Dark	201.54	4	0	23.72	23.72	44024.32	505.55	764.25	258.7	480147.2	1002	27
Light Low Amb - 1	Light	25.61	25	0	0	0	0	502.13	518.65	16.52	30661.12	1002	27
Light Low Amb - 2	Light	25.12	25	0	0	0	0	518.65	537.74	19.09	35431.04	1002	27
Light Low Amb - 3	Light	25.16	25	0	0	0	0	537.74	554.07	16.33	30308.48	1002	27
Dark Low Amb - 1	Dark	25.72	25	0	3.67	3.67	6811.52	418.15	460.17	42.02	77989.12	1002	27
Dark Low Amb - 2	Dark	25.3	25	0	4.09	4.09	7591.04	426.17	468.05	41.88	77729.28	1002	27
Dark Low Amb - 3	Dark	21.79	25	0	2.52	2.52	4677.12	454.03	484.78	30.75	57072	1002	27
Light Medium Amb - 1	Light	75.56	25	0	0	0	0	420.37	474.9	54.53	101207.68	1002	28
Light Medium Amb - 2	Light	75.04	25	0	0	0	0	474.9	530.88	55.98	103898.88	1002	27
Light Medium Amb - 3	Light	75.05	25	0	0	0	0	417.92	464.43	46.51	86322.56	1002	27
Dark Medium Amb - 1	Dark	73.7	25	0	10.12	10.12	18782.72	464.43	574.01	109.58	203380.48	1002	28
Dark Medium Amb - 2	Dark	64.59	25	0	12.56	12.56	23311.36	427.83	557.24	129.41	240184.96	1002	28
Dark Medium Amb - 3	Dark	75.45	25	0	9.48	9.48	17594.88	453	552.43	99.43	184542.08	1002	28
Light High Amb - 1	Light	199.53	25	0	0.29	0.29	538.24	447.27	591.77	144.5	268192	1002	28
Light High Amb - 2	Light	199.39	25	0	0.47	0.47	872.32	466.94	633.53	166.59	309191.04	1002	28
Light High Amb - 3	Light	199.74	25	0	0.27	0.27	501.12	455.55	604.78	149.23	276970.88	1002	28
Dark High Amb - 1	Dark	201.61	25	0	35.19	35.19	65312.64	438.64	732.67	294.03	545719.68	1002	28
Dark High Amb - 2	Dark	200.05	25	0	21.8	21.8	40460.8	449.87	657.83	207.96	385973.76	1002	28
Dark High Amb - 3	Dark	199.29	25	0	39.01	39.01	72402.56	428.72	746.75	318.03	590263.68	1002	28
Light Low Hot - 1	Light	25.03	38	0	0	0	0	424.64	443.51	18.87	35022.72	1002	28
Light Low Hot - 2	Light	25.04	38	0	0	0	0	443.51	460.05	16.54	30698.24	1002	28
Light Low Hot - 3	Light	27.24	38	0	0	0	0	460.05	480.09	20.04	37194.24	1002	28
Dark Low Hot - 1	Dark	13.67	38	0	2.19	2.19	4064.64	431.25	453.14	21.89	40627.84	1002	28

Dark Low Hot - 2	Dark	15.5	38	0	2.38	2.38	4417.28	432.61	458.28	25.67	47643.52	1002	28
Dark Low Hot - 3	Dark	15.04	38	0	2.83	2.83	5252.48	438.14	467.92	29.78	55271.68	1002	28
Light Medium Hot - 1	Light	75.07	38	0	0	0	0	423.28	487.78	64.5	119712	1002	28
Light Medium Hot - 2	Light	74.91	38	0	0	0	0	487.78	541.58	53.8	99852.8	1002	28
Light Medium Hot - 3	Light	74.89	38	0	0	0	0	421.3	485.57	64.27	119285.12	1002	28
Dark Medium Hot - 1	Dark	76.06	38	0	14.45	14.45	26819.2	485.57	599.06	113.49	210637.44	1002	28
Dark Medium Hot - 2	Dark	75.64	38	0	15.75	15.75	29232	486.22	610.46	124.24	230589.44	1002	28
Dark Medium Hot - 3	Dark	75	38	0	16.9	16.9	31366.4	435.27	568.7	133.43	247646.08	1002	28
Light High Hot - 1	Light	190.19	38	0	0.7	0.7	1299.2	464.19	623.13	158.94	294992.64	1002	28
Light High Hot - 2	Light	189	38	0	0.53	0.53	983.68	457.53	578.85	121.32	225169.92	1002	28
Light High Hot - 3	Light	188.6	38	0	0.51	0.51	946.56	522.56	674.94	152.38	282817.28	1002	28
Dark High Hot - 1	Dark	202.91	38	0	27.42	27.42	50891.52	485.43	680.4	194.97	361864.32	1002	28
Dark High Hot - 2	Dark	200.68	38	0	33.01	33.01	61266.56	430.13	664.87	234.74	435677.44	1002	28
Dark High Hot - 3	Dark	201.53	38	0	30.02	30.02	55717.12	445.32	659.22	213.9	396998.4	1002	28

May 23rd	Day 22												
System Conditions													
Loop Size	0.464	L											
Syringe Volume	0.00025	L											
Container Volume	0.95	L											
Sample Name	Roast	Mass	Storage Temp	Loop CO Background	Loop CO Concentration	Net Loop CO Concentration	Calculated Container CO Concentration	Loop CO2 Background	Loop CO2 Concentration	Net Loop CO2 Concentration	Calculated Container CO2 Concentration	Sample Loop Pressure	Sample Loop
Light Low Cold - 1	Light	49.96	4	0	0	0	0	437.84	472.41	34.57	64161.92	1005	26
Light Low Cold - 2	Light	50.07	4	0	0	0	0	472.41	498.4	25.99	48237.44	1005	26
Light Low Cold - 3	Light	49.97	4	0	0	0	0	498.4	519.81	21.41	39736.96	1005	27
Dark Low Cold - 1	Dark	51.1	4	0	7.9	7.9	14662.4	519.81	612.53	92.72	172088.32	1005	26
Dark Low Cold - 2	Dark	47.25	4	0	6.03	6.03	11191.68	432.29	505.36	73.07	135617.92	1005	26
Dark Low Cold - 3	Dark	51.25	4	0	6.52	6.52	12101.12	441.82	522.21	80.39	149203.84	1005	26
Light Medium Cold - 1	Light	99.97	4	0	0	0	0	447.42	495.01	47.59	88327.04	1005	26
Light Medium Cold - 2	Light	100.07	4	0	0	0	0	495.01	547.59	52.58	97588.48	1005	26

Light Medium Cold - 3	Light	100.05	4	0	0	0	0	547.59	598.6	51.01	94674.56	1005	26
Dark Medium Cold - 1	Dark	99.24	4	0	13.48	13.48	25018.88	431.52	572.74	141.22	262104.32	1004	27
Dark Medium Cold - 2	Dark	101.29	4	0	12.03	12.03	22327.68	437.51	568.01	130.5	242208	1004	27
Dark Medium Cold - 3	Dark	100.84	4	0	11.23	11.23	20842.88	450.33	572.63	122.3	226988.8	1004	27
Light High Cold - 1	Light	200.02	4	0	0	0	0	447.93	552.49	104.56	194063.36	1004	27
Light High Cold - 2	Light	200.08	4	0	0	0	0	441.29	546.33	105.04	194954.24	1004	26
Light High Cold - 3	Light	199.67	4	0	0	0	0	448.28	540.52	92.24	171197.44	1004	27
Dark High Cold - 1	Dark	201.22	4	0	23.17	23.17	43003.52	539.74	777.78	238.04	441802.24	1004	27
Dark High Cold - 2	Dark	199.95	4	0	17.81	17.81	33055.36	440.9	633.71	192.81	357855.36	1004	27
Dark High Cold - 3	Dark	201.54	4	0	22.88	22.88	42465.28	448.73	681.26	232.53	431575.68	1004	27
Light Low Amb - 1	Light	25.61	25	0	0	0	0	432.81	452.23	19.42	36043.52	1004	27
Light Low Amb - 2	Light	25.12	25	0	0	0	0	452.23	467.55	15.32	28433.92	1004	27
Light Low Amb - 3	Light	25.16	25	0	0	0	0	467.55	485.75	18.2	33779.2	1004	27
Dark Low Amb - 1	Dark	25.72	25	0	3.98	3.98	7386.88	485.75	522.94	37.19	69024.64	1004	27
Dark Low Amb - 2	Dark	25.3	25	0	3.87	3.87	7182.72	447.92	487.39	39.47	73256.32	1004	27
Dark Low Amb - 3	Dark	21.79	25	0	1.88	1.88	3489.28	432.31	458.3	25.99	48237.44	1004	27
Light Medium Amb - 1	Light	75.56	25	0	0	0	0	442	492.18	50.18	93134.08	1004	27
Light Medium Amb - 2	Light	75.04	25	0	0	0	0	492.18	548.23	56.05	104028.8	1004	27
Light Medium Amb - 3	Light	75.05	25	0	0	0	0	429.87	477.03	47.16	87528.96	1004	27
Dark Medium Amb - 1	Dark	73.7	25	0	8.83	8.83	16388.48	475.29	559.5	84.21	156293.76	1004	27
Dark Medium Amb - 2	Dark	64.59	25	0	11.7	11.7	21715.2	434.46	546.27	111.81	207519.36	1004	27
Dark Medium Amb - 3	Dark	75.45	25	0	9.12	9.12	16926.72	464.81	553.12	88.31	163903.36	1004	27
Light High Amb - 1	Light	199.53	25	0	0.46	0.46	853.76	628.81	773.55	144.74	268637.44	1004	27
Light High Amb - 2	Light	199.39	25	0	0.96	0.96	1781.76	476.92	644.91	167.99	311789.44	1004	27
Light High Amb - 3	Light	199.74	25	0	0.84	0.84	1559.04	442.54	582.98	140.44	260656.64	1004	27
Dark High Amb - 1	Dark	201.61	25	0	32.28	32.28	59911.68	471.84	730.44	258.6	479961.6	1004	27
Dark High Amb - 2	Dark	200.05	25	0	18.25	18.25	33872	461.57	628.45	166.88	309729.28	1004	27
Dark High Amb - 3	Dark	199.29	25	0	36.63	36.63	67985.28	443.43	728.34	284.91	528792.96	1004	27
Light Low Hot - 1	Light	25.03	38	0	0	0	0	443.64	462.31	18.67	34651.52	1004	27
Light Low Hot - 2	Light	25.04	38	0	0	0	0	456.16	474.3	18.14	33667.84	1004	27
Light Low Hot - 3	Light	27.24	38	0	0	0	0	474.3	488.83	14.53	26967.68	1004	27

Dark Low Hot - 1	Dark	13.67	38	0	1.92	1.92	3563.52	488.83	505.38	16.55	30716.8	1004	27
Dark Low Hot - 2	Dark	15.5	38	0	2.46	2.46	4565.76	462.91	486.69	23.78	44135.68	1004	27
Dark Low Hot - 3	Dark	15.04	38	0	3.06	3.06	5679.36	467.84	494.29	26.45	49091.2	1004	27
Light Medium Hot - 1	Light	75.07	38	0	0	0	0	479.05	542.42	63.37	117614.72	1004	27
Light Medium Hot - 2	Light	74.91	38	0	0	0	0	542.42	597.66	55.24	102525.44	1004	27
Light Medium Hot - 3	Light	74.89	38	0	0	0	0	453.35	520.27	66.92	124203.52	1004	27
Dark Medium Hot - 1	Dark	76.06	38	0	12.83	12.83	23812.48	445.25	541.34	96.09	178343.04	1004	27
Dark Medium Hot - 2	Dark	75.64	38	0	15.42	15.42	28619.52	466.57	575.33	108.76	201858.56	1004	27
Dark Medium Hot - 3	Dark	75	38	0	16.79	16.79	31162.24	474.21	594.15	119.94	222608.64	1004	27
Light High Hot - 1	Light	190.19	38	0	1.38	1.38	2561.28	470	622.43	152.43	282910.08	1004	27
Light High Hot - 2	Light	189	38	0	0.51	0.51	946.56	469.09	571.6	102.51	190258.56	1004	27
Light High Hot - 3	Light	188.6	38	0	0.86	0.86	1596.16	480.84	615.99	135.15	250838.4	1004	27
Dark High Hot - 1	Dark	202.91	38	0	24.15	24.15	44822.4	439.27	594.29	155.02	287717.12	1004	27
Dark High Hot - 2	Dark	200.68	38	0	30.57	30.57	56737.92	434.41	627.64	193.23	358634.88	1004	27
Dark High Hot - 3	Dark	201.53	38	0	28.15	28.15	52246.4	455.92	636.54	180.62	335230.72	1004	27

Appendix 3: Extended Statistics

Analysis of Variance Comparing Masses

				ANOVA				
Roast	Storage Temperature			Sum of Squares	df	Mean Square	F	Sig.
Dark	4	COD2	Between Groups	145318477.187	2	72659238.594	19.812	.002
			Within Groups	22004453.413	6	3667408.902		
			Total	167322930.600	8			
		CO2D2	Between Groups	13675493260.013	2	6837746630.007	17.216	.003
			Within Groups	2383111856.314	6	397185309.386		
			Total	16058605116.327	8			
		COD4	Between Groups	468465764.724	2	234232882.362	22.224	.002
			Within Groups	63238524.345	6	10539754.058		
			Total	531704289.069	8			
		CO2D4	Between Groups	31744566546.226	2	15872283273.113	15.610	.004
			Within Groups	6100797408.739	6	1016799568.123		

	Total		37845363954.965	8			
	COD6	Between Groups	167911070.663	2	83955535.331	3.753	.088
		Within Groups	134215033.803	6	22369172.300		
		Total	302126104.466	8			
	CO2D6	Between Groups	9584723961.623	2	4792361980.811	6.254	.034
		Within Groups	4597858270.570	6	766309711.762		
		Total	14182582232.193	8			
	COD9	Between Groups	98195874.065	2	49097937.033	.760	.508
		Within Groups	387804015.548	6	64634002.591		
		Total	485999889.613	8			
	CO2D9	Between Groups	12915217861.382	2	6457608930.691	.735	.518
		Within Groups	52705915626.837	6	8784319271.140		
		Total	65621133488.219	8			
	COD12	Between Groups	1861233559.517	2	930616779.758	71.069	.000
		Within Groups	78567720.336	6	13094620.056		
		Total	1939801279.853	8			

	CO2D12	Between Groups	236478243934 .685	2	11823912196 7.342	72.530	.000
		Within Groups	9781239257.3 66	6	1630206542.8 94		
		Total	246259483192 .051	8			
	COD15	Between Groups	1772929681.9 09	2	886464840.95 4	49.020	.000
		Within Groups	108502294.52 8	6	18083715.755		
		Total	1881431976.4 37	8			
	COD18	Between Groups	1264908666.7 43	2	632454333.37 2	55.242	.000
		Within Groups	68692628.821	6	11448771.470		
		Total	1333601295.5 65	8			
	CO2D18	Between Groups	130615132042 .672	2	65307566021. 336	116.575	.000
		Within Groups	3361324932.8 47	6	560220822.14 1		
		Total	133976456975 .519	8			
	COD22	Between Groups	1104338957.9 26	2	552169478.96 3	42.453	.000
		Within Groups	78040494.080	6	13006749.013		
		Total	1182379452.0 06	8			

25	CO2D22	Between Groups	102755447276 .976	2	51377723638. 488	56.098	.000
		Within Groups	5495100279.4 67	6	915850046.57 8		
		Total	108250547556 .443	8			
	COD2	Between Groups	689598131.85 9	2	344799065.93 0	17.318	.003
		Within Groups	119462412.20 7	6	19910402.035		
		Total	809060544.06 6	8			
	CO2D2	Between Groups	35332906149. 192	2	17666453074. 596	14.882	.005
		Within Groups	7122828688.2 69	6	1187138114.7 11		
		Total	42455734837. 461	8			
	COD4	Between Groups	1882686803.3 11	2	941343401.65 6	27.263	.001
		Within Groups	207167102.08 3	6	34527850.347		
		Total	2089853905.3 94	8			
	CO2D4	Between Groups	74542913691. 465	2	37271456845. 732	25.863	.001
		Within Groups	8646524736.6 49	6	1441087456.1 08		
		Total	83189438428. 114	8			

	COD6	Between Groups	4736085462.0 72	2	2368042731.0 36	111.060	.000
		Within Groups	127933005.97 5	6	21322167.662		
		Total	4864018468.0 46	8			
	CO2D6	Between Groups	156923122295 .121	2	78461561147. 560	86.952	.000
		Within Groups	5414125509.8 87	6	902354251.64 8		
		Total	162337247805 .008	8			
	COD9	Between Groups	5800651577.7 54	2	2900325788.8 77	71.012	.000
		Within Groups	245057141.14 6	6	40842856.858		
		Total	6045708718.8 99	8			
	CO2D9	Between Groups	442969806129 .015	2	22148490306 4.508	35.250	.000
		Within Groups	37699952529. 954	6	6283325421.6 59		
		Total	480669758658 .970	8			
	COD12	Between Groups	5987771180.6 11	2	2993885590.3 06	41.592	.000
		Within Groups	431889982.38 7	6	71981663.731		
		Total	6419661162.9 98	8			

	CO2D12	Between Groups	217661680058 .458	2	10883084002 9.229	3.803	.086
		Within Groups	171687767248 .800	6	28614627874. 800		
		Total	389349447307 .258	8			
	COD15	Between Groups	5250388836.7 16	2	2625194418.3 58	38.106	.000
		Within Groups	413354081.75 8	6	68892346.960		
		Total	5663742918.4 74	8			
	COD18	Between Groups	4555547923.0 69	2	2277773961.5 35	23.343	.001
		Within Groups	585469627.05 1	6	97578271.175		
		Total	5141017550.1 20	8			
	CO2D18	Between Groups	298374768704 .535	2	14918738435 2.267	35.849	.000
		Within Groups	24969066702. 165	6	4161511117.0 28		
		Total	323343835406 .700	8			
	COD22	Between Groups	3712511175.0 66	2	1856255587.5 33	16.812	.003
		Within Groups	662477159.62 9	6	110412859.93 8		
		Total	4374988334.6 94	8			

38	CO2D22	Between Groups	223480177403 .495	2	11174008870 1.747	23.659	.001
		Within Groups	28337574368. 870	6	4722929061.4 78		
		Total	251817751772 .365	8			
	COD2	Between Groups	5513542584.3 93	2	2756771292.1 96	39.504	.000
		Within Groups	418710978.65 5	6	69785163.109		
		Total	5932253563.0 47	8			
	CO2D2	Between Groups	239255670761 .563	2	11962783538 0.781	40.156	.000
		Within Groups	17874348388. 751	6	2979058064.7 92		
		Total	257130019150 .314	8			
	COD4	Between Groups	1340531890.3 61	2	670265945.18 0	66.886	.000
		Within Groups	60126049.831	6	10021008.305		
		Total	1400657940.1 91	8			
	CO2D4	Between Groups	42440092066. 802	2	21220046033. 401	55.006	.000
		Within Groups	2314671446.5 69	6	385778574.42 8		
		Total	44754763513. 371	8			

	COD6	Between Groups	3429108576.7 89	2	1714554288.3 95	12.021	.008
		Within Groups	855809260.51 9	6	142634876.75 3		
		Total	4284917837.3 08	8			
	CO2D6	Between Groups	81253319410. 379	2	40626659705. 189	10.410	.011
		Within Groups	23416109727. 238	6	3902684954.5 40		
		Total	104669429137 .617	8			
	COD9	Between Groups	6814896757.2 37	2	3407448378.6 18	87.047	.000
		Within Groups	234869678.89 9	6	39144946.483		
		Total	7049766436.1 36	8			
	CO2D9	Between Groups	483195085051 .858	2	24159754252 5.929	63.481	.000
		Within Groups	22835123482. 078	6	3805853913.6 80		
		Total	506030208533 .936	8			
	COD12	Between Groups	5192871205.7 95	2	2596435602.8 98	171.530	.000
		Within Groups	90821601.475	6	15136933.579		
		Total	5283692807.2 70	8			

	CO2D12	Between Groups	330642592031 .203	2	16532129601 5.602	74.656	.000
		Within Groups	13286615580. 202	6	2214435930.0 34		
		Total	343929207611 .405	8			
	COD15	Between Groups	5262434619.2 10	2	2631217309.6 05	170.726	.000
		Within Groups	92471641.429	6	15411940.238		
		Total	5354906260.6 39	8			
	COD18	Between Groups	3962447287.1 82	2	1981223643.5 91	182.872	.000
		Within Groups	65003775.863	6	10833962.644		
		Total	4027451063.0 46	8			
	CO2D18	Between Groups	184186553894 .594	2	92093276947. 297	156.987	.000
		Within Groups	3519783248.1 45	6	586630541.35 8		
		Total	187706337142 .739	8			
	COD22	Between Groups	3266587190.9 77	2	1633293595.4 89	95.582	.000
		Within Groups	102527514.76 1	6	17087919.127		
		Total	3369114705.7 38	8			

Light	4	CO2D22	Between Groups	123147388535 .967	2	61573694267. 984	97.910	.000
			Within Groups	3773285504.0 68	6	628880917.34 5		
			Total	126920674040 .035	8			
		COD2	Between Groups	117317.565	2	58658.783	33.985	.001
			Within Groups	10356.025	6	1726.004		
			Total	127673.590	8			
		CO2D2	Between Groups	1579364279.9 58	2	789682139.97 9	38.712	.000
			Within Groups	122393867.04 2	6	20398977.840		
			Total	1701758147.0 00	8			
		COD4	Between Groups	118179.848	2	59089.924	61.473	.000
			Within Groups	5767.415	6	961.236		
			Total	123947.263	8			
		CO2D4	Between Groups	1571664885.5 65	2	785832442.78 2	79.833	.000
			Within Groups	59060851.833	6	9843475.306		
			Total	1630725737.3 98	8			
		COD6	Between Groups	233167.290	2	116583.645	4.303	.069
			Within Groups	162553.647	6	27092.275		

	Total		395720.937	8			
	CO2D6	Between Groups	3178305549.5 89	2	1589152774.7 94	10.334	.011
		Within Groups	922649247.16 6	6	153774874.52 8		
		Total	4100954796.7 54	8			
	COD9	Between Groups	.000	2	.000	.	.
		Within Groups	.000	6	.000		
		Total	.000	8			
	CO2D9	Between Groups	7346890761.9 21	2	3673445380.9 61	3.355	.105
		Within Groups	6570392304.8 45	6	1095065384.1 41		
		Total	13917283066. 766	8			
	COD12	Between Groups	1872.720	2	936.360	1.000	.422
		Within Groups	5618.160	6	936.360		
		Total	7490.880	8			
	CO2D12	Between Groups	25393586779. 382	2	12696793389. 691	90.061	.000
		Within Groups	845876237.21 3	6	140979372.86 9		
		Total	26239463016. 595	8			
	COD15	Between Groups	.000	2	.000	.	.

		Within Groups	.000	6	.000		
		Total	.000	8			
	COD18	Between Groups	19596.720	2	9798.360	1.000	.422
		Within Groups	58790.161	6	9798.360		
		Total	78386.881	8			
	CO2D18	Between Groups	30798755873. 405	2	15399377936. 703	216.250	.000
		Within Groups	427266222.21 7	6	71211037.036		
		Total	31226022095. 622	8			
	COD22	Between Groups	.000	2	.000	.	.
		Within Groups	.000	6	.000		
		Total	.000	8			
	CO2D22	Between Groups	29024303158. 886	2	14512151579. 443	121.780	.000
		Within Groups	715003872.05 1	6	119167312.00 9		
		Total	29739307030. 938	8			
25	COD2	Between Groups	442426.857	2	221213.429	73.729	.000
		Within Groups	18002.098	6	3000.350		
		Total	460428.956	8			

	CO2D2	Between Groups	4427345140.2 98	2	2213672570.1 49	120.473	.000
		Within Groups	110249256.79 5	6	18374876.132		
		Total	4537594397.0 93	8			
	COD4	Between Groups	302345.893	2	151172.947	8.498	.018
		Within Groups	106729.979	6	17788.330		
		Total	409075.872	8			
	CO2D4	Between Groups	2751110964.0 13	2	1375555482.0 06	9.851	.013
		Within Groups	837802780.76 7	6	139633796.79 4		
		Total	3588913744.7 80	8			
	COD6	Between Groups	3398406.789	2	1699203.394	64.712	.000
		Within Groups	157547.872	6	26257.979		
		Total	3555954.660	8			
	CO2D6	Between Groups	22956357439. 911	2	11478178719. 955	40.923	.000
		Within Groups	1682896789.9 40	6	280482798.32 3		
		Total	24639254229. 850	8			
	COD9	Between Groups	1313669.211	2	656834.606	2.054	.209
		Within Groups	1918258.654	6	319709.776		

	Total		3231927.865	8			
	CO2D9	Between Groups	95862840796. 865	2	47931420398. 433	147.320	.000
		Within Groups	1952133498.7 43	6	325355583.12 4		
		Total	97814974295. 609	8			
	COD12	Between Groups	1189252.109	2	594626.054	1.498	.297
		Within Groups	2381200.934	6	396866.822		
		Total	3570453.043	8			
	CO2D12	Between Groups	104727938306 .890	2	52363969153. 445	76.475	.000
		Within Groups	4108323096.9 22	6	684720516.15 4		
		Total	108836261403 .811	8			
	COD15	Between Groups	6349337.395	2	3174668.698	57.480	.000
		Within Groups	331383.603	6	55230.601		
		Total	6680720.998	8			
	COD18	Between Groups	812115.649	2	406057.825	29.146	.001
		Within Groups	83592.260	6	13932.043		
		Total	895707.910	8			
	CO2D18	Between Groups	103268179236 .545	2	51634089618. 273	274.732	.000

38		Within Groups	1127660739.2 43	6	187943456.54 0		
		Total	104395839975 .788	8			
	COD22	Between Groups	3909851.910	2	1954925.955	24.988	.001
		Within Groups	469402.692	6	78233.782		
		Total	4379254.602	8			
	CO2D22	Between Groups	99569062113. 644	2	49784531056. 822	177.298	.000
		Within Groups	1684771232.7 00	6	280795205.45 0		
		Total	101253833346 .344	8			
	COD2	Between Groups	1037234.697	2	518617.348	5.586	.043
		Within Groups	557095.911	6	92849.318		
		Total	1594330.608	8			
	CO2D2	Between Groups	8167104488.2 98	2	4083552244.1 49	7.763	.022
		Within Groups	3156303918.9 46	6	526050653.15 8		
		Total	11323408407. 244	8			
	COD4	Between Groups	631879.687	2	315939.844	17.633	.003
		Within Groups	107504.414	6	17917.402		
		Total	739384.102	8			

	CO2D4	Between Groups	4250736392.1 39	2	2125368196.0 70	28.122	.001
		Within Groups	453453380.94 6	6	75575563.491		
		Total	4704189773.0 86	8			
	COD6	Between Groups	2522342.677	2	1261171.339	17.603	.003
		Within Groups	429865.161	6	71644.193		
		Total	2952207.838	8			
	CO2D6	Between Groups	13315618916. 889	2	6657809458.4 45	18.853	.003
		Within Groups	2118911724.1 48	6	353151954.02 5		
		Total	15434530641. 037	8			
	COD9	Between Groups	1839106.276	2	919553.138	28.981	.001
		Within Groups	190379.076	6	31729.846		
		Total	2029485.352	8			
	CO2D9	Between Groups	94285919884. 993	2	47142959942. 497	31.420	.001
		Within Groups	9002591331.6 69	6	1500431888.6 12		
		Total	103288511216 .663	8			
	COD12	Between Groups	210418.819	2	105209.410	3.388	.104
		Within Groups	186298.186	6	31049.698		

Total		396717.005	8			
CO2D12	Between Groups	39178171566. 806	2	19589085783. 403	3.395	.103
	Within Groups	34615256851. 296	6	5769209475.2 16		
	Total	73793428418. 102	8			
COD15	Between Groups	3523505.630	2	1761752.815	17.703	.003
	Within Groups	597087.573	6	99514.596		
	Total	4120593.203	8			
COD18	Between Groups	2317618.381	2	1158809.190	92.587	.000
	Within Groups	75095.245	6	12515.874		
	Total	2392713.626	8			
CO2D18	Between Groups	84574697213. 224	2	42287348606. 612	82.876	.000
	Within Groups	3061489829.4 78	6	510248304.91 3		
	Total	87636187042. 702	8			
COD22	Between Groups	5789070.222	2	2894535.111	13.154	.006
	Within Groups	1320252.484	6	220042.081		
	Total	7109322.706	8			
CO2D22	Between Groups	66829146139. 398	2	33414573069. 699	42.570	.000

	Within Groups	4709584269.0 39	6	784930711.50 6		
	Total	71538730408. 437	8			

Analysis of Variance Comparing storage temperature

			ANOVA					
Roast	Target Mass			Sum of Squares	df	Mean Square	F	Sig.
Dark	75	COD2	Between Groups	333788341.251	1	333788341.251	12.056	.026
			Within Groups	110746323.588	4	27686580.897		
			Total	444534664.838	5			
		CO2D2	Between Groups	16730929685.29 9	1	16730929685.29 9	9.815	.035
			Within Groups	6818458781.713	4	1704614695.428		
			Total	23549388467.01 2	5			
		COD4	Between Groups	155466965.262	1	155466965.262	32.039	.005
			Within Groups	19409962.397	4	4852490.599		
			Total	174876927.659	5			
		CO2D4	Between Groups	5650165684.533	1	5650165684.533	17.479	.014
			Within Groups	1293018005.255	4	323254501.314		
			Total	6943183689.788	5			
		COD6	Between Groups	64313827.394	1	64313827.394	1.137	.346
			Within Groups	226294738.911	4	56573684.728		
			Total	290608566.305	5			
		CO2D6	Between Groups	613209191.719	1	613209191.719	.440	.543
			Within Groups	5573987003.948	4	1393496750.987		
			Total	6187196195.667	5			
		COD9	Between Groups	24033291.537	1	24033291.537	.414	.555
			Within Groups	231949691.017	4	57987422.754		
			Total	255982982.554	5			
		CO2D9	Between Groups	3910981.018	1	3910981.018	.000	.984

		Within Groups	34145825723.187	4	8536456430.797		
		Total	34149736704.205	5			
COD12	Between Groups	186709940.546	1	186709940.546	15.063	.018	
	Within Groups	49580711.453	4	12395177.863			
	Total	236290651.999	5				
CO2D12	Between Groups	6965856861.660	1	6965856861.660	4.255	.108	
	Within Groups	6548891352.768	4	1637222838.192			
	Total	13514748214.428	5				
COD15	Between Groups	129867465.796	1	129867465.796	12.030	.026	
	Within Groups	43180684.356	4	10795171.089			
	Total	173048150.153	5				
COD18	Between Groups	128146246.042	1	128146246.042	17.954	.013	
	Within Groups	28550660.915	4	7137665.229			
	Total	156696906.957	5				
CO2D18	Between Groups	615406449.732	1	615406449.732	1.076	.358	
	Within Groups	2288078621.355	4	572019655.339			
	Total	2903485071.087	5				
COD22	Between Groups	135982159.258	1	135982159.258	12.071	.025	
	Within Groups	45061739.861	4	11265434.965			
	Total	181043899.119	5				
CO2D22	Between Groups	939845465.156	1	939845465.156	1.498	.288	
	Within Groups	2509104135.919	4	627276033.980			
	Total	3448949601.075	5				
200	COD2	Between Groups	4174866688.620	2	2087433344.310	28.237	.001
		Within Groups	443556904.083	6	73926150.680		
		Total	4618423592.703	8			
	CO2D2	Between Groups	148758775530.225	2	74379387765.112	22.183	.002
		Within Groups	20118312685.172	6	3353052114.195		
		Total	168877088215.397	8			
	COD4	Between Groups	388565123.811	2	194282561.905	3.762	.087
		Within Groups	309855293.253	6	51642548.875		
		Total	698420417.063	8			

	CO2D4	Between Groups	6198408476.998	2	3099204238.499	1.188	.368
		Within Groups	15652675850.617	6	2608779308.436		
		Total	21851084327.616	8			
	COD6	Between Groups	3138348690.887	2	1569174345.443	10.760	.010
		Within Groups	874991299.344	6	145831883.224		
		Total	4013339990.231	8			
	CO2D6	Between Groups	76126142443.599	2	38063071221.800	8.312	.019
		Within Groups	27475994979.202	6	4579332496.534		
		Total	103602137422.801	8			
	COD9	Between Groups	5429399135.937	2	2714699567.969	26.586	.001
		Within Groups	612662602.684	6	102110433.781		
		Total	6042061738.621	8			
	CO2D9	Between Groups	358893594748.610	2	179446797374.305	15.048	.005
		Within Groups	71550599973.547	6	11925099995.591		
		Total	430444194722.156	8			
	COD12	Between Groups	849812544.835	2	424906272.418	4.951	.054
		Within Groups	514907510.170	6	85817918.362		
		Total	1364720055.005	8			
	CO2D12	Between Groups	7085181430.080	2	3542590715.040	.117	.892
		Within Groups	181679160747.485	6	30279860124.581		
		Total	188764342177.565	8			
	COD15	Between Groups	704612557.983	2	352306278.992	3.873	.083
		Within Groups	545788564.821	6	90964760.804		
		Total	1250401122.805	8			
	COD18	Between Groups	558708697.862	2	279354348.931	2.486	.164
		Within Groups	674215671.671	6	112369278.612		
		Total	1232924369.533	8			

		CO2D18	Between Groups	17867196720.28 7	2	8933598360.144	1.883	.232
			Within Groups	28467768395.63 9	6	4744628065.940		
			Total	46334965115.92 7	8			
		COD22	Between Groups	353152114.779	2	176576057.390	1.375	.322
			Within Groups	770678384.230	6	128446397.372		
			Total	1123830499.009	8			
		CO2D22	Between Groups	20382269665.09 8	2	10191134832.54 9	1.839	.238
			Within Groups	33257804244.30 9	6	5542967374.052		
			Total	53640073909.40 7	8			
Light	25	COD2	Between Groups	38393.856	1	38393.856	8.582	.043
			Within Groups	17895.312	4	4473.828		
			Total	56289.168	5			
		CO2D2	Between Groups	99876049.934	1	99876049.934	20.787	.010
			Within Groups	19218991.083	4	4804747.771		
			Total	119095041.017	5			
		COD4	Between Groups	7477.387	1	7477.387	.605	.480
			Within Groups	49443.044	4	12360.761		
			Total	56920.431	5			
		CO2D4	Between Groups	17601411.076	1	17601411.076	.695	.451
			Within Groups	101339905.943	4	25334976.486		
			Total	118941317.018	5			
		COD6	Between Groups	47289.910	1	47289.910	4.018	.116
			Within Groups	47078.059	4	11769.515		
			Total	94367.969	5			
		CO2D6	Between Groups	556243913.996	1	556243913.996	10.532	.032
			Within Groups	211250809.771	4	52812702.443		
			Total	767494723.767	5			
		COD9	Between Groups	.000	1	.000	.	.
			Within Groups	.000	4	.000		
			Total	.000	5			
		CO2D9	Between Groups	109970670.660	1	109970670.660	15.478	.017
			Within Groups	28420679.543	4	7105169.886		

75	COD12	Total	138391350.204	5			
		Between Groups	.000	1	.000	.	.
		Within Groups	.000	4	.000		
	CO2D12	Total	.000	5			
		Between Groups	42719589.734	1	42719589.734	.770	.430
		Within Groups	221808102.970	4	55452025.742		
	COD15	Total	264527692.704	5			
		Between Groups	.000	1	.000	.	.
		Within Groups	.000	4	.000		
	COD18	Total	.000	5			
		Between Groups	.000	1	.000	.	.
		Within Groups	.000	4	.000		
	CO2D18	Total	.000	5			
		Between Groups	7073248.666	1	7073248.666	.740	.438
		Within Groups	38243918.370	4	9560979.593		
	COD22	Total	45317167.036	5			
		Between Groups	.000	1	.000	.	.
		Within Groups	.000	4	.000		
	CO2D22	Total	.000	5			
		Between Groups	1469754.027	1	1469754.027	.090	.779
		Within Groups	65502114.338	4	16375528.585		
	COD2	Total	66971868.365	5			
		Between Groups	64046.828	1	64046.828	15.089	.018
		Within Groups	16977.955	4	4244.489		
	CO2D2	Total	81024.784	5			
		Between Groups	558873968.640	1	558873968.640	21.889	.009
		Within Groups	102128480.561	4	25532120.140		
	COD4	Total	661002449.201	5			
		Between Groups	809.101	1	809.101	.067	.809
		Within Groups	48371.722	4	12092.930		
	CO2D4	Total	49180.823	5			
		Between Groups	27416746.450	1	27416746.450	.225	.660
		Within Groups	486734272.354	4	121683568.089		
	COD6	Total	514151018.804	5			
		Between Groups	290639.409	1	290639.409	14.079	.020
		Within Groups	82574.915	4	20643.729		
	CO2D6	Total	373214.324	5			
		Between Groups	1013886019.203	1	1013886019.203	4.916	.091

		Within Groups	824905441.307	4	206226360.327		
		Total	1838791460.511	5			
	COD9	Between Groups	.000	1	.000	.	.
		Within Groups	.000	4	.000		
		Total	.000	5			
	CO2D9	Between Groups	48283.716	1	48283.716	.000	.996
		Within Groups	6431458064.247	4	1607864516.062		
		Total	6431506347.964	5			
	COD12	Between Groups	.000	1	.000	.	.
		Within Groups	.000	4	.000		
		Total	.000	5			
	CO2D12	Between Groups	5175539107.286	1	5175539107.286	2.342	.201
		Within Groups	8839371363.120	4	2209842840.780		
		Total	14014910470.40	5			
	COD15	Between Groups	1125280.427	1	1125280.427	13.832	.020
		Within Groups	325412.727	4	81353.182		
		Total	1450693.154	5			
	COD18	Between Groups	.000	1	.000	.	.
		Within Groups	.000	4	.000		
		Total	.000	5			
	CO2D18	Between Groups	374788712.107	1	374788712.107	3.433	.138
		Within Groups	436640497.118	4	109160124.279		
		Total	811429209.225	5			
	COD22	Between Groups	.000	1	.000	.	.
		Within Groups	.000	4	.000		
		Total	.000	5			
	CO2D22	Between Groups	593057002.564	1	593057002.564	6.117	.069
		Within Groups	387798274.321	4	96949568.580		
		Total	980855276.885	5			
200	COD2	Between Groups	93938.094	1	93938.094	19.187	.012
		Within Groups	19583.898	4	4895.975		
		Total	113521.993	5			
	CO2D2	Between Groups	562174751.419	1	562174751.419	14.009	.020
		Within Groups	160512677.768	4	40128169.442		
		Total	722687429.187	5			
	COD4	Between Groups	56909.067	1	56909.067	5.045	.088
		Within Groups	45125.537	4	11281.384		

	Total	102034.604	5			
CO2D4	Between Groups	129862097.013	1	129862097.013	1.523	.285
	Within Groups	341181010.728	4	85295252.682		
	Total	471043107.741	5			
COD6	Between Groups	917999.323	1	917999.323	14.283	.019
	Within Groups	257093.853	4	64273.463		
	Total	1175093.175	5			
CO2D6	Between Groups	4775492636.164	1	4775492636.164	8.280	.045
	Within Groups	2307020032.740	4	576755008.185		
	Total	7082512668.904	5			
COD9	Between Groups	985251.908	1	985251.908	2.054	.225
	Within Groups	1918258.654	4	479564.663		
	Total	2903510.562	5			
CO2D9	Between Groups	34986954699.84	1	34986954699.84	19.601	.011
		4		4		
	Within Groups	7139865496.508	4	1784966374.127		
	Total	42126820196.35	5			
		2				
COD12	Between Groups	822554.806	1	822554.806	1.378	.305
	Within Groups	2386819.094	4	596704.774		
	Total	3209373.900	5			
CO2D12	Between Groups	17989080670.85	1	17989080670.85	40.115	.003
		8		8		
	Within Groups	1793755787.386	4	448438946.846		
	Total	19782836458.24	5			
		3				
COD15	Between Groups	4762003.046	1	4762003.046	57.480	.002
	Within Groups	331383.603	4	82845.901		
	Total	5093386.650	5			
COD18	Between Groups	434553.446	1	434553.446	12.208	.025
	Within Groups	142382.421	4	35595.605		
	Total	576935.868	5			
CO2D18	Between Groups	13322188598.54	1	13322188598.54	48.345	.002
		5		5		
	Within Groups	1102268212.292	4	275567053.073		
	Total	14424456810.83	5			
		7				
COD22	Between Groups	2932388.932	1	2932388.932	24.988	.007

		Within Groups	469402.692	4	117350.673		
		Total	3401791.625	5			
	CO2D22	Between Groups	13147850509.58	1	13147850509.58	28.032	.006
			5		5		
		Within Groups	1876127006.447	4	469031751.612		
		Total	15023977516.03	5			
		2					

Tukey Post Hoc Test Comparing Individual Temperatures

Multiple Comparisons

Tukey HSD

					Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
Target	Dependent	(I) Storage	(J) Storage					Lower Bound	Upper Bound
Roast	Mass	Variable	Temperature (°C)	Temperature (°C)	(I-J)				
Dark	200	COD2	4	25	-	7020.263	.302	-	10051.45
					11488.63	56012660		33028.73	64266367
					99999999	5000		64266367	25000
					98000			20000	
			38		-	7020.263	.001	-	-
					50336.26	56012660		71876.36	28796.17
					66666666	5000		30933034	02400299
					80000*			00000	55000
			25	4	11488.63	7020.263	.302	-	33028.73
					99999999	56012660		10051.45	64266367
					98000	5000		64266367	20000
								25000	
			38		-	7020.263	.004	-	-
					38847.62	56012660		60387.72	17307.53
					66666666	5000		30933034	02400299
					80000*			00000	55000

	38	4	50336.26	7020.263	.001	28796.17	71876.36	
			66666666	56012660		02400299	30933034	
			80000*	5000		55000	00000	
		25	38847.62	7020.263	.004	17307.53	60387.72	
			66666666	56012660		02400299	30933034	
			80000*	5000		55000	00000	
	CO2D2	4	25	-	47279.67	.569	-	94860.38
				50206.65	93150104		195273.6	35410939
				60000000	80000		95541094	60000
				20000			000000	
			38	-	47279.67	.002	-	-
				294340.8	93150104		439407.9	149273.8
74666666				80000		14207760	35125572	
			700000*			700000	750000	
25		4	50206.65	47279.67	.569	-	195273.6	
			60000000	93150104		94860.38	95541094	
			20000	80000		35410939	000000	
						60000		
	38	-	47279.67	.005	-	-		
		244134.2	93150104		389201.2	99067.17		
		18666666	80000		58207760	91255727		
		680000*			630000	00000		
38	4	294340.8	47279.67	.002	149273.8	439407.9		
		74666666	93150104		35125572	14207760		
		700000*	80000		750000	700000		
	25	244134.2	47279.67	.005	99067.17	389201.2		
18666666		93150104		91255727	58207760			
680000*		80000		00000	630000			
COD4	4	25	-	5867.568	.083	-	2394.564	
			15608.74	99550018		33612.06	62928407	
			83333333	3500		12959507	5600	
			33000			40000		

38			-	5867.568	.216	-	6799.263
			11204.04	99550018		29207.36	29595073
			96666666	3500		26292840	9000
			70000			78000	
25	4		15608.74	5867.568	.083	-	33612.06
			83333333	99550018		2394.564	12959507
			33000	3500		62928407	40000
						5600	
38			4404.698	5867.568	.744	-	22408.01
			66666666	99550018		13598.61	16292840
			3500	3500		42959507	72000
						45000	
38	4		11204.04	5867.568	.216	-	29207.36
			96666666	99550018		6799.263	26292840
			70000	3500		29595073	78000
						9000	
25			-	5867.568	.744	-	13598.61
			4404.698	99550018		22408.01	42959507
			66666666	3500		16292840	45000
			3500			72000	
CO2D4	4	25	-	41703.55	.401	-	69831.65
			58126.29	14749541		186084.2	67422685
			13333333	30000		39408935	60000
			30000			220000	
38			-	41703.55	.991	-	122668.8
			5289.106	14749541		133247.0	41408935
			66666665	30000		54742268	230000
			9000			550000	
25	4		58126.29	41703.55	.401	-	186084.2
			13333333	14749541		69831.65	39408935
			30000	30000		67422685	220000
						60000	

38			52837.18	41703.55	.462	-	180795.1
			46666666	14749541		75120.76	32742268
			70000	30000		34089352	560000
						20000	
38 4			5289.106	41703.55	.991	-	133247.0
			66666665	14749541		122668.8	54742268
			9000	30000		41408935	550000
						230000	
25			-	41703.55	.462	-	75120.76
			52837.18	14749541		180795.1	34089352
			46666666	30000		32742268	20000
			70000			560000	
COD6	4	25	-	9860.083	.013	-	-
			42026.95	94907007		72280.39	11773.50
			46666666	6000		98854487	94478845
			70000*			70000	71000
38			-	9860.083	.023	-	-
			36649.19	94907007		66902.63	6395.749
			46666666	6000		98854487	44788456
			70000*			60000	9000
25	4		42026.95	9860.083	.013	11773.50	72280.39
			46666666	94907007		94478845	98854487
			70000*	6000		71000	70000
38			5377.760	9860.083	.853	-	35631.20
			00000000	94907007		24875.68	52187821
			2000	6000		52187821	00000
						00000	
38	4		36649.19	9860.083	.023	6395.749	66902.63
			46666666	94907007		44788456	98854487
			70000*	6000		9000	60000
25			-	9860.083	.853	-	24875.68
			5377.760	94907007		35631.20	52187821
			00000000	6000		52187821	00000
			2000			00000	

CO2D6	4	25	-	55252.94	.017	-	-
			220546.9	86183534		390078.1	51015.71
			33333333	80000		52624746	40419205
			400000*			300000	24000
		38	-	55252.94	.078	-	19478.87
			150052.3	86183534		319583.5	79580794
			41333333	80000		60624746	80000
			400000			260000	
	25	4	220546.9	55252.94	.017	51015.71	390078.1
			33333333	86183534		40419205	52624746
			400000*	80000		24000	300000
		38	70494.59	55252.94	.457	-	240025.8
			20000000	86183534		99036.62	11291412
			00000	80000		72914128	900000
						80000	
	38	4	150052.3	55252.94	.078	-	319583.5
			41333333	86183534		19478.87	60624746
			400000	80000		79580794	260000
						80000	
		25	-	55252.94	.457	-	99036.62
			70494.59	86183534		240025.8	72914128
			20000000	80000		11291412	80000
			00000			900000	
COD9	4	25	-	8250.674	.002	-	-
			50514.13	06460919		75829.46	25198.79
			33333333	7000		70689271	95977395
			30000*			30000	37000
		38	-	8250.674	.002	-	-
			53557.97	06460919		78873.30	28242.63
			33333333	7000		70689271	95977395
			30000*			30000	33000
	25	4	50514.13	8250.674	.002	25198.79	75829.46
			33333333	06460919		95977395	70689271
			30000*	7000		37000	30000

38			-	8250.674	.929	-	22271.49
			3043.839	06460919		28359.17	37355938
			99999999	7000		37355937	00000
			6500			90000	
38			4	53557.97	8250.674	.002	28242.63
				33333333	06460919		78873.30
				30000*	7000	95977395	70689271
						33000	30000
25			3043.839	8250.674	.929	-	28359.17
			99999999	06460919		22271.49	37355937
			6500	7000		37355938	90000
						00000	
CO2D9	4	25	-	89163.14	.006	-	-
			439902.9	63314715		713479.9	166325.9
			33333333	20000		51237712	15428954
			470000*			60000	30000
38			-	89163.14	.009	-	-
			405183.3	63314715		678760.3	131606.3
			60000000	20000		77904379	42095620
			000000*			20000	80000
25	4	439902.9	89163.14	.006	166325.9	713479.9	
		33333333	63314715		15428954	51237712	
		470000*	20000		30000	60000	
38			34719.57	89163.14	.921	-	308296.5
			33333334	63314715		238857.4	91237712
			80000	20000		44571045	65000
						70000	
38	4	405183.3	89163.14	.009	131606.3	678760.3	
		60000000	63314715		42095620	77904379	
		000000*	20000		80000	20000	
25			-	89163.14	.921	-	238857.4
			34719.57	63314715		308296.5	44571045
			33333334	20000		91237712	70000
			80000			65000	

COD12	4	25	-	7563.857	.055	-	612.9529
			22595.03	84995990		45803.03	83467297
			99999999	1000		29834672	600
			94000			90000	
		38	-	7563.857	.124	-	5429.392
			17778.60	84995990		40986.59	98346729
			00000000	1000		29834672	3000
			00000			86000	
	25	4	22595.03	7563.857	.055	-	45803.03
			99999999	84995990		612.9529	29834672
			94000	1000		83467297	90000
						600	
		38	4816.439	7563.857	.806	-	28024.43
			99999999	84995990		18391.55	29834672
			5000	1000		29834672	86000
						96000	
	38	4	17778.60	7563.857	.124	-	40986.59
			00000000	84995990		5429.392	29834672
			00000	1000		98346729	86000
						3000	
		25	-	7563.857	.806	-	18391.55
			4816.439	84995990		28024.43	29834672
			99999999	1000		29834672	96000
			5000			86000	
CO2D12	4	25	66769.20	142079.4	.888	-	502708.0
			00000000	61627594		369169.6	04503777
			70000	900000		04503777	70000
						60000	
		38	19278.00	142079.4	.990	-	455216.8
			00000000	61627594		416660.8	04503777
			60000	900000		04503777	70000
						60000	

	25	4	-	142079.4	.888	-	369169.6
			66769.20	61627594		502708.0	04503777
			00000000	900000		04503777	60000
			70000			70000	
	38		-	142079.4	.941	-	388447.6
			47491.20	61627594		483430.0	04503777
			00000000	900000		04503777	63000
			10000			66000	
	38	4	-	142079.4	.990	-	416660.8
			19278.00	61627594		455216.8	04503777
			00000000	900000		04503777	60000
			60000			70000	
	25		47491.20	142079.4	.941	-	483430.0
			00000000	61627594		388447.6	04503777
			10000	900000		04503777	66000
						63000	
COD15	4	25	-	7787.372	.121	-	5463.717
			18430.07	71928325		42323.87	98163824
			99999999	5000		79816382	5000
			94000			30000	
	38		-	7787.372	.109	-	4801.744
			19092.05	71928325		42985.85	64830491
			33333333	5000		13149715	0000
			30000			70000	
	25	4	18430.07	7787.372	.121	-	42323.87
			99999999	71928325		5463.717	79816382
			94000	5000		98163824	30000
						5000	
	38		-	7787.372	.996	-	23231.82
			661.9733	71928325		24555.77	46483049
			33333335	5000		13149715	04000
			200			75000	

	38	4	19092.05	7787.372	.109	-	42985.85	
			33333333	71928325		4801.744	13149715	
			30000	5000		64830491 0000	70000	
	25	661.9733	7787.372	.996	-	24555.77		
		33333335	71928325		23231.82	13149715		
		200	5000		46483049 04000	75000		
	COD18	4	25	-	8655.221	.170	-	8392.541
				18164.05	10681990		44720.64	81982639
				33333333	1000		84864930 70000	8000
		38	-	8655.221	.279	-	11826.14	
14730.45			10681990		41287.04	18198263		
33333333			1000		84864930 80000	96000		
25		4	18164.05	8655.221	.170	-	44720.64	
			33333333	10681990		8392.541	84864930	
			37000	1000		81982639 8000	70000	
38		3433.599	8655.221	.918	-	29990.19		
	99999999	10681990		23122.99	51531597			
	8500	1000		51531597 36000	33000			
	38	4	14730.45	8655.221	.279	-	41287.04	
			33333333	10681990		11826.14	84864930	
			38000	1000		18198263 96000	80000	
	25	-	8655.221	.918	-	23122.99		
		3433.599	10681990		29990.19	51531597		
		99999999	1000		51531597 33000	36000		
	8500							

CO2D18	4	25	-	56241.31	.617	-	117663.3
			54900.48	37941609		227464.2	15064285
			00000000	10000		75064285	65000
			40000			73000	
		38	54238.50	56241.31	.624	-	226802.3
			66666665	37941609		118325.2	01730952
			95000	10000		88397619	28000
						10000	
	25	4	54900.48	56241.31	.617	-	227464.2
			00000000	37941609		117663.3	75064285
			40000	10000		15064285	73000
						65000	
		38	109138.9	56241.31	.208	-	281702.7
			86666666	37941609		63424.80	81730952
			630000	10000		83976190	30000
						5400	
	38	4	-	56241.31	.624	-	118325.2
			54238.50	37941609		226802.3	88397619
			66666665	10000		01730952	10000
			95000			28000	
		25	-	56241.31	.208	-	63424.80
			109138.9	37941609		281702.7	83976190
			86666666	10000		81730952	5400
			630000			30000	
COD22	4	25	-	9253.698	.332	-	13977.95
			14414.93	26508059		42807.82	40882953
			33333333	3000		07549620	62000
			27000			10000	
		38	-	9253.698	.460	-	16632.03
			11760.85	26508059		40153.74	40882953
			33333333	3000		07549620	57000
			33000			26000	

	25	4	14414.93	9253.698	.332	-	42807.82
			33333333	26508059		13977.95	07549620
			27000	3000		40882953	10000
						62000	
		38	2654.079	9253.698	.956	-	31046.96
			99999999	26508059		25738.80	74216286
			4500	3000		74216286	84000
						95000	
	38	4	11760.85	9253.698	.460	-	40153.74
			33333333	26508059		16632.03	07549620
			33000	3000		40882953	26000
						57000	
		25	-	9253.698	.956	-	25738.80
			2654.079	26508059		31046.96	74216286
			99999999	3000		74216286	95000
			4500			84000	
CO2D22	4	25	-	60789.07	.884	-	157434.0
			29083.52	45340067		215601.0	53867967
			00000001	95000		93867967	16000
			35000			43000	
		38	83216.85	60789.07	.413	-	269734.4
			33333333	45340067		103300.7	27201300
			90000	95000		20534633	70000
						90000	
	25	4	29083.52	60789.07	.884	-	215601.0
			00000001	45340067		157434.0	93867967
			35000	95000		53867967	43000
						16000	
		38	112300.3	60789.07	.234	-	298817.9
			73333333	45340067		74217.20	47201300
			530000	95000		05346337	80000
						7000	

38	4	-	60789.07	.413	-	103300.7
		83216.85	45340067		269734.4	20534633
		33333333	95000		27201300	90000
		90000			70000	
	25	-	60789.07	.234	-	74217.20
		112300.3	45340067		298817.9	05346337
		73333333	95000		47201300	7000
		530000			80000	

T – Test Comparing Roast Temperature

Independent Samples Test ^a												
Storage Temperature Target Mass				Levene's Test for Equality of Variances		t-test for Equality of Means						
				F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
4	50	COD2	Equal variances assumed	9.717	.036	-25.742	4	.000	-3968.12799999999700	154.148283288815350	-4396.112246611874000	-3540.143753388125300
			Equal variances not assumed			-25.742	2.000	.002	-3968.12799999999700	154.148283288815350	-4631.292641102388000	-3304.963358897611000
		CO2D2	Equal variances assumed	.015	.909	-17.723	4	.000	-36027.434666666670000	2032.781875877051800	-41671.341955880300000	-30383.527377453040000
			Equal variances not assumed			-17.723	3.997	.000	-36027.434666666670000	2032.781875877051800	-41672.896693503510000	-30381.972639829823000
		COD4	Equal variances assumed	7.119	.056	-27.214	4	.000	-4472.825333333333000	164.357169583333080	-4929.153992327142000	-4016.496674339524400
			Equal variances not assumed			-27.214	2.050	.001	-4472.825333333333000	164.357169583333080	-5163.697109950332000	-3781.953556716335000

	CO2D4	Equal variances assumed	.025	.881	-11.806	4	.000	-30494.425000000003000	2583.023908902938000	-37666.049088482430000	-23322.800911517570000
		Equal variances not assumed			-11.806	3.960	.000	-30494.425000000003000	2583.023908902938000	-37694.933180410230000	-23293.916819589773000
	COD6	Equal variances assumed	3.531	.133	-29.614	4	.000	-8996.0320000000001000	303.774940784932200	-9839.446447424076000	-8152.617552575926000
		Equal variances not assumed			-29.614	2.066	.001	-8996.0320000000001000	303.774940784932200	-10263.818602403053000	-7728.245397596949000
	CO2D6	Equal variances assumed	.511	.514	-21.803	4	.000	-61138.805333333340000	2804.184485186062400	-68924.469621299770000	-53353.141045366900000
		Equal variances not assumed			-21.803	3.181	.000	-61138.805333333340000	2804.184485186062400	-69782.601277083030000	-52495.009389583650000
	COD9	Equal variances assumed	8.692	.042	-34.540	4	.000	-9496.533333333335000	274.941480642296200	-10259.893261478472000	-8733.173405188198000
		Equal variances not assumed			-34.540	2.000	.001	-9496.533333333335000	274.941480642296260	-10679.511045540270000	-8313.555621126400000
	CO2D9	Equal variances assumed	.058	.822	-18.032	4	.000	- 106447.786666666662000 0	5903.117504897063000	- 122837.46836854548000 0	-90058.104964787770000
		Equal variances not assumed			-18.032	3.998	.000	- 106447.786666666662000 0	5903.117504897064000	- 122841.24400696461000 0	-90054.329326368640000

	COD12	Equal variances assumed	15.405	.017	-18.598	4	.000	-10550.8800000000000000	567.314427103700200	-12125.997364240158000	-8975.762635759840000
		Equal variances not assumed			-18.598	2.000	.003	-10550.8800000000000000	567.314427103700300	-12991.836968403988000	-8109.923031596010000
	CO2D1 2	Equal variances assumed	.282	.624	-6.544	4	.003	- 109951.92000000004000 0	16800.91265321024200 0	- 156598.73169886130000 0	-63305.108301138804000
		Equal variances not assumed			-6.544	3.865	.003	- 109951.92000000004000 0	16800.91265321024200 0	- 157248.60846586325000 0	-62655.231534136845000
	COD15	Equal variances assumed	4.235	.109	-32.789	4	.000	-12299.09333333332000	375.097758161493060	-13340.531667951476000	-11257.654998715188000
		Equal variances not assumed			-32.789	2.000	.001	-12299.09333333332000	375.097758161493060	-13913.008726409786000	-10685.177940256879000
	COD18	Equal variances assumed	10.145	.033	-11.480	4	.000	-12528.0000000000000000	1091.311165403036300	-15557.965543430959000	-9498.034456569041000
		Equal variances not assumed			-11.480	2.000	.008	-12528.0000000000000000	1091.311165403036300	-17223.532964827442000	-7832.467035172557000
	CO2D1 8	Equal variances assumed	1.080	.357	-10.940	4	.000	- 110685.65333333338000 0	10117.25066267399000 0	- 138775.64441377370000 0	-82595.662252893050000
		Equal variances not assumed									

100		Equal variances not assumed			-10.940	3.532	.001	-	10117.25066267399000	-	-81063.586847670490000
								110685.65333333338000	0	140307.71981899627000	0
								0		0	
	COD22	Equal variances assumed	9.915	.035	-12.176	4	.000	-12651.73333333332000	1039.046936978519900	-15536.590115578103000	-9766.876551088560000
		Equal variances not assumed			-12.176	2.000	.007	-12651.73333333332000	1039.046936978520000	-17122.391473061780000	-8181.075193604884000
	CO2D2	Equal variances assumed	.478	.527	-7.921	4	.001	-	12825.30618603362000	-	-65982.494750457360000
	2							101591.25333333338000	0	137200.01191620942000	0
								0		0	
		Equal variances not assumed			-7.921	3.502	.002	-	12825.30618603362000	-	-63895.984772113260000
								101591.25333333338000	0	139286.52189455350000	0
								0		0	
100	COD2	Equal variances assumed	5.242	.084	-12.796	4	.000	-8034.93333333333000	627.912380016334900	-9778.297587322782000	-6291.569079343884000
		Equal variances not assumed			-12.796	2.005	.006	-8034.93333333333000	627.912380016334900	-10730.257533877457000	-5339.609132789210000
	CO2D2	Equal variances assumed	2.013	.229	-9.282	4	.001	-65883.050666666660000	7097.620391178007000	-85589.204060304880000	-46176.897273028444000
		Equal variances not assumed			-9.282	2.736	.004	-65883.050666666660000	7097.620391178007000	-89754.694770957720000	-42011.406562375600000
	COD4	Equal variances assumed	9.671	.036	-63.685	4	.000	-11240.280666666667000	176.498047548533950	-11730.317806859763000	-10750.243526473572000

	Equal variances not assumed			-63.685	2.060	.000	-11240.28066666667000	176.498047548533950	-11978.853383565360000	-10501.707949767975000
CO2D4	Equal variances assumed	.005	.949	-22.674	4	.000	-84490.072666666660000	3726.301466205657000	-94835.944133004710000	-74144.201200328600000
	Equal variances not assumed			-22.674	3.914	.000	-84490.072666666660000	3726.301466205657000	-94925.924196045830000	-74054.221137287490000
COD6	Equal variances assumed	11.709	.027	-23.778	4	.000	-19457.685333333330000	818.319160538777300	-21729.703561100785000	-17185.667105565877000
	Equal variances not assumed			-23.778	2.053	.002	-19457.685333333330000	818.319160538777300	-22892.407397086370000	-16022.963269580294000
CO2D6	Equal variances assumed	.335	.594	-17.771	4	.000	-119881.20533333333000 0	6745.967716260471000	138611.01437896705000 0	101151.39628769961000 0
	Equal variances not assumed			-17.771	3.841	.000	-119881.20533333333000 0	6745.967716260471000	138920.75475520170000 0	100841.65591146497000 0
COD9	Equal variances assumed	6.309	.066	-10.755	4	.000	-16450.346666666665000	1529.533692658576000	-20697.013000883670000	-12203.680332449656000
	Equal variances not assumed			-10.755	2.000	.009	-16450.346666666665000	1529.533692658576200	-23031.398984627864000	-9869.294348705465000
CO2D9	Equal variances assumed	7.008	.057	-9.904	4	.001	-164552.95999999999000 0	16614.65472703208800 0	210682.63679141953000 0	118423.28320858028000 0

	Equal variances not assumed			-9.904	2.263	.007	-164552.9599999999900000	16614.65472703209000	-228634.14809950997000	-100471.77190048984000
							0	0	0	0
COD12	Equal variances assumed	15.657	.017	-9.245	4	.001	-19883.8800000000000000	2150.733794405993600	-25855.274316061998000	-13912.485683938005000
	Equal variances not assumed			-9.245	2.000	.011	-19883.8800000000000000	2150.733794405993600	-29137.740631465370000	-10630.019368534631000
CO2D12	Equal variances assumed	9.597	.036	-6.087	4	.004	-169762.6800000000100000	27888.88096112864500	-247194.62703396965000	-92330.732966030570000
							0	0	0	0
	Equal variances not assumed			-6.087	2.113	.023	-169762.6800000000100000	27888.88096112864000	-283818.17152644990000	-55707.188473550326000
							0	0	0	0
COD15	Equal variances assumed	9.319	.038	-11.146	4	.000	-20886.186666666665000	1873.865657985592600	-26088.871800579007000	-15683.501532754324000
	Equal variances not assumed			-11.146	2.000	.008	-20886.186666666665000	1873.865657985592900	-28948.779855182150000	-12823.593478151179000
COD18	Equal variances assumed	6.606	.062	-28.373	4	.000	-23045.333333333332000	812.222394941462000	-25300.424226100582000	-20790.242440566082000
	Equal variances not assumed			-28.373	2.000	.001	-23045.333333333332000	812.222394941462100	-26540.044238091860000	-19550.622428574803000

	CO2D1 8	Equal variances assumed	1.907	.239	-22.690	4	.000	- 171259.30666666664000 0	7547.926030327039000	- 192215.70894796317000 0	- 150302.90438537012000 0
		Equal variances not assumed			-22.690	2.842	.000	- 171259.30666666664000 0	7547.926030327039000	- 196055.13592097835000 0	- 146463.47741235493000 0
	COD22	Equal variances assumed	7.073	.056	-18.598	4	.000	-22729.813333333335000	1222.160302269896000	-26123.074322337640000	-19336.552344329030000
		Equal variances not assumed			-18.598	2.000	.003	-22729.813333333335000	1222.160302269896000	-27988.344694086332000	-17471.281972580340000
	CO2D2 2	Equal variances assumed	2.547	.186	-14.270	4	.000	- 150237.01333333337000 0	10528.11989610894300 0	- 179467.76028582052000 0	- 121006.26638084620000 0
		Equal variances not assumed			-14.270	2.288	.003	- 150237.01333333337000 0	10528.11989610894500 0	- 190490.67209774145000 0	- 109983.35456892528000 0
	200 COD2	Equal variances assumed	4.111	.113	-7.487	4	.002	-13499.616000000000000	1803.080490725678400	-18505.770002752943000	-8493.461997247055000
		Equal variances not assumed			-7.487	2.002	.017	-13499.616000000000000	1803.080490725678400	-21251.985920788375000	-5747.246079211626000
	CO2D2	Equal variances assumed	3.720	.126	-5.211	4	.006	-99289.194666666680000 0	19054.54984653071400 0	- 152193.10631981422000 0	-46385.283013519120000

	Equal variances not assumed			-5.211	2.117	.031	-99289.194666666680000	19054.54984653071400 0	- 177084.83278086272000 0	-21493.556552470633000
COD4	Equal variances assumed	15.814	.016	-6.713	4	.003	-21736.122666666663000	3237.676706139209000	-30725.354309639784000	-12746.891023693543000
	Equal variances not assumed			-6.713	2.000	.021	-21736.122666666663000	3237.676706139209000	-35666.298417616184000	-7805.946915717142500
CO2D4	Equal variances assumed	15.373	.017	-4.546	4	.010	- 144198.451000000000000 0	31718.85414540887000 0	- 232264.10833450320000 0	-56132.793665496820000
	Equal variances not assumed			-4.546	2.001	.045	- 144198.451000000000000 0	31718.85414540887000 0	- 280607.22954758455000 0	-7789.672452415485000
COD6	Equal variances assumed	11.463	.028	-3.174	4	.034	-14762.933333333334000	4651.272848567607000	-27676.937066678263000	-1848.929599988407000
	Equal variances not assumed			-3.174	2.003	.086	-14762.933333333334000	4651.272848567607000	-34746.051891924760000	5220.185225258094000
CO2D6	Equal variances assumed	3.757	.125	-1.887	4	.132	-55545.749333333330000	29439.99074785167600 0	- 137284.26754227444000 0	26192.768875607762000
	Equal variances not assumed			-1.887	2.652	.168	-55545.749333333330000	29439.99074785167600 0	- 156582.44095870803000 0	45490.942292041370000

	COD9	Equal variances assumed	12.273	.025	-2.099	4	.104	-16555.5200000000000000	7887.898101302610500	-38455.836073660600000	5344.796073660596000
		Equal variances not assumed			-2.099	2.000	.171	-16555.5200000000000000	7887.898101302611000	-50494.406297555295000	17383.366297555290000
	CO2D9	Equal variances assumed	4.610	.098	-1.084	4	.339	- 106039.46666666659000 0	97818.66441178410000 0	- 377627.61866975017000 0	165548.68533641697000 0
		Equal variances not assumed			-1.084	2.491	.372	- 106039.46666666659000 0	97818.66441178410000 0	- 456593.97692005490000 0	244515.04358672167000 0
	COD12	Equal variances assumed	9.758	.035	-15.625	4	.000	-44602.560000000005000	2854.479795409315000	-52527.866455850190000	-36677.253544149820000
		Equal variances not assumed			-15.625	2.000	.004	-44602.560000000005000	2854.479795409315000	-56881.690912961145000	-32323.429087038865000
	CO2D12	Equal variances assumed	5.679	.076	-13.759	4	.000	- 366906.24000000010000 0	26666.93774167554500 0	- 440945.52876348945000 0	- 292866.95123651077000 0
		Equal variances not assumed			-13.759	2.027	.005	- 366906.24000000010000 0	26666.93774167554500 0	- 480166.51190648595000 0	- 253645.96809351427000 0
	COD15	Equal variances assumed	10.975	.030	-11.957	4	.000	-45422.506666666675000	3798.900488603395000	-55969.945333383075000	-34875.067999950275000

	Equal variances not assumed			-11.957	2.000	.007	-45422.506666666675000	3798.900488603395000	-61767.856224002644000	-29077.157109330707000
COD18	Equal variances assumed	14.575	.019	-13.269	4	.000	-41128.960000000000000	3099.662006061664700	-49735.001404497480000	-32522.918595502517000
	Equal variances not assumed			-13.269	2.004	.006	-41128.960000000000000	3099.662006061664700	-54439.721875590770000	-27818.198124409228000
CO2D18	Equal variances assumed	6.221	.067	-12.052	4	.000	-261875.413333333300000 0	21727.90626927909400 0	-322201.75234086970000 0	-201549.07432579692000 0
	Equal variances not assumed			-12.052	2.255	.004	-261875.41333333330000 0	21727.90626927909400 0	-345937.34119744690000 0	-177813.48546921968000 0
COD22	Equal variances assumed	15.673	.017	-12.231	4	.000	-39508.053333333340000	3230.085861342459300	-48476.209412426210000	-30539.897254240466000
	Equal variances not assumed			-12.231	2.000	.007	-39508.053333333340000	3230.085861342459300	-53405.991081963610000	-25610.115584703057000
CO2D22	Equal variances assumed	6.603	.062	-8.115	4	.001	-223672.74666666662000 0	27562.43043118572300 0	-300198.32172468690000 0	-147147.17160864630000 0
	Equal variances not assumed			-8.115	2.343	.009	-223672.74666666662000 0	27562.43043118572300 0	-327079.40187136724000 0	-120266.09146196599000 0

25	25	COD2	Equal variances assumed	15.582	.017	-8.674	4	.001	-4425.0752000000000000	510.177216380800700	-5841.554235203910000	-3008.596164796090800
			Equal variances not assumed			-8.674	2.000	.013	-4425.0752000000000000	510.177216380800700	-6620.016083485889000	-2230.134316514112000
		CO2D2	Equal variances assumed	4.216	.109	-9.392	4	.001	-32850.890666666670000	3497.599444204489000	-42561.783523470745000	-23139.997809862600000
			Equal variances not assumed			-9.392	2.012	.011	-32850.890666666670000	3497.599444204489000	-47811.806318318160000	-17889.975015015190000
		COD4	Equal variances assumed	4.600	.099	-15.073	4	.000	-4955.286000000001000	328.748177261697950	-5868.037267600938000	-4042.534732399063000
			Equal variances not assumed			-15.073	2.115	.003	-4955.286000000001000	328.748177261697950	-6298.525097256839000	-3612.046902743162300
		CO2D4	Equal variances assumed	.209	.671	-7.824	4	.001	-28021.117333333343000	3581.593756294989400	-37965.215786805544000	-18077.018879861140000
			Equal variances not assumed			-7.824	3.913	.002	-28021.117333333343000	3581.593756294990000	-38052.733152115140000	-17989.501514551543000
		COD6	Equal variances assumed	7.861	.049	-2.908	4	.044	-3399.57333333333700	1169.226029089519000	-6645.865218668781000	-153.281447997886520
			Equal variances not assumed			-2.908	2.000	.101	-3399.57333333333700	1169.226029089519200	-8429.739604860933000	1630.592938194267000
		CO2D6	Equal variances assumed	.399	.562	-2.222	4	.090	-16359.712000000009000	7364.224961365106500	-36806.078347557566000	4086.654347557547000

	Equal variances not assumed			-2.222	3.412	.102	-16359.7120000000009000	7364.224961365106500	-38274.250735308540000	5554.826735308519000
COD9	Equal variances assumed	6.832	.059	-7.089	4	.002	-7380.693333333334000	1041.199641780789500	-10271.526982289302000	-4489.859684377365000
	Equal variances not assumed			-7.089	2.000	.019	-7380.693333333334000	1041.199641780789500	-11860.613814255612000	-2900.772852411056000
CO2D9	Equal variances assumed	14.492	.019	-3.692	4	.021	- 114298.66666666674000 0	30957.48716725206000 0	- 200250.43038140720000 0	-28346.902951926270000
	Equal variances not assumed			-3.692	2.010	.066	- 114298.66666666674000 0	30957.48716725206400 0	- 246864.04275397767000 0	18266.709420644183000
COD12	Equal variances assumed	12.201	.025	-7.311	4	.002	-6780.9600000000000000	927.518255130323600	-9356.163519438185000	-4205.756480561815000
	Equal variances not assumed			-7.311	2.000	.018	-6780.9600000000000000	927.518255130323600	-10771.748952328946000	-2790.171047671053700
CO2D1 2	Equal variances assumed	2.977	.160	-4.967	4	.008	-65067.8400000000000000	13101.10760001610300 0	- 101442.34606873430000 0	-28693.333931265683000
	Equal variances not assumed			-4.967	2.960	.016	-65067.8400000000000000	13101.10760001610300 0	- 107080.56544059543000 0	-23055.114559404567000

	COD15	Equal variances assumed	10.936	.030	-11.389	4	.000	-6069.120000000000000	532.879977981283900	-7548.632006524043000	-4589.607993475956000
		Equal variances not assumed			-11.389	2.000	.008	-6069.120000000000000	532.879977981283900	-8361.917491890006000	-3776.322508109994500
	COD18	Equal variances assumed	9.734	.036	-7.302	4	.002	-6359.893333333333000	870.958748761641600	-8778.062488161788000	-3941.724178504879500
		Equal variances not assumed			-7.302	2.000	.018	-6359.893333333333000	870.958748761641700	-10107.326371191788000	-2612.460295474878400
	CO2D18	Equal variances assumed	8.769	.042	-5.446	4	.006	-38796.586666666640000	7123.645117369504000	-58574.996283953355000	-19018.177049379923000
		Equal variances not assumed			-5.446	2.227	.025	-38796.586666666640000	7123.645117369504000	-66643.941682833960000	-10949.231650499318000
	COD22	Equal variances assumed	15.694	.017	-4.753	4	.009	-6019.626666666667000	1266.545303378884700	-9536.120174744225000	-2503.133158589109000
		Equal variances not assumed			-4.753	2.000	.042	-6019.626666666667000	1266.545303378885000	-11469.131273601190000	-570.122059732145300
	CO2D22	Equal variances assumed	5.979	.071	-3.819	4	.019	-30753.920000000027000	8053.861501090983000	-53115.024342645030000	-8392.815657355019000
		Equal variances not assumed			-3.819	2.338	.048	-30753.920000000027000	8053.861501090984000	-61021.302776404890000	-486.537223595161800
	75	COD2	Equal variances assumed	6.837	.059	-2.427	4	.072	-10325.546666666667000	4254.913170838833000	-22139.079512883764000

	Equal variances not assumed			-2.427	2.000	.136	-10325.546666666667000	4254.913170838833000	-28631.092254358040000	7979.998921024702000
CO2D2	Equal variances assumed	5.977	.071	-1.951	4	.123	-64449.599999999990000	33029.41403219507600 0	- 156153.95491723932000 0	27254.754917239334000
	Equal variances not assumed			-1.951	2.007	.190	-64449.599999999990000	33029.41403219507000 0	- 206090.29433572484000 0	77191.094335724850000
COD4	Equal variances assumed	5.341	.082	-5.324	4	.006	-9100.174333333336000	1709.141816933021800	-13845.512765045887000	-4354.835901620785000
	Equal variances not assumed			-5.324	2.010	.033	-9100.174333333336000	1709.141816933021800	-16418.477815844093000	-1781.870850822580000
CO2D4	Equal variances assumed	.706	.448	-1.870	4	.135	-30772.505666666670000	16453.69291957905400 0	-76455.280835659520000	14910.269502326177000
	Equal variances not assumed			-1.870	3.349	.149	-30772.505666666670000	16453.69291957905400 0	-80183.122841999530000	18638.111508666190000
COD6	Equal variances assumed	5.094	.087	-6.862	4	.002	-16674.922666666670000	2429.997922120740000	-23421.678503179606000	-9928.166830153732000
	Equal variances not assumed			-6.862	2.000	.021	-16674.922666666670000	2429.997922120740000	-27130.018590121290000	-6219.826743212046500
CO2D6	Equal variances assumed	6.942	.058	-5.780	4	.004	- 101197.472000000001000 0	17508.31274962133000 0	- 149808.34123395826000 0	-52586.602766041750000

	Equal variances not assumed			-5.780	2.061	.027	-	17508.31274962133000	-	-27949.783656871223000
							101197.472000000001000	0	174445.16034312878000	0
							0		0	
COD9	Equal variances assumed	9.646	.036	-12.391	4	.000	-22117.333333333332000	1784.925706216117300	-27073.081573498785000	-17161.585093167880000
	Equal variances not assumed			-12.391	2.000	.006	-22117.333333333332000	1784.925706216117300	-29797.248795584100000	-14437.417871082565000
CO2D9	Equal variances assumed	4.249	.108	-3.732	4	.020	-	48982.01431071340600	-	-46801.566124291510000
							182797.440000000000000	0	318793.31387570850000	0
							0		0	
	Equal variances not assumed			-3.732	2.349	.050	-	48982.01431071340600	-	614.458613654744100
							182797.440000000000000	0	366209.33861365470000	0
							0		0	
COD12	Equal variances assumed	7.916	.048	-7.514	4	.002	-21083.400000000000000	2805.944917207036000	-28873.952030834100000	-13292.847969165901000
	Equal variances not assumed			-7.514	2.000	.017	-21083.400000000000000	2805.944917207036300	-33156.406557547490000	-9010.393442452514000
CO2D1 2	Equal variances assumed	.618	.476	-4.261	4	.013	-	37027.10107784298500	-	-54963.766452758850000
							157767.47999999992000	0	260571.19354724098000	0
							0		0	
	Equal variances not assumed			-4.261	3.248	.020	-	37027.10107784298500	-	-44860.946445448720000
							157767.47999999992000	0	270674.01355455110000	0
							0		0	

	COD15	Equal variances assumed	8.022	.047	-12.375	4	.000	-23960.960000000003000	1936.298185301013500	-29336.985618782370000	-18584.934381217634000
		Equal variances not assumed			-12.375	2.000	.006	-23960.960000000003000	1936.298185301013500	-32292.178672594342000	-15629.741327405663000
	COD18	Equal variances assumed	11.739	.027	-11.424	4	.000	-19896.320000000003000	1741.609850837244700	-24731.804145521330000	-15060.835854478677000
		Equal variances not assumed			-11.424	2.000	.008	-19896.320000000003000	1741.609850837245000	-27389.862378863432000	-12402.777621136574000
	CO2D18	Equal variances assumed	2.971	.160	-6.514	4	.003	- 112226.13333333335000 0	17229.37017118287000 0	- 160062.53381075490000 0	-64389.732855911810000
		Equal variances not assumed			-6.514	2.442	.013	- 112226.13333333335000 0	17229.37017118287000 0	- 174873.38864639570000 0	-49578.878020270980000
	COD22	Equal variances assumed	14.864	.018	-10.835	4	.000	-18343.466666666664000	1693.011599461478500	-23044.020435034574000	-13642.912898298755000
		Equal variances not assumed			-10.835	2.000	.008	-18343.466666666664000	1693.011599461478500	-25627.907646587100000	-11059.025686746227000
	CO2D22	Equal variances assumed	5.987	.071	-4.857	4	.008	-81008.213333333330000	16677.79724603677500 0	- 127313.20186257336000 0	-34703.224804093300000
		Equal variances not assumed									

		Equal variances not assumed			-4.857	2.365	.028	-81008.213333333330000	16677.79724603677500 0	- 143123.80171942926000 0	-18892.624947237410000
200	COD2	Equal variances assumed	14.880	.018	-19.878	4	.000	-24738.005333333330000	1244.522197804621800	-28193.352897737972000	-21282.657768928690000
		Equal variances not assumed			-19.878	2.005	.002	-24738.005333333330000	1244.522197804621800	-30079.370725301455000	-19396.639941365207000
	CO2D2	Equal variances assumed	3.652	.129	-12.864	4	.000	- 130136.53333333335000 0	10116.20470639257800 0	- 158223.62037357590000 0	- 102049.44629309080000 0
		Equal variances not assumed			-12.864	2.738	.002	- 130136.53333333335000 0	10116.20470639257800 0	- 164144.24959131386000 0	-96128.817075352850000
	COD4	Equal variances assumed	10.686	.031	-6.617	4	.003	-37150.090666666660000	5613.946701077456000	-52736.905505714465000	-21563.275827618860000
		Equal variances not assumed			-6.617	2.001	.022	-37150.090666666660000	5613.946701077456000	-61294.155756999010000	-13006.025576334316000
	CO2D4	Equal variances assumed	4.849	.092	-5.359	4	.006	- 193020.188000000000000 0	36016.23839847395000 0	- 293017.29680907980000 0	-93023.079190920200000
		Equal variances not assumed			-5.359	2.182	.027	- 193020.188000000000000 0	36016.23839847395000 0	- 336226.79032372650000 0	-49813.585676273535000

	COD6	Equal variances assumed	4.612	.098	-14.928	4	.000	-56007.584000000010000	3751.859036859221800	-66424.414658279900000	-45590.753341720120000
		Equal variances not assumed			-14.928	2.007	.004	-56007.584000000010000	3751.859036859221800	-72093.467999266520000	-39921.700000733500000
	CO2D6	Equal variances assumed	.727	.442	-7.662	4	.002	- 219668.736000000010000 0	28671.66240996496700 0	- 299274.03275603090000 0	- 140063.43924396930000 0
		Equal variances not assumed			-7.662	3.524	.003	- 219668.736000000010000 0	28671.66240996496700 0	- 303694.44320432560000 0	- 135643.02879567453000 0
	COD9	Equal variances assumed	11.743	.027	-10.909	4	.000	-66259.200000000000000	6073.920493592988000	-83123.106823796810000	-49395.293176203180000
		Equal variances not assumed			-10.909	2.035	.008	-66259.200000000000000	6073.920493592988000	-91967.552325798010000	-40550.847674201985000
	CO2D9	Equal variances assumed	7.931	.048	-6.896	4	.002	- 393218.34666666670000 0	57018.21872995881000 0	- 551526.30096655790000 0	- 234910.39236677543000 0
		Equal variances not assumed			-6.896	2.165	.016	- 393218.34666666670000 0	57018.21872995881000 0	- 621470.52654620870000 0	- 164966.16678712465000 0
	COD12	Equal variances assumed	10.094	.034	-8.330	4	.001	-66457.080000000000000	7977.776229100440000	-88606.937761649230000	-44307.222238350776000

		Equal variances not assumed			-8.330	2.025	.014	-66457.0800000000000000	7977.776229100440000	-	-32535.945103417143000
										100378.21489658285000	0
	CO2D1 2	Equal variances assumed	6.106	.069	-1.144	4	.316	-	166603.4308061440000	-	271939.51997087774000
								190625.75999999995000	00	653191.03997087760000	0
								0		0	
		Equal variances not assumed			-1.144	2.043	.369	-	166603.4308061440000	-	511998.77506190440000
								190625.75999999995000	00	893250.29506190420000	0
								0		0	
	COD15	Equal variances assumed	5.126	.086	-7.704	4	.002	-62070.826666666670000	8056.945191997057000	-84440.492707833800000	-39701.160625499540000
		Equal variances not assumed			-7.704	2.003	.016	-62070.826666666670000	8056.945191997058000	-96680.643938482650000	-27461.009394850676000
	COD18	Equal variances assumed	10.982	.030	-6.067	4	.004	-58754.773333333330000	9685.062168303880000	-85644.816784056970000	-31864.729882609700000
		Equal variances not assumed			-6.067	2.001	.026	-58754.773333333330000	9685.062168303880000	-	-17095.172651203276000
										100414.37401546339000	0
	CO2D1 8	Equal variances assumed	6.992	.057	-3.518	4	.024	-	63260.23282690424000	-	-46895.836214069070000
								222534.40000000008000	0	398172.96378593110000	0
								0		0	
		Equal variances not assumed			-3.518	2.161	.064	-	63260.23282690424000	-	31085.960171077110000
								222534.40000000008000	0	476154.76017107730000	0
								0		0	

38	75	COD22	Equal variances assumed	10.180	.033	-5.101	4	.007	-52524.799999999996000	10296.63384018075900 0	-81112.838625583810000	-23936.761374416175000
			Equal variances not assumed			-5.101	2.003	.036	-52524.799999999996000	10296.63384018075900 0	-96765.088747780740000	-8284.511252219258000
		CO2D2 2	Equal variances assumed	6.147	.068	-2.331	4	.080	- 159133.44000000018000 0	68269.39768937239000 0	- 348679.67504945970000 0	30412.795049459295000
			Equal variances not assumed			-2.331	2.228	.132	- 159133.44000000018000 0	68269.39768937240000 0	- 425854.47573636286000 0	107587.59573636250000 0
		COD2	Equal variances assumed	6.058	.070	-41.945	4	.000	-25036.202666666664000	596.878686025151300	-26693.403572878087000	-23379.001760455240000
			Equal variances not assumed			-41.945	2.021	.001	-25036.202666666664000	596.878686025151300	-27578.893953272500000	-22493.511380060827000
		CO2D2	Equal variances assumed	1.734	.258	-19.071	4	.000	- 150759.47733333337000 0	7904.999624849528000	- 172707.27484833723000 0	- 128811.67981832952000 0
			Equal variances not assumed			-19.071	3.159	.000	- 150759.47733333337000 0	7904.999624849527000	- 175217.22411539540000 0	- 126301.73055127136000 0
		COD4	Equal variances assumed	5.415	.081	-33.943	4	.000	-19257.550666666666000	567.353448976130700	-20832.776372993530000	-17682.324960339804000

	Equal variances not assumed			-33.943	2.008	.001	-19257.550666666666000	567.353448976130700	-21689.223321448564000	-16825.878011884768000
CO2D4	Equal variances assumed	2.553	.185	-18.946	4	.000	-96421.839000000000000	5089.338749756646000	-110552.108660455300000	-82291.569339544720000
	Equal variances not assumed			-18.946	2.998	.000	-96421.839000000000000	5089.338749756646000	-112623.586230329850000	-80220.091769670170000
COD6	Equal variances assumed	8.655	.042	-4.039	4	.016	-22782.709333333332000	5641.335161364234000	-38445.566728883260000	-7119.851937783402000
	Equal variances not assumed			-4.039	2.002	.056	-22782.709333333332000	5641.335161364234000	-47035.464242149040000	1470.045575482378000
CO2D6	Equal variances assumed	1.625	.271	-3.461	4	.026	-95417.887999999980000	27567.028473715000000	-171956.229270694170000	-18879.546729305788000
	Equal variances not assumed			-3.461	2.811	.045	-95417.887999999980000	27567.028473715000000	-186573.972411556750000	-4261.803588443203000
COD9	Equal variances assumed	15.368	.017	-4.386	4	.012	-26120.106666666667000	5955.864509823722000	-42656.237532187995000	-9583.975801145345000
	Equal variances not assumed			-4.386	2.000	.048	-26120.106666666667000	5955.864509823722000	-51746.123357877660000	-494.089975455681270

	CO2D9	Equal variances assumed	2.798	.170	-2.794	4	.049	-	66057.87542227026000	-	-1185.508457405521800
								184591.57333333336000	0	367997.63820926123000	0
		Equal variances not assumed			-2.794	2.947	.070	-	66057.87542227026000	-	27771.655170109647000
								184591.57333333336000	0	396954.80183677640000	0
	COD12	Equal variances assumed	15.836	.016	-51.617	4	.000	-32240.160000000000000	624.599896253594000	-33974.327324660340000	-30505.992675339658000
		Equal variances not assumed			-51.617	2.000	.000	-32240.160000000000000	624.599896253594000	-34927.596448616760000	-29552.723551383242000
	CO2D1 2	Equal variances assumed	4.518	.101	-4.839	4	.008	-	34550.02515801106000	-	-71247.671765579570000
								167173.91999999998000	0	263100.16823442040000	0
		Equal variances not assumed			-4.839	2.271	.031	-	34550.02515801107000	-	-34298.840920489690000
								167173.91999999998000	0	300048.99907951030000	0
	COD15	Equal variances assumed	5.542	.078	-17.314	4	.000	-32399.573333333330000	1871.300488489816400	-37595.136414955120000	-27204.010251711540000
		Equal variances not assumed			-17.314	2.063	.003	-32399.573333333330000	1871.300488489816600	-40220.345392716816000	-24578.801273949844000
	COD18	Equal variances assumed	4.521	.101	-22.185	4	.000	-29139.19999999997000	1313.483389058778800	-32786.014526310850000	-25492.385473689140000

	CO2D1 8	Equal variances not assumed			-22.185	2.000	.002	-29139.199999999997000	1313.483389058778800	-34790.662889414330000	-23487.737110585666000
		Equal variances assumed	.395	.564	-9.304	4	.001	- 116674.34666666666000 0	12540.68006860520500 0	- 151492.85645899712000 0	-81855.836874336220000
		Equal variances not assumed			-9.304	3.315	.002	- 116674.34666666666000 0	12540.68006860520500 0	- 154520.64925368986000 0	-78828.044079643470000
		Equal variances assumed	7.335	.054	-12.930	4	.000	-27864.746666666670000	2154.994594187600300	-33847.970859426540000	-21881.522473906803000
	CO2D2 2	Equal variances assumed	.821	.416	-6.022	4	.004	-86155.520000000120000	14306.22757380230500 0	- 125875.97552112924000 0	-46435.064478871010000
		Equal variances not assumed			-6.022	2.947	.010	-86155.520000000120000	14306.22757380230500 0	- 132149.79573149650000 0	-40161.244268503746000

APPENDIX 4: Extended Tables and Graphs

A4.1 CO Concentration Data Grouped by Roast

Table 9: CO Concentration over time in Light Roast Samples

Carbon Monoxide Light						Day							
Sample Name	Roast	Mass	Target Mass	Storage Temperature	Replicate Number	2	4	6	9	12	15	18	22
Light Low Cold - 1	Light	49.96	50	4	1	0.00	75.25	263.55	0.00	0.00	0.00	0.00	0.00
Light Low Cold - 2	Light	50.07	50	4	2	3.71	19.51	139.20	0.00	0.00	0.00	0.00	0.00
Light Low Cold - 3	Light	49.97	50	4	3	0.00	73.39	157.76	0.00	0.00	0.00	0.00	0.00
Light Medium Cold - 1	Light	99.97	100	4	1	120.64	74.32	349.86	0.00	0.00	0.00	0.00	0.00
Light Medium Cold - 2	Light	100.07	100	4	2	44.54	114.27	69.60	0.00	0.00	0.00	0.00	0.00
Light Medium Cold - 3	Light	100.05	100	4	3	88.16	148.64	352.64	0.00	0.00	0.00	0.00	0.00
Light High Cold - 1	Light	200.02	200	4	1	220.86	340.01	758.18	0.00	0.00	0.00	296.96	0.00
Light High Cold - 2	Light	200.08	200	4	2	340.58	297.28	600.42	0.00	91.80	0.00	0.00	0.00
Light High Cold - 3	Light	199.67	200	4	3	260.77	329.80	315.52	0.00	0.00	0.00	0.00	0.00
Light Low Amb - 1	Light	25.61	25	25	1	0.74	179.30	0.00	0.00	0.00	0.00	0.00	0.00
Light Low Amb - 2	Light	25.12	25	25	2	0.00	17.65	0.00	0.00	0.00	0.00	0.00	0.00
Light Low Amb - 3	Light	25.16	25	25	3	10.21	11.15	27.84	0.00	0.00	0.00	0.00	0.00
Light Medium Amb - 1	Light	75.56	75	25	1	94.66	424.55	73.31	0.00	0.00	0.00	0.00	0.00
Light Medium Amb - 2	Light	75.04	75	25	2	192.10	389.25	46.40	0.00	0.00	0.00	0.00	0.00
Light Medium Amb - 3	Light	75.05	75	25	3	103.94	150.50	78.88	0.00	0.00	0.00	0.00	0.00
Light High Amb - 1	Light	199.53	200	25	1	524.32	559.26	1027.30	37.12	0.00	1614.72	538.24	853.76
Light High Amb - 2	Light	199.39	200	25	2	602.27	640.08	1428.19	1911.68	2019.60	2245.76	872.32	1781.76
Light High Amb - 3	Light	199.74	200	25	3	446.37	352.09	1565.54	482.56	293.76	1484.80	501.12	1559.04
Light Low Hot - 1	Light	25.03	25	38	1	120.64	275.91	360.06	0.00	0.00	0.00	0.00	0.00
Light Low Hot - 2	Light	25.04	25	38	2	271.90	114.27	72.38	0.00	0.00	0.00	0.00	0.00
Light Low Hot - 3	Light	27.24	25	38	3	98.37	29.73	128.06	0.00	0.00	0.00	0.00	0.00

Light Medium Hot - 1	Light	75.07	75	38	1	290.46	320.51	690.43	0.00	0.00	408.32	0.00	0.00
Light Medium Hot - 2	Light	74.91	75	38	2	423.17	395.75	539.17	0.00	0.00	1020.80	0.00	0.00
Light Medium Hot - 3	Light	74.89	75	38	3	296.96	317.72	289.54	0.00	0.00	1169.28	0.00	0.00
Light High Hot - 1	Light	190.19	190	38	1	1476.45	969.88	1856.00	631.04	0.00	1262.08	1299.20	2561.28
Light High Hot - 2	Light	189	190	38	2	449.15	589.92	1091.33	1002.24	367.20	1373.44	983.68	946.56
Light High Hot - 3	Light	188.6	190	38	3	938.21	767.35	1357.66	1243.52	605.88	1948.80	946.56	1596.16

Table 10: CO Concentration over time in Dark Roast Samples

Carbon Monoxide Dark						Day							
Sample Name	Roast	Mass	Target Mass	Storage Temperature	Replicate Number	2	4	6	9	12	15	18	22
Dark Low Cold - 1	Dark	51.1	50	4	1	4186.21	4842.88	9687.39	10022.40	9418.68	12954.88	14643.84	14662.40
Dark Low Cold - 2	Dark	47.25	50	4	2	4050.72	4449.91	9215.97	9094.40	11052.72	11655.68	11006.08	11191.68
Dark Low Cold - 3	Dark	51.25	50	4	3	3671.17	4293.84	8645.25	9372.80	11181.24	12286.72	11934.08	12101.12
Dark Medium Cold - 1	Dark	99.24	100	4	1	8243.42	11128.49	20416.00	16852.48	15587.64	17279.36	24554.88	25018.88
Dark Medium Cold - 2	Dark	101.29	100	4	2	6975.78	11697.97	20635.01	13623.04	22215.60	23571.20	22810.24	22327.68
Dark Medium Cold - 3	Dark	100.84	100	4	3	9138.94	11231.61	18094.14	18875.52	21848.40	21808.00	21770.88	20842.88
Dark High Cold - 1	Dark	201.22	200	4	1	10615.39	18704.49	12246.82	32071.68	48635.64	50576.00	44618.24	43003.52
Dark High Cold - 2	Dark	199.95	200	4	2	13846.69	28532.38	9257.73	11265.92	39106.80	38010.88	35041.28	33055.36
Dark High Cold - 3	Dark	201.54	200	4	3	16858.98	18938.59	24458.37	6328.96	46157.04	47680.64	44024.32	42465.28
Dark Low Amb - 1	Dark	25.72	25	25	1	5448.29	5630.67	5158.75	9001.60	7399.08	6792.96	6811.52	7386.88
Dark Low Amb - 2	Dark	25.3	25	25	2	3953.28	4920.91	1190.62	7702.40	7986.60	6384.64	7591.04	7182.72
Dark Low Amb - 3	Dark	21.79	25	25	3	3884.61	4522.37	3877.18	5438.08	4957.20	5029.76	4677.12	3489.28
Dark Medium Amb - 1	Dark	73.7	75	25	1	18408.74	9025.24	12367.46	23032.96	16872.84	23181.44	18782.72	16388.48
Dark Medium Amb - 2	Dark	64.59	75	25	2	9100.90	12556.36	20763.07	24647.68	26401.68	27635.84	23311.36	21715.20
Dark Medium Amb - 3	Dark	75.45	75	25	3	3857.70	6683.23	17092.83	18671.36	19975.68	21065.60	17594.88	16926.72
Dark High Amb - 1	Dark	201.61	200	25	1	23968.38	30063.37	64083.04	71920.00	72430.20	62398.72	65312.64	59911.68
Dark High Amb - 2	Dark	200.05	200	25	2	27749.06	34316.33	56831.65	74240.00	51609.96	50687.36	40460.80	33872.00
Dark High Amb - 3	Dark	199.29	200	25	3	24069.54	48622.00	51129.09	55048.96	77644.44	78471.68	72402.56	67985.28
Dark Low Hot - 1	Dark	13.67	15	38	1	4384.80	3330.47	2874.94	2709.76	2698.92	4250.24	4064.64	3563.52

Dark Low Hot - 2	Dark	15.5	15	38	2	3384.42	3817.26	5327.65	4361.60	3396.60	5697.92	4417.28	4565.76
Dark Low Hot - 3	Dark	15.04	15	38	3	5284.96	3063.84	5296.10	4602.88	4645.08	5994.88	5252.48	5679.36
Dark Medium Hot - 1	Dark	76.06	75	38	1	25571.97	19469.98	15127.33	14235.52	31652.64	29770.24	26819.20	23812.48
Dark Medium Hot - 2	Dark	75.64	75	38	2	26290.24	20643.31	20626.66	31366.40	31579.20	33927.68	29232.00	28619.52
Dark Medium Hot - 3	Dark	75	75	38	3	24256.99	18693.34	34113.28	32758.40	33488.64	36099.20	31366.40	31162.24
Dark High Hot - 1	Dark	202.91	200	38	1	74613.06	27058.98	33017.31	70509.44	54914.76	61285.12	50891.52	44822.40
Dark High Hot - 2	Dark	200.68	200	38	2	47693.63	36063.78	69262.21	66778.88	67215.96	71344.64	61266.56	56737.92
Dark High Hot - 3	Dark	201.53	200	38	3	70023.17	36664.84	53630.98	73052.16	65104.56	60913.92	55717.12	52246.40

A4.2 CO₂ Concentration Data Grouped by Roast

Table 11: CO₂ Concentration over time in Light Roast Samples

Carbon Dioxide Light						Day							
Sample Name	Roast	Mass	Target Mass	Storage Temperature	Replicate Number	2	4	6	9	12	15	18	22
Light Low Cold - 1	Light	49.96	50	4	1	3460.51	10633.33	20391.87	48961.28	58274.64	4231.68	61619.20	64161.92
Light Low Cold - 2	Light	50.07	50	4	2	8123.71	8892.39	15635.87	42632.32	54988.20	7256.96	47624.96	48237.44
Light Low Cold - 3	Light	49.97	50	4	3	7131.68	15310.85	18695.49	34707.20	24620.76	5159.68	42539.52	39736.96
Light Medium Cold - 1	Light	99.97	100	4	1	22024.22	15440.91	43757.06	78824.32	101145.24	30586.88	94897.28	88327.04
Light Medium Cold - 2	Light	100.07	100	4	2	12208.77	21608.54	29017.63	64551.68	108838.08	88438.40	98924.80	97588.48
Light Medium Cold - 3	Light	100.05	100	4	3	16513.76	23495.34	45525.82	72810.88	92828.16	83891.20	87937.28	94674.56
Light High Cold - 1	Light	200.02	200	4	1	34291.46	42677.33	78493.95	143728.64	179983.08	55976.96	196550.40	194063.36
Light High Cold - 2	Light	200.08	200	4	2	44496.67	42207.26	71945.98	145120.64	173428.56	31440.64	195158.40	194954.24
Light High Cold - 3	Light	199.67	200	4	3	35552.61	43903.61	42236.06	46715.52	173318.40	180236.16	179920.64	171197.44
Light Low Amb - 1	Light	25.61	25	25	1	5447.36	15779.99	2123.26	27413.12	36003.96	12008.32	30661.12	36043.52
Light Low Amb - 2	Light	25.12	25	25	2	5395.39	8014.48	7808.19	24406.40	20306.16	28675.20	35431.04	28433.92
Light Low Amb - 3	Light	25.16	25	25	3	4841.38	7304.73	15850.24	22067.84	39547.44	25816.96	30308.48	33779.20
Light Medium Amb - 1	Light	75.56	75	25	1	16157.41	48073.89	15820.54	50538.88	105496.56	87825.92	101207.68	93134.08
Light Medium Amb - 2	Light	75.04	75	25	2	20925.47	47525.78	18681.57	98627.84	117393.84	70639.36	103898.88	104028.80
Light Medium Amb - 3	Light	75.05	75	25	3	18254.69	21709.80	23172.16	77896.32	55814.40	70026.88	86322.56	87528.96

Light High Amb - 1	Light	199.53	200	25	1	58243.14	55076.69	89060.16	250077.44	250907.76	327713.92	268192.00	268637.44
Light High Amb - 2	Light	199.39	200	25	2	64077.47	63609.56	130809.95	286974.72	304647.48	-264888.32	309191.04	311789.44
Light High Amb - 3	Light	199.74	200	25	3	50098.08	38015.61	142077.73	256684.80	299708.64	143450.24	276970.88	260656.64
Light Low Hot - 1	Light	25.03	25	38	1	14291.20	17883.25	35166.56	34336.00	29339.28	44878.08	35022.72	34651.52
Light Low Hot - 2	Light	25.04	25	38	2	15917.06	15747.48	19960.35	35078.40	25942.68	37416.96	30698.24	33667.84
Light Low Hot - 3	Light	27.24	25	38	3	9955.58	7745.07	28425.57	30160.00	24565.68	46214.40	37194.24	26967.68
Light Medium Hot - 1	Light	75.07	75	38	1	33558.34	31542.34	60819.26	131813.12	215711.64	150391.68	119712.00	117614.72
Light Medium Hot - 2	Light	74.91	75	38	2	45516.54	39351.51	52132.26	31347.84	136157.76	128175.36	99852.80	102525.44
Light Medium Hot - 3	Light	74.89	75	38	3	34169.89	33589.85	22718.37	63363.84	103054.68	138884.48	119285.12	124203.52
Light High Hot - 1	Light	190.19	190	38	1	123424.00	80149.48	140293.18	292505.60	129639.96	266410.24	294992.64	282910.08
Light High Hot - 2	Light	189	190	38	2	45519.33	53185.25	91301.28	218562.56	91414.44	279792.00	225169.92	190258.56
Light High Hot - 3	Light	188.6	190	38	3	88720.51	66643.67	118605.82	294008.96	312395.40	328994.56	282817.28	250838.40

Table 12: CO₂ Concentration over time in Dark Roast Samples

Carbon Dioxide Dark						Day							
Sample Name	Roast	Mass	Target Mass	Storage Temperature	Replicate Number	2	4	6	9	12	15	18	22
Dark Low Cold - 1	Dark	51.1	50	4	1	45177.82	45570.24	83565.47	156906.24	130043.88	45008.00	177990.40	172088.32
Dark Low Cold - 2	Dark	47.25	50	4	2	40868.19	40347.40	79441.44	145436.16	168049.08	150967.04	153101.44	135617.92
Dark Low Cold - 3	Dark	51.25	50	4	3	40752.19	40402.21	75132.74	143301.76	169646.40	166705.92	152748.80	149203.84
Dark Medium Cold - 1	Dark	99.24	100	4	1	80476.16	99742.09	161517.47	248741.12	216078.84	212215.04	278177.28	262104.32
Dark Medium Cold - 2	Dark	101.29	100	4	2	72874.91	109520.74	165336.19	204735.36	303637.68	277683.58	262327.04	242208.00
Dark Medium Cold - 3	Dark	100.84	100	4	3	95044.83	104752.18	151090.46	256369.28	292383.00	261770.24	255032.96	226988.80
Dark High Cold - 1	Dark	201.22	200	4	1	103126.78	153729.06	101013.73	399392.64	583811.28	541525.12	466023.04	441802.24
Dark High Cold - 2	Dark	199.95	200	4	2	141231.39	250527.15	84845.18	155718.40	492874.20	442117.76	411085.44	357855.36
Dark High Cold - 3	Dark	201.54	200	4	3	167850.14	157127.34	173454.34	98572.16	550763.28	507003.52	480147.20	431575.68
Dark Low Amb - 1	Dark	25.72	25	25	1	44302.72	42867.78	35955.36	108427.52	107497.80	81144.32	77989.12	69024.64
Dark Low Amb - 2	Dark	25.3	25	25	2	32222.02	37297.49	14518.56	107592.32	109884.60	74332.80	77729.28	73256.32
Dark Low Amb - 3	Dark	21.79	25	25	3	37712.06	34997.29	24386.91	200763.52	73678.68	71047.68	57072.00	48237.44
Dark Medium Amb - 1	Dark	73.7	75	25	1	144119.33	64895.30	87041.76	191093.76	198875.52	242597.76	203380.48	156293.76

Dark Medium Amb - 2	Dark	64.59	75	25	2	73634.02	96169.15	145490.91	348835.20	308723.40	313329.92	240184.96	207519.36
Dark Medium Amb - 3	Dark	75.45	75	25	3	30933.02	48562.55	128734.02	235526.40	244408.32	242634.88	184542.08	163903.36
Dark High Amb - 1	Dark	201.61	200	25	1	176603.04	192877.12	373023.52	697707.52	162339.12	19042.56	545719.68	479961.60
Dark High Amb - 2	Dark	200.05	200	25	2	206029.92	230648.40	353694.21	728238.72	538939.44	-25575.68	385973.76	309729.28
Dark High Amb - 3	Dark	199.29	200	25	3	180195.33	312236.90	294236.32	547445.76	725862.60	143394.56	590263.68	528792.96
Dark Low Hot - 1	Dark	13.67	15	38	1	38143.58	26929.85	38740.29	64960.00	47405.52	52710.40	40627.84	30716.80
Dark Low Hot - 2	Dark	15.5	15	38	2	27715.65	28634.57	37850.34	71641.60	52491.24	71827.20	47643.52	44135.68
Dark Low Hot - 3	Dark	15.04	15	38	3	41538.21	22841.32	36119.62	54566.40	64994.40	64718.72	55271.68	49091.20
Dark Medium Hot - 1	Dark	76.06	75	38	1	197518.30	134796.04	101760.77	142652.16	328166.64	286826.24	210637.44	178343.04
Dark Medium Hot - 2	Dark	75.64	75	38	2	193014.72	136679.13	132743.90	308263.04	301379.40	319046.40	230589.44	201858.56
Dark Medium Hot - 3	Dark	75	75	38	3	174990.18	122274.05	187418.88	329384.32	326899.80	331258.88	247646.08	222608.64
Dark High Hot - 1	Dark	202.91	200	38	1	496902.24	154349.63	165435.49	617769.60	436894.56	499783.68	361864.32	287717.12
Dark High Hot - 2	Dark	200.68	200	38	2	324606.05	210883.00	362668.90	596314.24	593670.60	574209.28	435677.44	358634.88
Dark High Hot - 3	Dark	201.53	200	38	3	473722.66	212018.24	281365.89	655149.44	539049.60	504572.16	396998.40	335230.72

A4.3 Comparison of Mass and Concentration

The standard deviation and means were taken for each sample group. Tables 13 & 14 depict the results for the light roasted sample groups stored in the refrigerator (4° C) over the sample period.

Table 13: Light Roasted Coffee stored in 4°C CO concentrations

Carbon Monoxide Light						Day							
Sample Name	Roast	Mass	Target Mass	Storage Temperature	Replicate Number	2	4	6	9	12	15	18	22
Light Low Cold - 1	Light	49.96	50	4	1	0.00	75.25	263.55	0.00	0.00	0.00	0.00	0.00
Light Low Cold - 2	Light	50.07	50	4	2	3.71	19.51	139.20	0.00	0.00	0.00	0.00	0.00
Light Low Cold - 3	Light	49.97	50	4	3	0.00	73.39	157.76	0.00	0.00	0.00	0.00	0.00
Standard Deviation:						1.7498536	25.849285	54.772094	0	0	0	0	0
Mean:						1.24	56.05	186.84	0.00	0.00	0.00	0.00	0.00
Light Medium Cold - 1	Light	99.97	100	4	1	120.64	74.32	349.86	0.00	0.00	0.00	0.00	0.00
Light Medium Cold - 2	Light	100.07	100	4	2	44.54	114.27	69.60	0.00	0.00	0.00	0.00	0.00
Light Medium Cold - 3	Light	100.05	100	4	3	88.16	148.64	352.64	0.00	0.00	0.00	0.00	0.00
Standard Deviation:						31.176749	30.369444	132.77501	0	0	0	0	0
Mean:						84.45	112.41	257.37	0.00	0.00	0.00	0.00	0.00
Light High Cold - 1	Light	200.02	200	4	1	220.86	340.01	758.18	0.00	0.00	0.00	296.96	0.00
Light High Cold - 2	Light	200.08	200	4	2	340.58	297.28	600.42	0.00	91.80	0.00	0.00	0.00
Light High Cold - 3	Light	199.67	200	4	3	260.77	329.80	315.52	0.00	0.00	0.00	0.00	0.00
Standard Deviation:						49.769032	18.220404	183.18123	0	43.274935	0	139.98829	0
Mean:						274.07	322.36	558.04	0.00	30.60	0.00	98.99	0.00

Table 14: Light Roasted Coffee stored in 4°C CO₂ concentrations

Carbon Dioxide Light						Day							
Sample Name	Roast	Mass	Target Mass	Storage Temperature	Replicate Number	2	4	6	9	12	15	18	22
Light Low Cold - 1	Light	49.96	50	4	1	3460.51	10633.33	20391.87	48961.28	58274.64	4231.68	61619.20	64161.92
Light Low Cold - 2	Light	50.07	50	4	2	8123.71	8892.39	15635.87	42632.32	54988.20	7256.96	47624.96	48237.44
Light Low Cold - 3	Light	49.97	50	4	3	7131.68	15310.85	18695.49	34707.20	24620.76	5159.68	42539.52	39736.96
					Standard Deviation:	2005.74276	2710.20050			15149.4984	1265.44179	8067.31844	10123.8217
						1	8	1968.03638	5831.3526	8	7	5	1
					Mean:	6238.63	11612.19	18241.08	42100.27	45961.20	5549.44	50594.56	50712.11
Light Medium Cold - 1	Light	99.97	100	4	1	22024.22	15440.91	43757.06	78824.32	101145.24	30586.88	94897.28	88327.04
Light Medium Cold - 2	Light	100.0	100	4	2	12208.77	21608.54	29017.63	64551.68	108838.08	88438.40	98924.80	97588.48
Light Medium Cold - 3	Light	100.0	100	4	3	16513.76	23495.34	45525.82	72810.88	92828.16	83891.20	87937.28	94674.56
					Standard Deviation:	4017.20392	3439.53364	7400.44715	5850.77485	6537.67836	26265.3678	4538.57678	3866.61222
						1	5	8	7	3	3	5	4
					Mean:	16915.58	20181.60	39433.50	72062.29	100937.16	67638.83	93919.79	93530.03
Light High Cold - 1	Light	200.0	200	4	1	34291.46	42677.33	78493.95	143728.64	179983.08	55976.96	196550.40	194063.36
Light High Cold - 2	Light	200.0	200	4	2	44496.67	42207.26	71945.98	145120.64	173428.56	31440.64	195158.40	194954.24
Light High Cold - 3	Light	199.6	200	4	3	35552.61	43903.61	42236.06	46715.52	173318.40	180236.16	179920.64	171197.44
					Standard Deviation:	4542.79917	715.102875	15776.8806	46064.0264	3116.11986	65134.4648	7532.71318	10995.0974
						1	1	7	1	6	1	6	5
					Mean:	38113.58	42929.40	64225.33	111854.93	175576.68	89217.92	190543.15	186738.35

Except for when concentrations fell below the limit of detection, the data on Tables 13 and 14 show that averages of CO and CO₂ concentrations for each day for each mass group had different averages with the average concentration increasing with the increase in mass. This can be seen visually by plotting the averages on a graph. Figures 35 and 36 are charts of the mean concentrations of the sample groups over time.

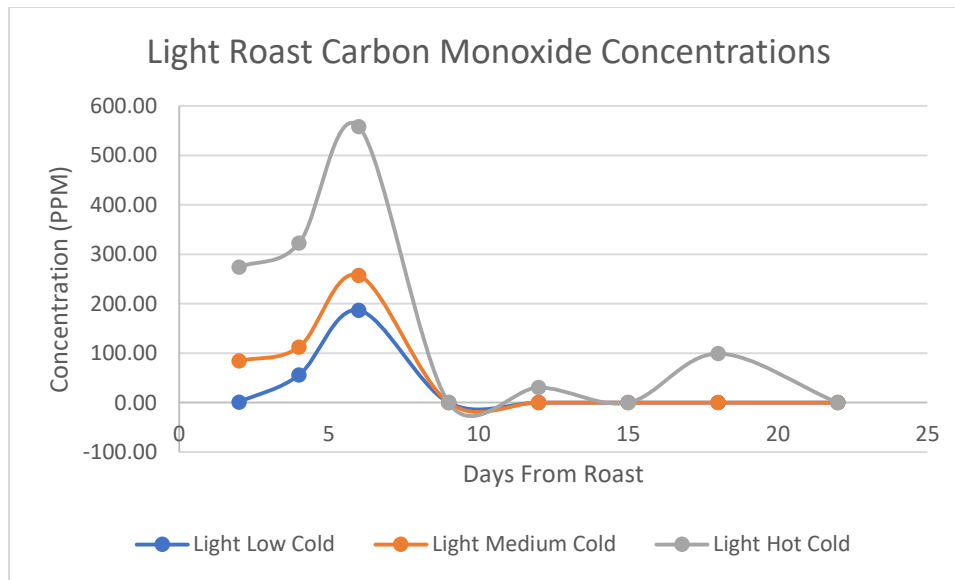


Figure 35: Light Roasted Coffee stored in 4°C average CO concentrations

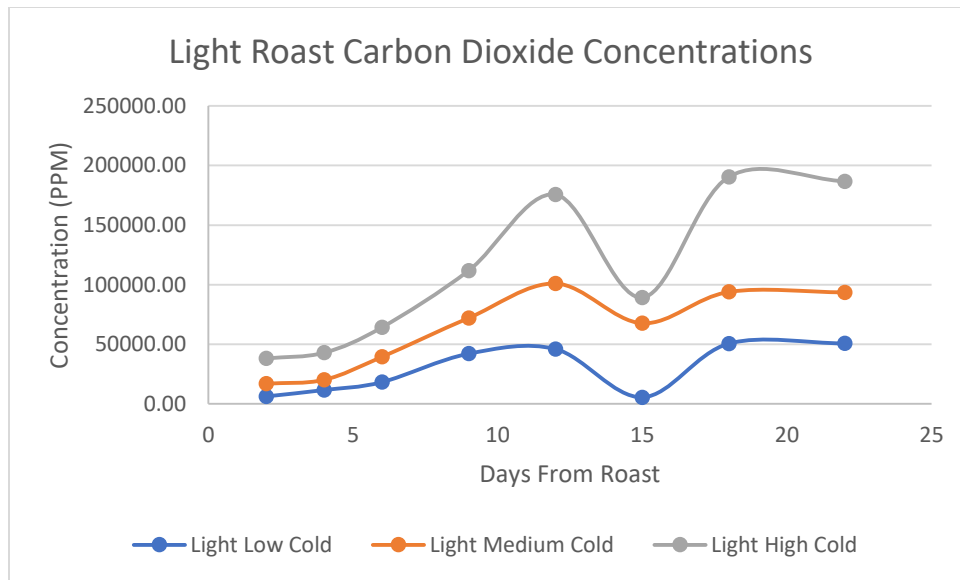


Figure 36: Light Roasted Coffee stored in 4°C average CO₂ concentrations

Figures 35 and 36 show visually that both CO and CO₂ concentrations of light roasts stored at 4° C, increase with an increase in coffee mass. Tables 15 and 16 show the mean and standard deviation results for the dark roasted sample groups stored in the refrigerator (4° C) over the sample period.

Table 15: Dark Roasted Coffee stored in 4°C CO concentrations

Carbon Monoxide Dark						Day							
Sample Name	Roast	Mass	Target Mass	Storage Temperature	Replicate Number	2	4	6	9	12	15	18	22
Dark Low Cold - 1	Dark	51.1	50	4	1	4186.21	4842.88	9687.39	10022.40	9418.68	12954.88	14643.84	14662.40
Dark Low Cold - 2	Dark	47.25	50	4	2	4050.72	4449.91	9215.97	9094.40	11052.72	11655.68	11006.08	11191.68
Dark Low Cold - 3	Dark	51.25	50	4	3	3671.17	4293.84	8645.25	9372.80	11181.24	12286.72	11934.08	12101.12
Standard Deviation:						217.99157	230.99431	426.09676	388.82597	802.30376	530.46834	1543.3471	1469.4343
Mean:						3969.37	4528.88	9182.87	9496.53	10550.88	12299.09	12528.00	12651.73
Dark Medium Cold - 1	Dark	99.24	100	4	1	8243.42	11128.49	20416.00	16852.48	15587.64	17279.36	24554.88	25018.88
Dark Medium Cold - 2	Dark	101.29	100	4	2	6975.78	11697.97	20635.01	13623.04	22215.60	23571.20	22810.24	22327.68
Dark Medium Cold - 3	Dark	100.84	100	4	3	9138.94	11231.61	18094.14	18875.52	21848.40	21808.00	21770.88	20842.88
Standard Deviation:						887.45474	247.75153	1149.6362	2163.0873	3041.5969	2650.0462	1148.6559	1728.3957
Mean:						8119.38	11352.69	19715.05	16450.35	19883.88	20886.19	23045.33	22729.81
Dark High Cold - 1	Dark	201.22	200	4	1	10615.39	18704.49	12246.82	32071.68	48635.64	50576.00	44618.24	43003.52
Dark High Cold - 2	Dark	199.95	200	4	2	13846.69	28532.38	9257.73	11265.92	39106.80	38010.88	35041.28	33055.36
Dark High Cold - 3	Dark	201.54	200	4	3	16858.98	18938.59	24458.37	6328.96	46157.04	47680.64	44024.32	42465.28
Standard Deviation:						2549.4551	4578.7301	6575.342	11155.172	4036.6121	5372.4566	4381.3482	4568.0312
Mean:						13773.69	22058.49	15320.97	16555.52	44633.16	45422.51	41227.95	39508.05

Table 16: Dark Roasted Coffee stored in 4°C CO₂ concentrations

Carbon Dioxide Dark						Day							
Sample Name	Roast	Mass	Target Mass	Storage Temperature	Replicate Number	2	4	6	9	12	15	18	22
Dark Low Cold - 1	Dark	51.1	50	4	1	45177.82	45570.24	83565.47	156906.24	130043.88	45008.00	177990.40	172088.32
Dark Low Cold - 2	Dark	47.25	50	4	2	40868.19	40347.40	79441.44	145436.16	168049.08	150967.04	153101.44	135617.92
Dark Low Cold - 3	Dark	51.25	50	4	3	40752.19	40402.21	75132.74	143301.76	169646.40	166705.92	152748.80	149203.84
					Standard Deviation:	2059.46602	2449.252587	3442.925219	5974.020372	18303.93476	54042.59044	11816.76331	15049.42495
					Mean:	42266.07	42106.62	79379.88	148548.05	155913.12	120893.65	161280.21	152303.36
Dark Medium Cold - 1	Dark	99.24	100	4	1	80476.16	99742.09	161517.47	248741.12	216078.84	212215.04	278177.28	262104.32
Dark Medium Cold - 2	Dark	101.29	100	4	2	72874.91	109520.74	165336.19	204735.36	303637.68	277683.58	262327.04	242208.00
Dark Medium Cold - 3	Dark	100.84	100	4	3	95044.83	104752.18	151090.46	256369.28	292383.00	261770.24	255032.96	226988.80
					Standard Deviation:	9198.614194	3992.524708	6020.759315	22756.58008	38895.21981	27878.87017	9661.454108	14378.17537
					Mean:	82798.63	104671.67	159314.71	236615.25	270699.84	250556.29	265179.09	243767.04
Dark High Cold - 1	Dark	201.22	200	4	1	103126.78	153729.06	101013.73	399392.64	583811.28	541525.12	466023.04	441802.24
Dark High Cold - 2	Dark	199.95	200	4	2	141231.39	250527.15	84845.18	155718.40	492874.20	442117.76	411085.44	357855.36
Dark High Cold - 3	Dark	201.54	200	4	3	167850.14	157127.34	173454.34	98572.16	550763.28	507003.52	480147.20	431575.68
					Standard Deviation:	26561.52698	44851.53336	38529.41924	130441.8939	37583.78552	41209.12243	29790.30134	37396.29627
					Mean:	137402.77	187127.85	119771.08	217894.40	542482.92	496882.13	452418.56	410411.09

Except for days 6 and 9 on Table 18, the data on Tables 15 and 16 show that averages of CO and CO₂ concentrations for each day for each mass group had different averages with the average concentration increasing with the increase in mass. On days 6 and 9 the sample containers storing approximately 200g of coffee beans recorded lower concentrations on average of both CO and CO₂ than did the containers with 100g of coffee beans. This can be seen visually by plotting the averages on a graph. The Figures 37 and 38 are charts of the mean concentrations of the sample groups over time of the dark roasted sample groups that were stored in the refrigerator.

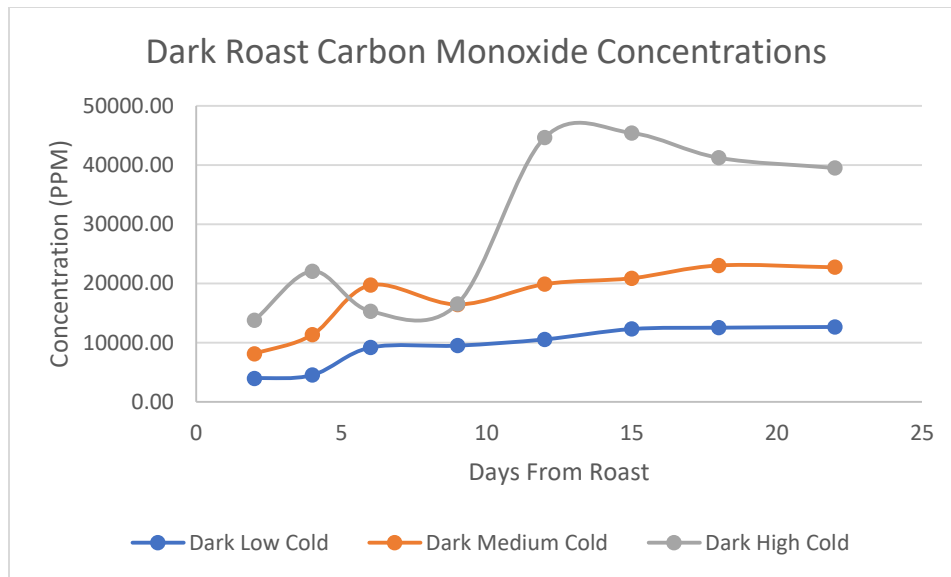


Figure 37: Dark Roasted Coffee stored in 4°C average CO concentrations

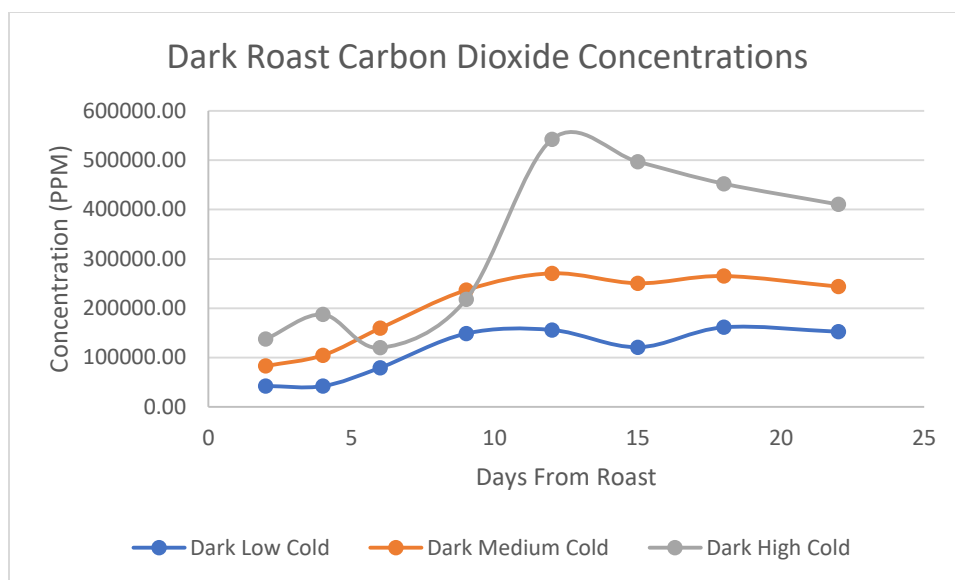


Figure 38: Dark Roasted Coffee stored in 4°C average CO concentrations

Table 17 and 18 show the results with the standard deviations and means of the light roasted sample groups labeled Amb which were stored in an incubator set at 25° C. Except on day 15, the data on Table 17 & 18 and Figures 39 and 40 show that averages of CO and CO₂ concentrations for each day for each mass group had different averages with the average concentration increasing with the increase in mass. On day 15 CO₂ concentration were unreliable as QA/QC measures discovered. This likely explains why CO₂ concentrations were measured to be so low on that day.

Table 17: Light Roasted Coffee stored in 25°C CO concentrations

Carbon Monoxide Light						Day							
Sample Name	Roast	Mass	Target Mass	Storage Temperature	Replicate Number	2	4	6	9	12	15	18	22
Light Low Amb - 1	Light	25.61	25	25	1	0.74	179.30	0.00	0.00	0.00	0.00	0.00	0.00
Light Low Amb - 2	Light	25.12	25	25	2	0.00	17.65	0.00	0.00	0.00	0.00	0.00	0.00
Light Low Amb - 3	Light	25.16	25	25	3	10.21	11.15	27.84	0.00	0.00	0.00	0.00	0.00
Standard Deviation:						4.6470063	77.778749	13.123902	0	0	0	0	0
Mean:						3.65	69.37	9.28	0.00	0.00	0.00	0.00	0.00
Light Medium Amb - 1	Light	75.56	75	25	1	94.66	424.55	73.31	0.00	0.00	0.00	0.00	0.00
Light Medium Amb - 2	Light	75.04	75	25	2	192.10	389.25	46.40	0.00	0.00	0.00	0.00	0.00
Light Medium Amb - 3	Light	75.05	75	25	3	103.94	150.50	78.88	0.00	0.00	0.00	0.00	0.00
Standard Deviation:						43.910082	121.72618	14.182183	0	0	0	0	0
Mean:						130.23	321.43	66.20	0.00	0.00	0.00	0.00	0.00
Light High Amb - 1	Light	199.53	200	25	1	524.32	559.26	1027.30	37.12	0.00	1614.72	538.24	853.76
Light High Amb - 2	Light	199.39	200	25	2	602.27	640.08	1428.19	1911.68	2019.60	2245.76	872.32	1781.76
Light High Amb - 3	Light	199.74	200	25	3	446.37	352.09	1565.54	482.56	293.76	1484.80	501.12	1559.04
Standard Deviation:						63.647541	121.28422	228.34751	799.63714	890.91731	332.35704	166.92539	395.55981
Mean:						524.32	517.14	1340.34	810.45	771.12	1781.76	637.23	1398.19

Table 18: Light Roasted Coffee stored in 25°C CO₂ concentrations

Carbon Dioxide Light						Day							
Sample Name	Roast	Mass	Target Mass	Storage Temperature	Replicate Number	2	4	6	9	12	15	18	22
Light Low Amb - 1	Light	25.61	25	25	1	5447.36	15779.99	2123.26	27413.12	36003.96	12008.32	30661.12	36043.52
Light Low Amb - 2	Light	25.12	25	25	2	5395.39	8014.48	7808.19	24406.40	20306.16	28675.20	35431.04	28433.92
Light Low Amb - 3	Light	25.16	25	25	3	4841.38	7304.73	15850.24	22067.84	39547.44	25816.96	30308.48	33779.20
Standard Deviation:						274.2365179	3838.938878	5631.487	2187.876858	8361.313237	7277.308442	2336.120068	3190.353089
Mean:						5228.04	10366.40	8593.90	24629.12	31952.52	22166.83	32133.55	32752.21
Light Medium Amb - 1	Light	75.56	75	25	1	16157.41	48073.89	15820.54	50538.88	105496.56	87825.92	101207.68	93134.08
Light Medium Amb - 2	Light	75.04	75	25	2	20925.47	47525.78	18681.57	98627.84	117393.84	70639.36	103898.88	104028.80
Light Medium Amb - 3	Light	75.05	75	25	3	18254.69	21709.80	23172.16	77896.32	55814.40	70026.88	86322.56	87528.96
Standard Deviation:						1951.241909	12300.99632	3025.762212	19694.25612	26670.6033	8249.975093	7729.714524	6850.442112
Mean:						18445.86	39103.16	19224.76	75687.68	92901.60	76164.05	97143.04	94897.28
Light High Amb - 1	Light	199.53	200	25	1	58243.14	55076.69	89060.16	250077.44	250907.76	327713.92	268192.00	268637.44
Light High Amb - 2	Light	199.39	200	25	2	64077.47	63609.56	130809.95	286974.72	304647.48	-264888.32	309191.04	311789.44
Light High Amb - 3	Light	199.74	200	25	3	50098.08	38015.61	142077.73	256684.80	299708.64	143450.24	276970.88	260656.64
Standard Deviation:						5732.992378	10640.28343	22805.62899	16064.26583	24253.00791	247626.7124	17626.14449	22460.71016
Mean:						57472.90	52233.95	120649.28	264578.99	285087.96	68758.61	284784.64	280361.17

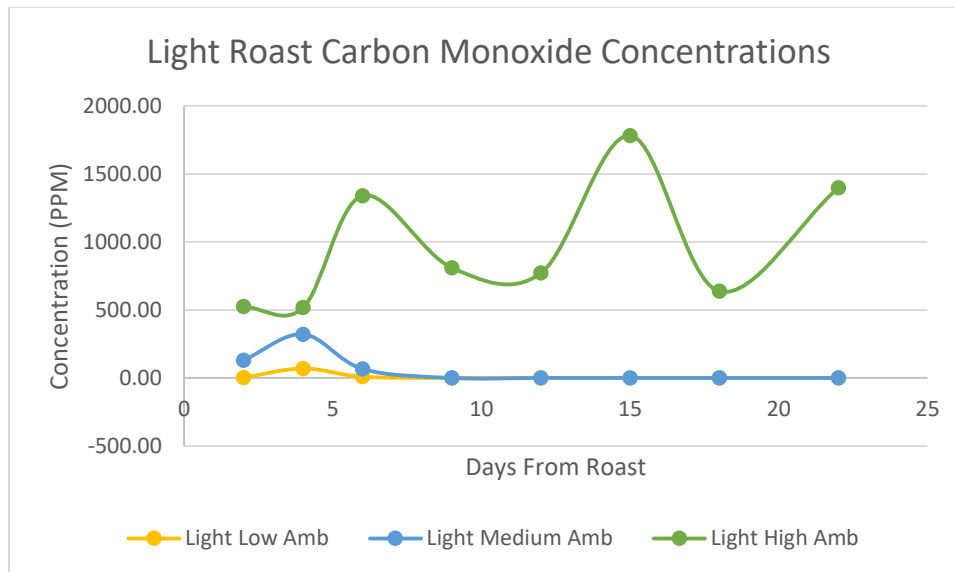


Figure 39: Light Roasted Coffee stored in 25°C average CO concentrations

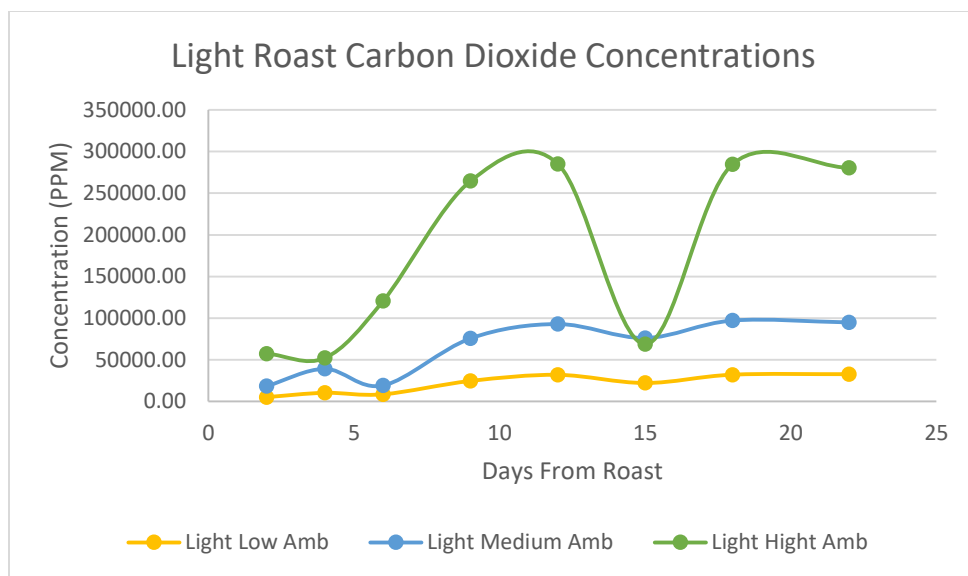


Figure 40: Light Roasted Coffee stored in 25°C average CO₂ concentrations

Table 19 & 20 show the results for the dark roasted sample groups stored in the 25° C incubator. Except on day 15, the data on Table 19 & 20 show that averages of CO and CO₂ concentrations for each day for each mass group had different averages with the average concentration increasing with the increase in mass.

Table 19: Dark Roasted Coffee stored in 25°C CO concentrations

Carbon Monoxide Dark						Day							
Sample Name	Roast	Mass	Target Mass	Storage Temperature	Replicate Number	2	4	6	9	12	15	18	22
Dark Low Amb - 1	Dark	25.72	25	25	1	5448.29	5630.67	5158.75	9001.60	7399.08	6792.96	6811.52	7386.88
Dark Low Amb - 2	Dark	25.3	25	25	2	3953.28	4920.91	1190.62	7702.40	7986.60	6384.64	7591.04	7182.72
Dark Low Amb - 3	Dark	21.79	25	25	3	3884.61	4522.37	3877.18	5438.08	4957.20	5029.76	4677.12	3489.28
					Standard Deviation:	721.48457	458.36797	1653.4832	1472.4787	1311.7089	753.60609	1231.7217	1791.1655
					Mean:	4428.73	5024.65	3408.85	7380.69	6780.96	6069.12	6359.89	6019.63
Dark Medium Amb - 1	Dark	73.7	75	25	1	18408.74	9025.24	12367.46	23032.96	16872.84	23181.44	18782.72	16388.48
Dark Medium Amb - 2	Dark	64.59	75	25	2	9100.90	12556.36	20763.07	24647.68	26401.68	27635.84	23311.36	21715.20
Dark Medium Amb - 3	Dark	75.45	75	25	3	3857.70	6683.23	17092.83	18671.36	19975.68	21065.60	17594.88	16926.72
					Standard Deviation:	6017.1957	2414.0245	3436.5068	2524.2661	3968.2054	2738.3392	2463.0083	2394.28
					Mean:	10455.78	9421.61	16741.12	22117.33	21083.40	23960.96	19896.32	18343.47
Dark High Amb - 1	Dark	201.61	200	25	1	23968.38	30063.37	64083.04	71920.00	72430.20	62398.72	65312.64	59911.68
Dark High Amb - 2	Dark	200.05	200	25	2	27749.06	34316.33	56831.65	74240.00	51609.96	50687.36	40460.80	33872.00
Dark High Amb - 3	Dark	199.29	200	25	3	24069.54	48622.00	51129.09	55048.96	77644.44	78471.68	72402.56	67985.28
					Standard Deviation:	1758.869	7938.3931	5301.014	8552.5201	11247.048	11389.393	13695.729	14556.266
					Mean:	25262.33	37667.23	57347.93	67069.65	67228.20	63852.59	59392.00	53922.99

Table 20: Dark Roasted Coffee stored in 25°C CO concentrations

Carbon Dioxide Dark						Day							
Sample Name	Roast	Mass	Target Mass	Storage Temperature	Replicate Number	2	4	6	9	12	15	18	22
Dark Low Amb - 1	Dark	25.72	25	25	1	44302.72	42867.78	35955.36	108427.52	107497.80	81144.32	77989.12	69024.64
Dark Low Amb - 2	Dark	25.3	25	25	2	32222.02	37297.49	14518.56	107592.32	109884.60	74332.80	77729.28	73256.32
Dark Low Amb - 3	Dark	21.79	25	25	3	37712.06	34997.29	24386.91	200763.52	73678.68	71047.68	57072.00	48237.44
					Standard Deviation:	4938.74458 5	3304.26632 7	8760.70617 8	43725.7958	16533.7981 6	4204.90398 1	9799.75420 8	10933.9387 8
					Mean:	38078.93	38387.52	24953.61	138927.79	97020.36	75508.27	70930.13	63506.13
Dark Medium Amb - 1	Dark	73.7	75	25	1	144119.33	64895.30	87041.76	191093.76	198875.52	242597.76	203380.48	156293.76
Dark Medium Amb - 2	Dark	64.59	75	25	2	73634.02	96169.15	145490.91	348835.20	308723.40	313329.92	240184.96	207519.36
Dark Medium Amb - 3	Dark	75.45	75	25	3	30933.02	48562.55	128734.02	235526.40	244408.32	242634.88	184542.08	163903.36
					Standard Deviation:	46669.8729 1	19751.7976 6	24574.9220 5	66412.4365 4	45063.1928 3	33334.7141 7	23107.4426 6	22569.2109 9
					Mean:	82895.46	69875.66	120422.23	258485.12	250669.08	266187.52	209369.17	175905.49
Dark High Amb - 1	Dark	201.6 1	200	25	1	176603.04	192877.12	373023.52	697707.52	162339.12	19042.56	545719.68	479961.60
Dark High Amb - 2	Dark	200.0 5	200	25	2	206029.92	230648.40	353694.21	728238.72	538939.44	-25575.68	385973.76	309729.28
Dark High Amb - 3	Dark	199.2 9	200	25	3	180195.33	312236.90	294236.32	547445.76	725862.60	143394.56	590263.68	528792.96
					Standard Deviation:	13107.5548 3	49810.8745 7	33526.5825 4	79019.5792	234361.255 2	71496.0366	87709.9375 5	93898.5506 9
					Mean:	187609.43	245254.14	340318.02	657797.33	475713.72	45620.48	507319.04	439494.61

The following charts are of the mean concentrations of the full data set of the above sample groups over time.

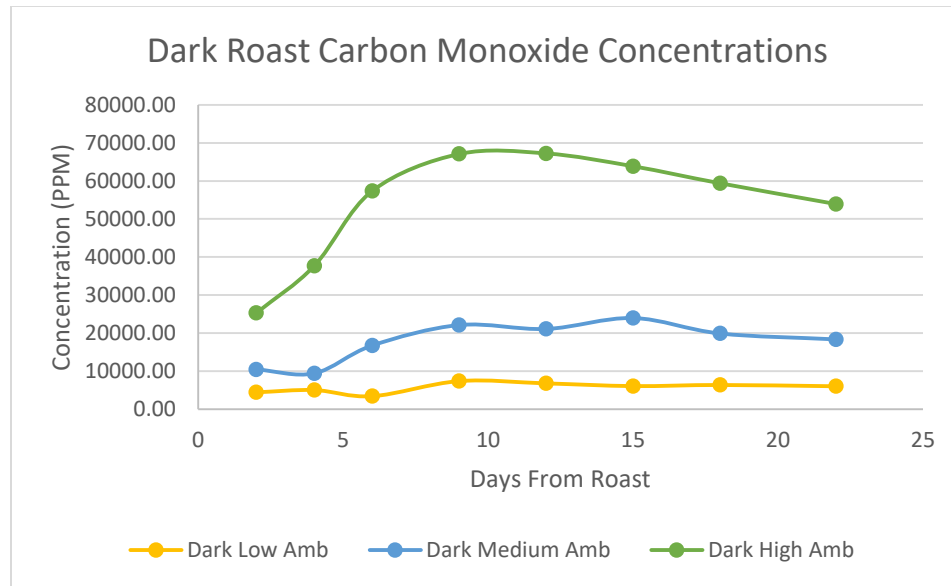


Figure 41: Dark Roasted Coffee stored in 25°C average CO concentrations

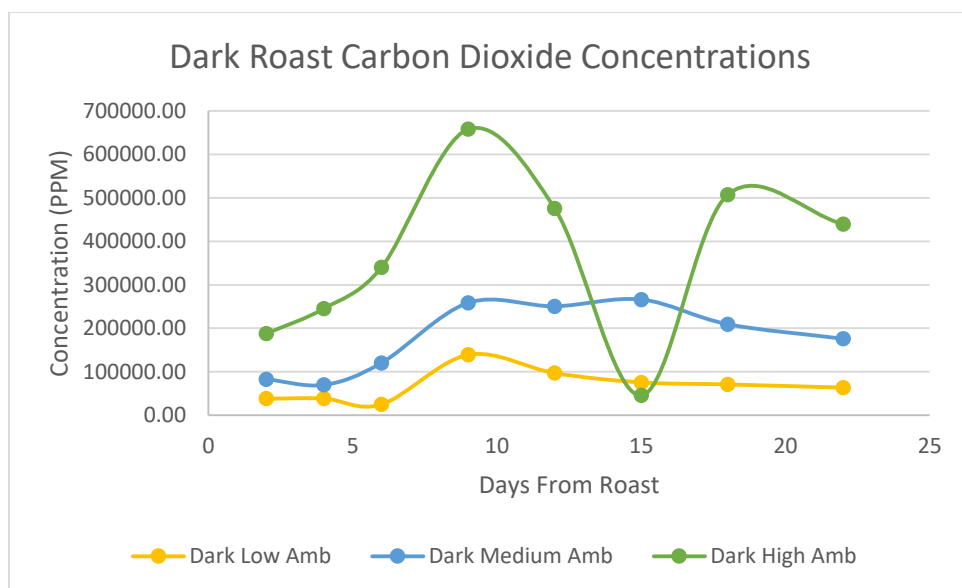


Figure 42: Dark Roasted Coffee stored in 25°C average CO₂ concentrations

Below are the CO and CO₂ concentration observations over time with the calculated standard deviations and means for the light roasted sample groups stored in the 38° C incubator. Except for when concentrations fell below the limit of detection, the data on tables 21 and 22 show that averages of CO and CO₂ concentrations for each day for each mass group had different averages with the average concentration increasing with the increase in mass. This can be seen visually by plotting the averages on a graph.

Table 21: Light Roasted Coffee stored in 38°C CO concentrations

Carbon Monoxide Light						Day							
Sample Name	Roast	Mass	Target Mass	Storage Temperature	Replicate Number	2	4	6	9	12	15	18	22
Light Low Hot - 1	Light	25.03	25	38	1	120.64	275.91	360.06	0.00	0.00	0.00	0.00	0.00
Light Low Hot - 2	Light	25.04	25	38	2	271.90	114.27	72.38	0.00	0.00	0.00	0.00	0.00
Light Low Hot - 3	Light	27.24	25	38	3	98.37	29.73	128.06	0.00	0.00	0.00	0.00	0.00
Standard Deviation:						77.094158	102.13462	124.5811	0	0	0	0	0
Mean:						163.64	139.97	186.84	0.00	0.00	0.00	0.00	0.00
Light Medium Hot - 1	Light	75.07	75	38	1	290.46	320.51	690.43	0.00	0.00	408.32	0.00	0.00
Light Medium Hot - 2	Light	74.91	75	38	2	423.17	395.75	539.17	0.00	0.00	1020.80	0.00	0.00
Light Medium Hot - 3	Light	74.89	75	38	3	296.96	317.72	289.54	0.00	0.00	1169.28	0.00	0.00
Standard Deviation:						61.083739	36.147532	165.29924	0	0	329.34922	0	0
Mean:						336.86	344.66	506.38	0.00	0.00	866.13	0.00	0.00
Light High Hot - 1	Light	190.19	190	38	1	1476.45	969.88	1856.00	631.04	0.00	1262.08	1299.20	2561.28
Light High Hot - 2	Light	189	190	38	2	449.15	589.92	1091.33	1002.24	367.20	1373.44	983.68	946.56
Light High Hot - 3	Light	188.6	190	38	3	938.21	767.35	1357.66	1243.52	605.88	1948.80	946.56	1596.16
Standard Deviation:						419.55203	155.23105	316.92917	251.91207	249.1975	300.92903	158.21425	663.38839
Mean:						954.60	775.72	1435.00	958.93	324.36	1528.11	1076.48	1701.33

Table 22: Light Roasted Coffee stored in 38°C CO₂ concentrations

Carbon Dioxide Light						Day							
Sample Name	Roast	Mass	Target Mass	Storage Temperature	Replicate Number	2	4	6	9	12	15	18	22
Light Low Hot - 1	Light	25.03	25	38	1	14291.20	17883.25	35166.56	34336.00	29339.28	44878.08	35022.72	34651.52
Light Low Hot - 2	Light	25.04	25	38	2	15917.06	15747.48	19960.35	35078.40	25942.68	37416.96	30698.24	33667.84
Light Low Hot - 3	Light	27.24	25	38	3	9955.58	7745.07	28425.57	30160.00	24565.68	46214.40	37194.24	26967.68
Standard Deviation:						2516.172628	4363.773245	6221.196891	2164.891383	2006.109489	3870.81693	2700.095521	3414.042366
Mean:						13387.95	13791.93	27850.83	33191.47	26615.88	42836.48	34305.07	31762.35
Light Medium Hot - 1	Light	75.07	75	38	1	33558.34	31542.34	60819.26	131813.12	215711.64	150391.68	119712.00	117614.72
Light Medium Hot - 2	Light	74.91	75	38	2	45516.54	39351.51	52132.26	31347.84	136157.76	128175.36	99852.80	102525.44
Light Medium Hot - 3	Light	74.89	75	38	3	34169.89	33589.85	22718.37	63363.84	103054.68	138884.48	119285.12	124203.52
Standard Deviation:						5498.680011	3306.092411	16303.78004	41904.12427	47277.22539	9071.725166	9262.739646	9074.003213
Mean:						37748.26	34827.90	45223.30	75508.27	151641.36	139150.51	112949.97	114781.23
Light High Hot - 1	Light	190.19	190	38	1	123424.00	80149.48	140293.18	292505.60	129639.96	266410.24	294992.64	282910.08
Light High Hot - 2	Light	189	190	38	2	45519.33	53185.25	91301.28	218562.56	91414.44	279792.00	225169.92	190258.56
Light High Hot - 3	Light	188.6	190	38	3	88720.51	66643.67	118605.82	294008.96	312395.40	328994.56	282817.28	250838.40
Standard Deviation:						31867.45518	11008.10442	20044.63454	35216.77714	96432.6627	26908.8183	30453.37006	38417.03012
Mean:						85887.95	66659.47	116733.43	268359.04	177816.60	291732.27	267659.95	241335.68

Figures 43 and 44 depict the mean concentrations of the low mass sample groups in the 38°C incubator over time.

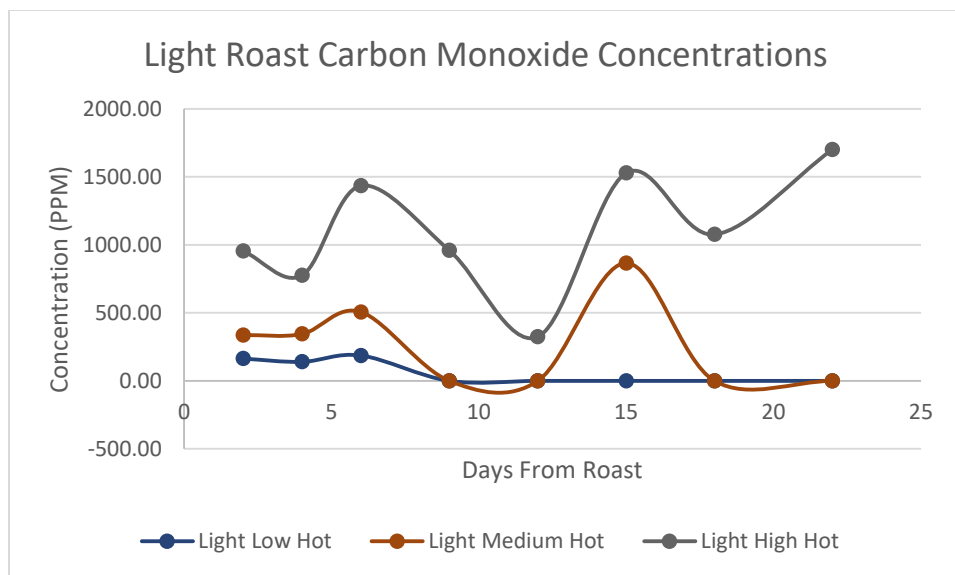


Figure 43: Light Roasted Coffee stored in 38°C average CO concentrations

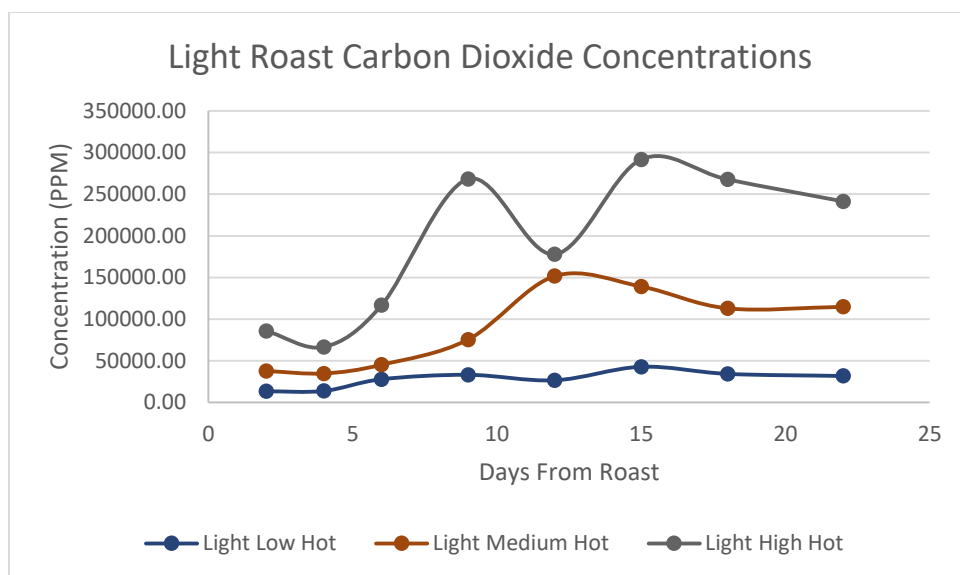


Figure 44: Light Roasted Coffee stored in 38°C average CO₂ concentrations

Table 23 and 24 are the observed concentrations of CO and CO₂ observed over time which can be seen visually in Figures 45 and 46. The standard deviation and average have been calculated for each day for each group and the results are displayed on the table below for the dark roasted sample groups stored in the incubator set at 38° C. The averages of the entire set CO and CO₂ concentrations for each day for each mass group had different averages with the average concentration increasing with the increase in mass.

Table 23: Dark Roasted Coffee stored in 38°C CO concentrations

Carbon Monoxide Dark						Day							
Sample Name	Roast	Mass	Target Mass	Storage Temperature	Replicate Number	2	4	6	9	12	15	18	22
Dark Low Hot - 1	Dark	13.67	15	38	1	4384.80	3330.47	2874.94	2709.76	2698.92	4250.24	4064.64	3563.52
Dark Low Hot - 2	Dark	15.5	15	38	2	3384.42	3817.26	5327.65	4361.60	3396.60	5697.92	4417.28	4565.76
Dark Low Hot - 3	Dark	15.04	15	38	3	5284.96	3063.84	5296.10	4602.88	4645.08	5994.88	5252.48	5679.36
Standard Deviation:						776.25337	311.92919	1148.8511	841.34118	805.05338	762.14109	498.09391	864.18676
Mean:						4351.39	3403.86	4499.56	3891.41	3580.20	5314.35	4578.13	4602.88
Dark Medium Hot - 1	Dark	76.06	75	38	1	25571.97	19469.98	15127.33	14235.52	31652.64	29770.24	26819.20	23812.48
Dark Medium Hot - 2	Dark	75.64	75	38	2	26290.24	20643.31	20626.66	31366.40	31579.20	33927.68	29232.00	28619.52
Dark Medium Hot - 3	Dark	75	75	38	3	24256.99	18693.34	34113.28	32758.40	33488.64	36099.20	31366.40	31162.24
Standard Deviation:						841.90089	801.54428	7976.3401	8422.8644	883.31764	2625.8447	1857.546	3047.6226
Mean:						25373.07	19602.21	23289.09	26120.11	32240.16	33265.71	29139.20	27864.75
Dark High Hot - 1	Dark	202.91	200	38	1	74613.06	27058.98	33017.31	70509.44	54914.76	61285.12	50891.52	44822.40
Dark High Hot - 2	Dark	200.68	200	38	2	47693.63	36063.78	69262.21	66778.88	67215.96	71344.64	61266.56	56737.92
Dark High Hot - 3	Dark	201.53	200	38	3	70023.17	36664.84	53630.98	73052.16	65104.56	60913.92	55717.12	52246.40
Standard Deviation:						11758.357	4393.4319	14843.446	2576.314	5370.8013	4831.9728	4239.0271	4913.3508
Mean:						64109.95	33262.54	51970.17	70113.49	62411.76	64514.56	55958.40	51268.91

Table 24: Dark Roasted Coffee stored in 38°C CO₂ concentrations

Carbon Dioxide Dark					Day								
Sample Name	Roast	Mass	Target Mass	Storage Temperature	Replicate Number	2	4	6	9	12	15	18	22
Dark Low Hot - 1	Dark	13.67	15	38	1	38143.58	26929.85	38740.29	64960.00	47405.52	52710.40	40627.84	30716.80
Dark Low Hot - 2	Dark	15.5	15	38	2	27715.65	28634.57	37850.34	71641.60	52491.24	71827.20	47643.52	44135.68
Dark Low Hot - 3	Dark	15.04	15	38	3	41538.21	22841.32	36119.62	54566.40	64994.40	64718.72	55271.68	49091.20
Standard Deviation:						5881.501001	2430.907436	1088.083331	7025.613097	7390.401113	7889.390058	5980.06541	7762.030764
Mean:						35799.15	26135.25	37570.08	63722.67	54963.72	63085.44	47847.68	41314.56
Dark Medium Hot - 1	Dark	76.06	75	38	1	197518.30	134796.04	101760.77	142652.16	328166.64	286826.24	210637.44	178343.04
Dark Medium Hot - 2	Dark	75.64	75	38	2	193014.72	136679.13	132743.90	308263.04	301379.40	319046.40	230589.44	201858.56
Dark Medium Hot - 3	Dark	75	75	38	3	174990.18	122274.05	187418.88	329384.32	326899.80	331258.88	247646.08	222608.64
Standard Deviation:						9733.578801	6393.159688	35412.83488	83494.49192	12339.87181	18742.53296	15124.11873	18083.10705
Mean:						188507.73	131249.74	140641.18	260099.84	318815.28	312377.17	229624.32	200936.75
Dark High Hot - 1	Dark	202.91	200	38	1	496902.24	154349.63	165435.49	617769.60	436894.56	499783.68	361864.32	287717.12
Dark High Hot - 2	Dark	200.68	200	38	2	324606.05	210883.00	362668.90	596314.24	593670.60	574209.28	435677.44	358634.88
Dark High Hot - 3	Dark	201.53	200	38	3	473722.66	212018.24	281365.89	655149.44	539049.60	504572.16	396998.40	335230.72
Standard Deviation:						76346.45715	26921.65201	80932.79378	24310.87016	64976.77581	34012.13502	30145.66193	29504.47343
Mean:						431743.65	192416.96	269823.42	623077.76	523204.92	526188.37	398180.05	327194.24

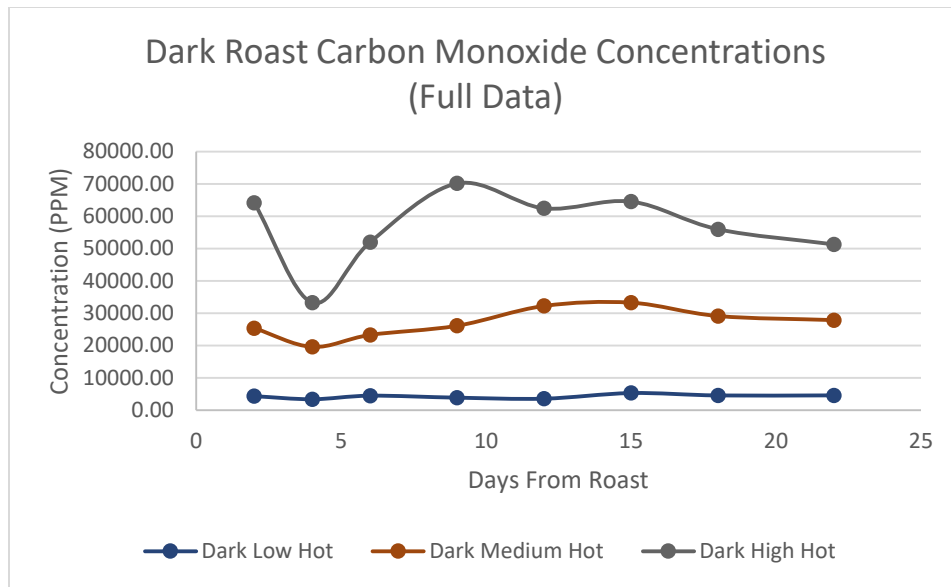


Figure 45: Dark Roasted Coffee stored in 38°C average CO concentrations

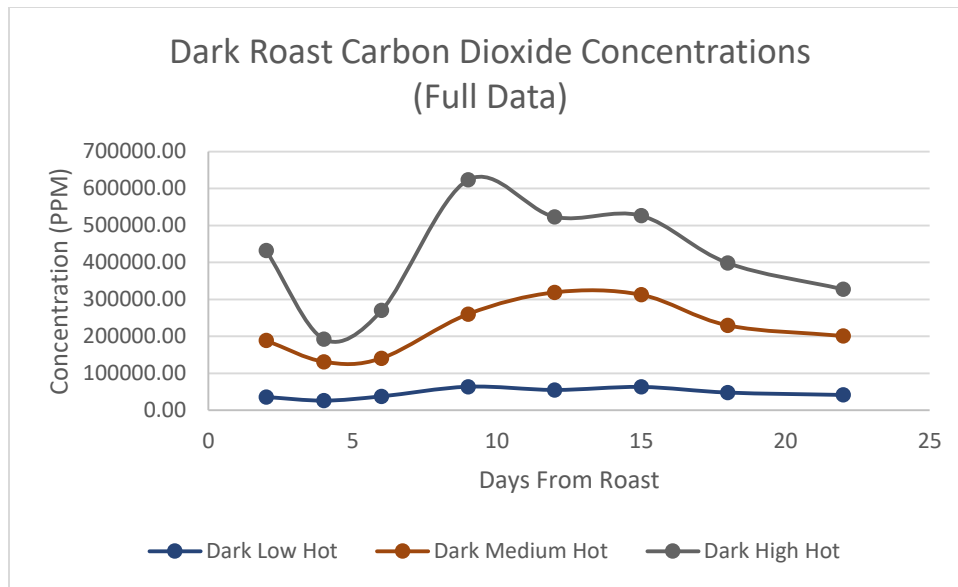


Figure 46: Dark Roasted Coffee stored in 38°C average CO₂ concentrations

Figures 47 to 55 show the relationship of mass to concentration for each sample group. The positive slope of each trendline implies a positive correlation between mass and concentration.

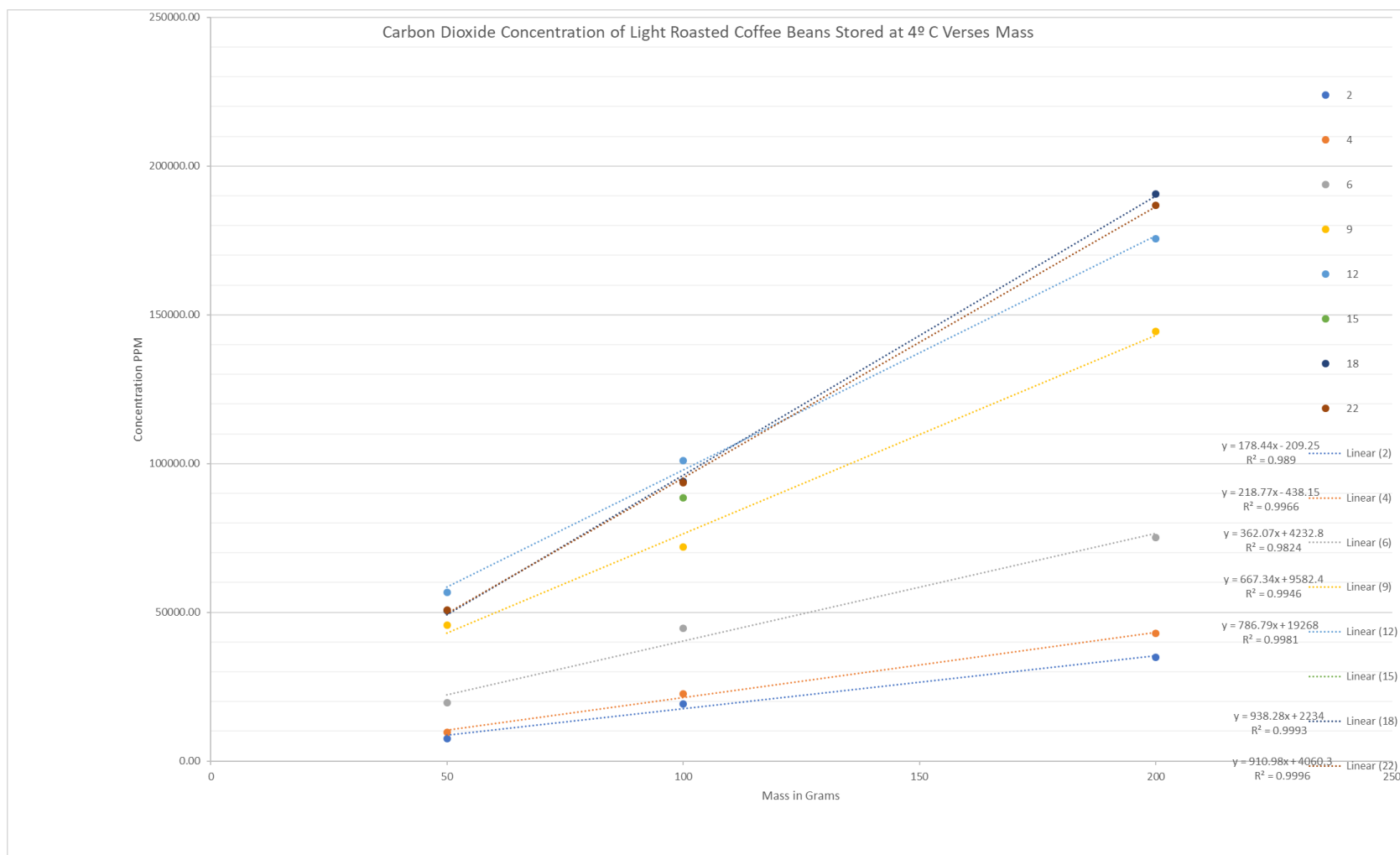


Figure 47: CO₂ Concentration of Light Roasted Coffee Beans Stored at 4° C Verses Mass

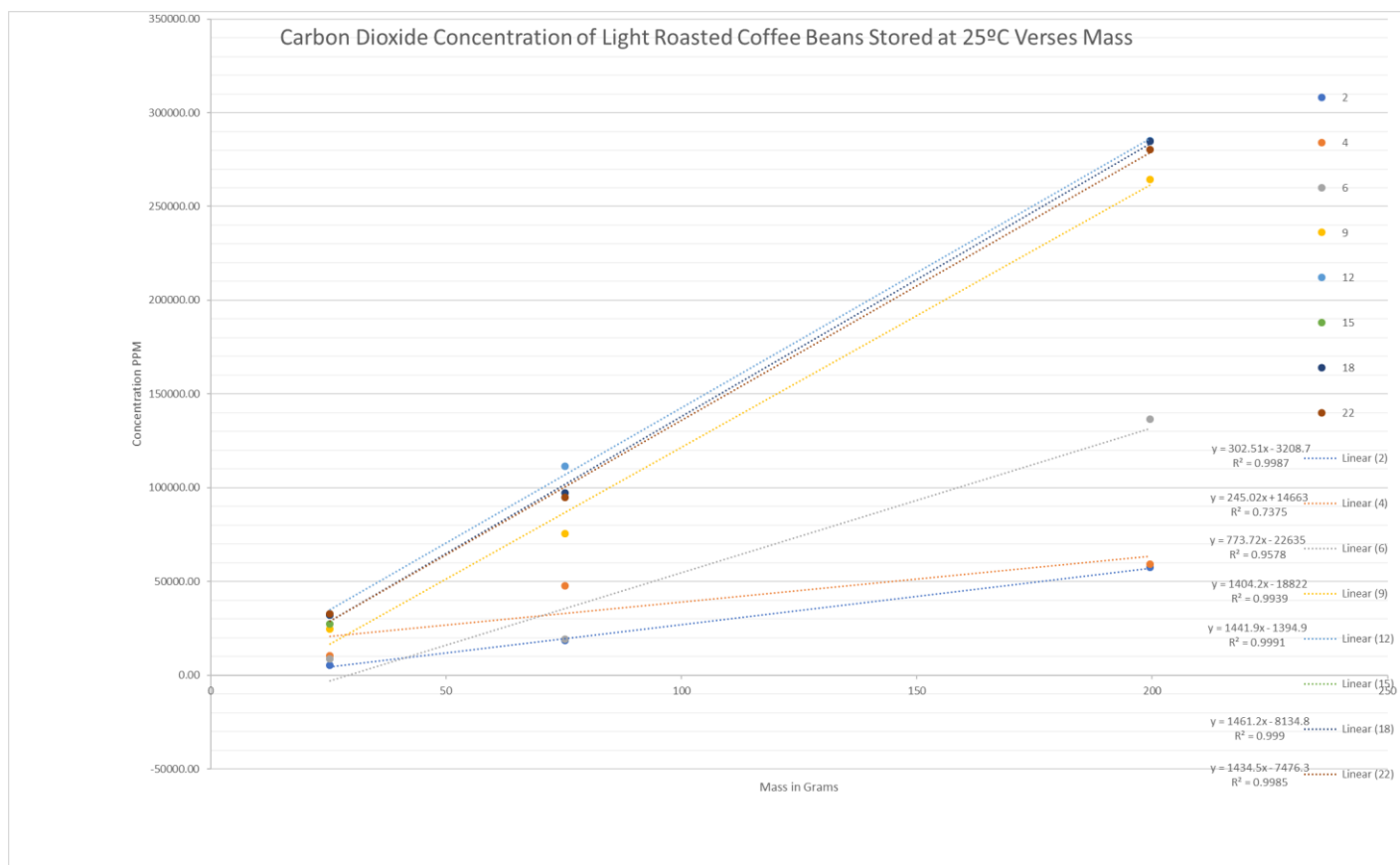


Figure 48: CO₂ Concentration of Light Roasted Coffee Beans Stored at 25° C Verses Mass

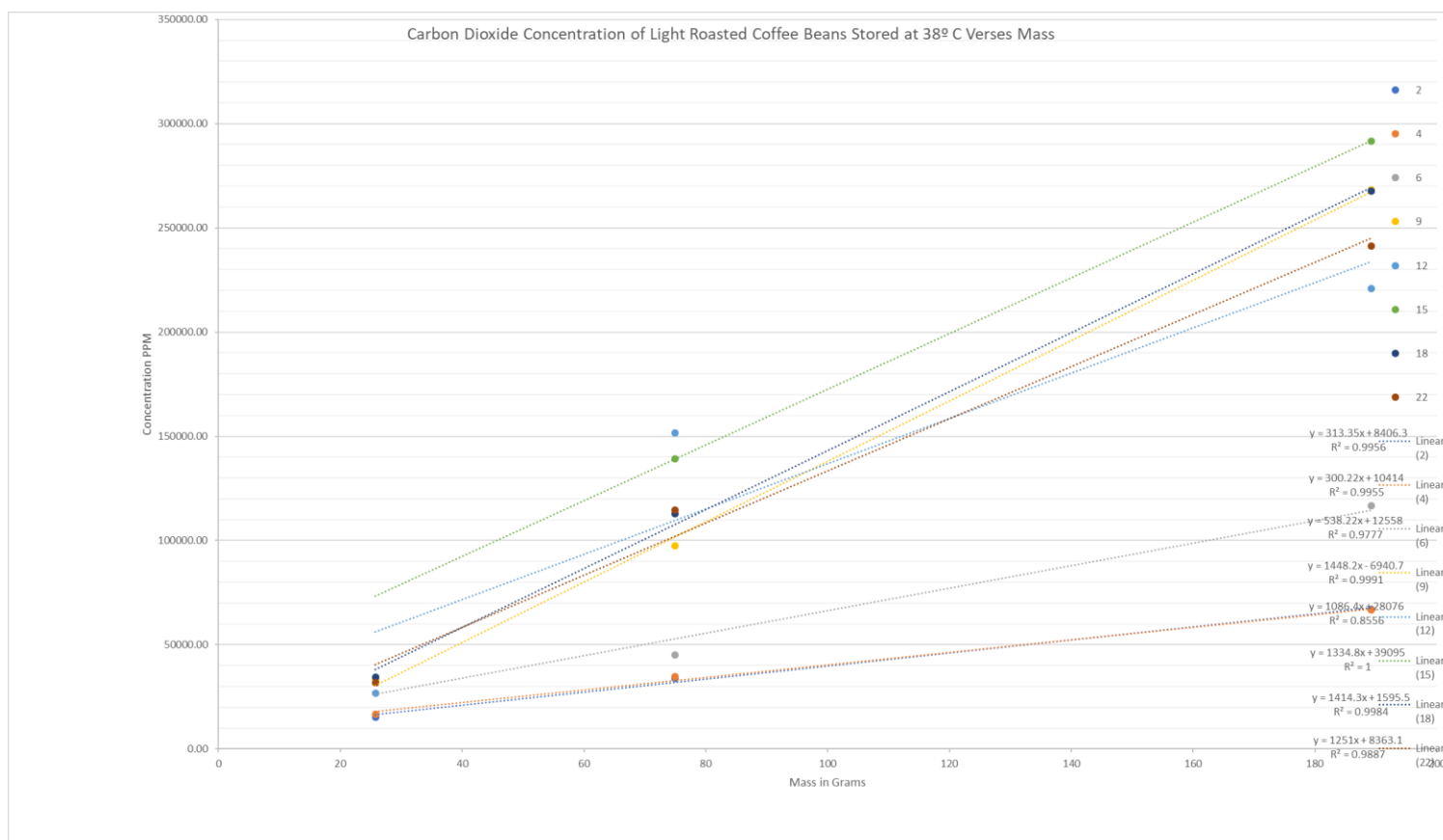


Figure 49: CO₂ Concentration of Light Roasted Coffee Beans Stored at 38° C Verses Mass

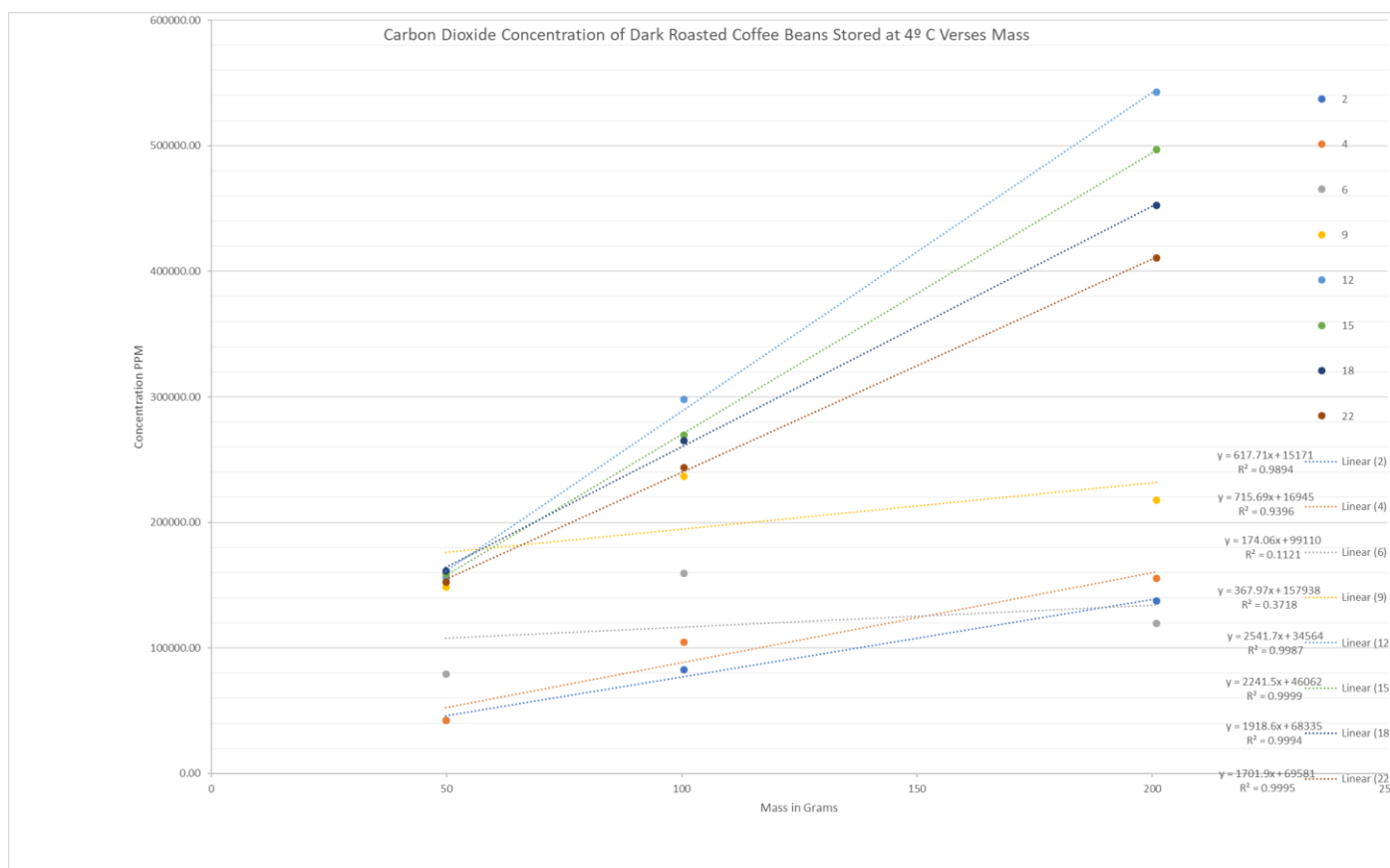


Figure 50: CO₂ Concentration of Dark Roasted Coffee Beans Stored at 4° C Verses Mass

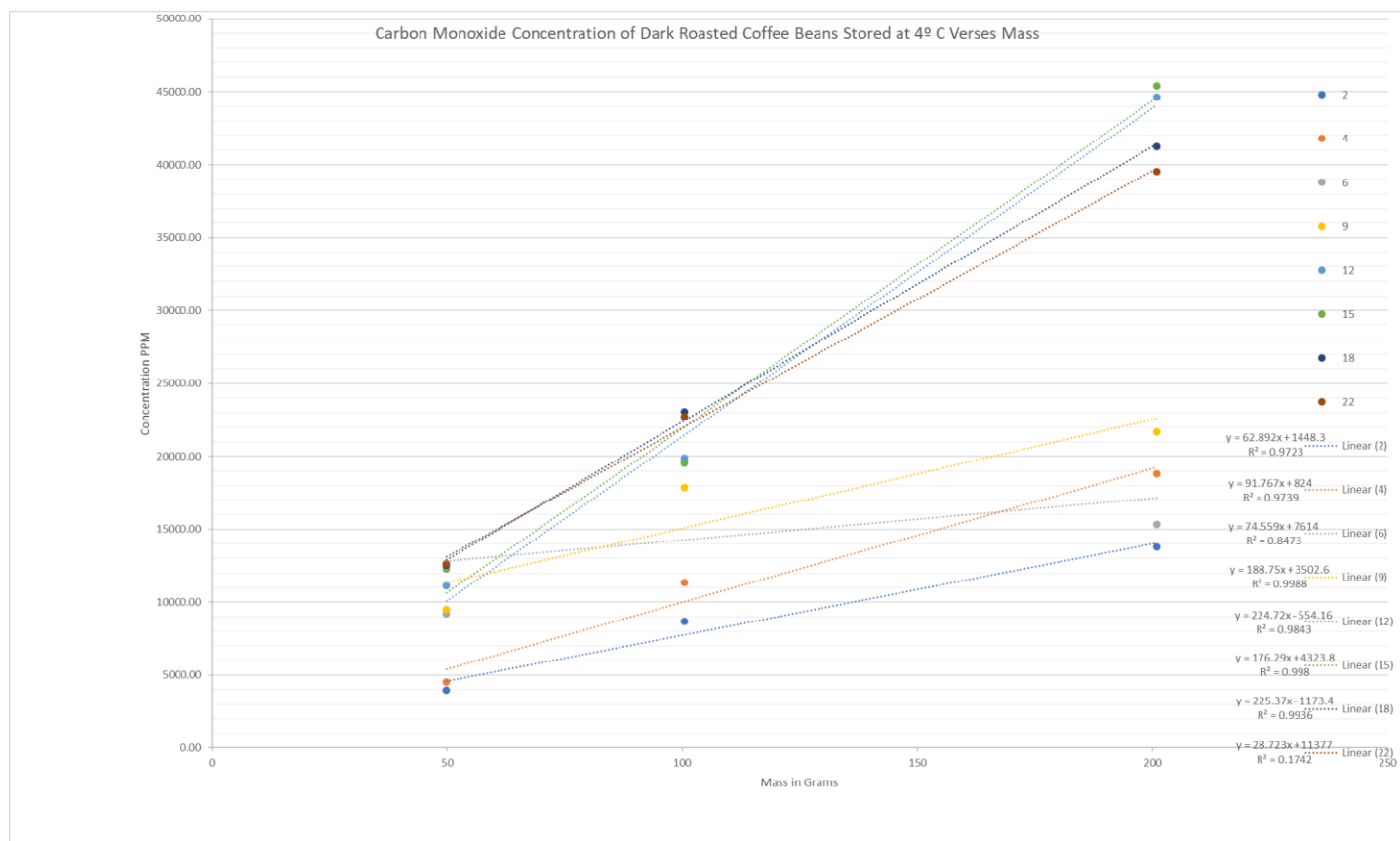


Figure 51: CO Concentration of Dark Roasted Coffee Beans Stored at 4° C Verses Mass

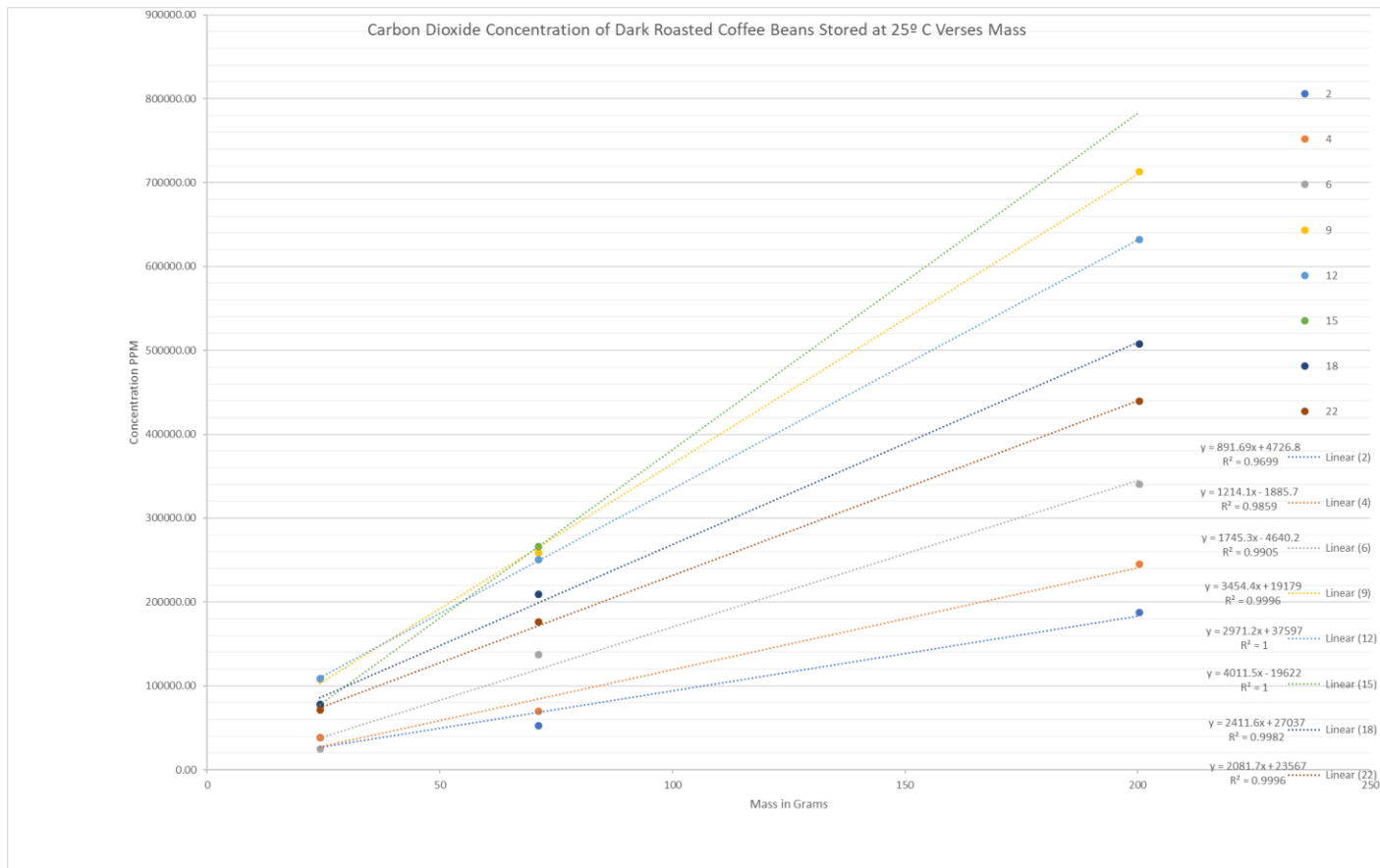


Figure 52: CO₂ Concentration of Dark Roasted Coffee Beans Stored at 25° C Verses Mass

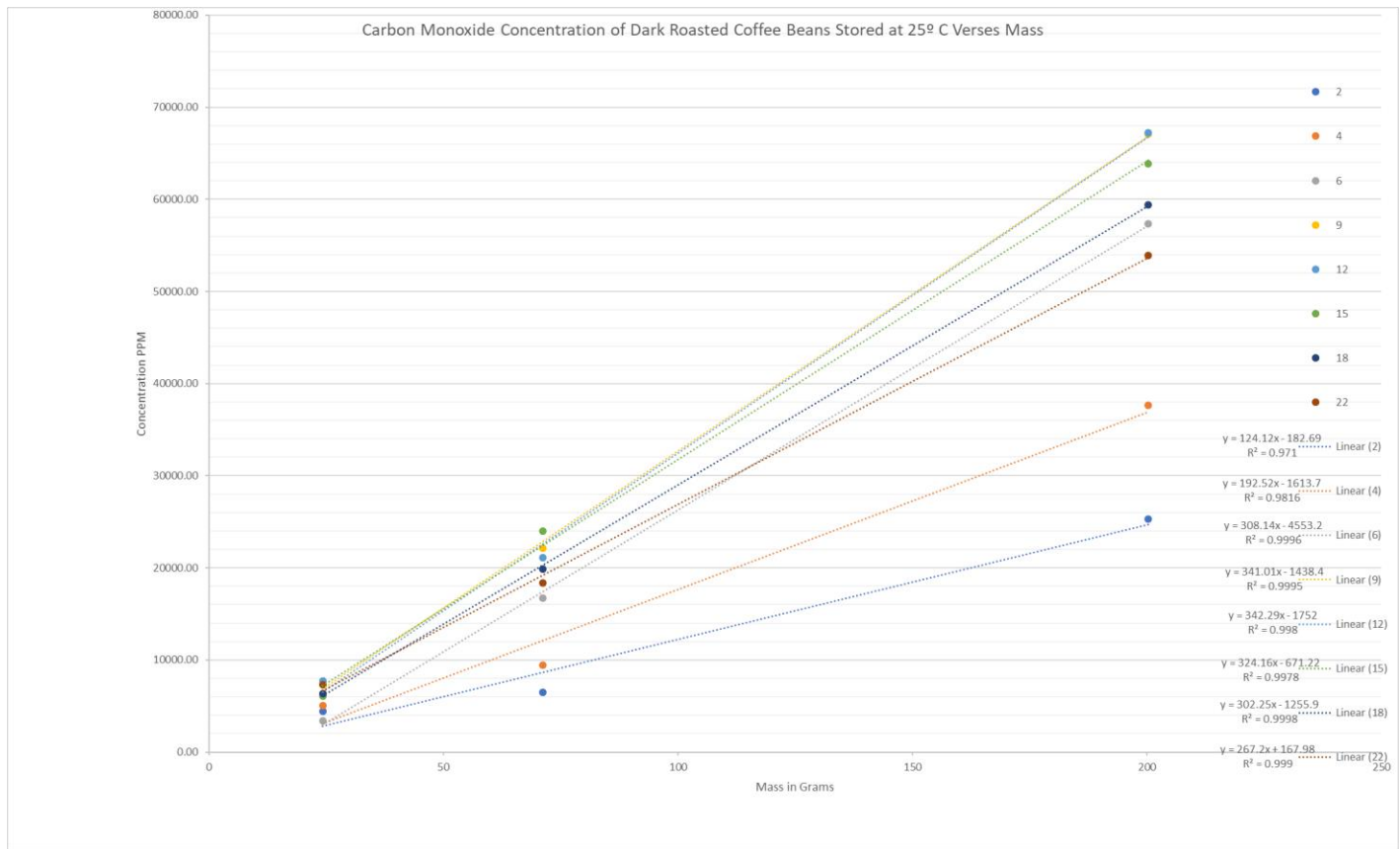


Figure 53: CO Concentration of Dark Roasted Coffee Beans Stored at 25° C Verses Mass

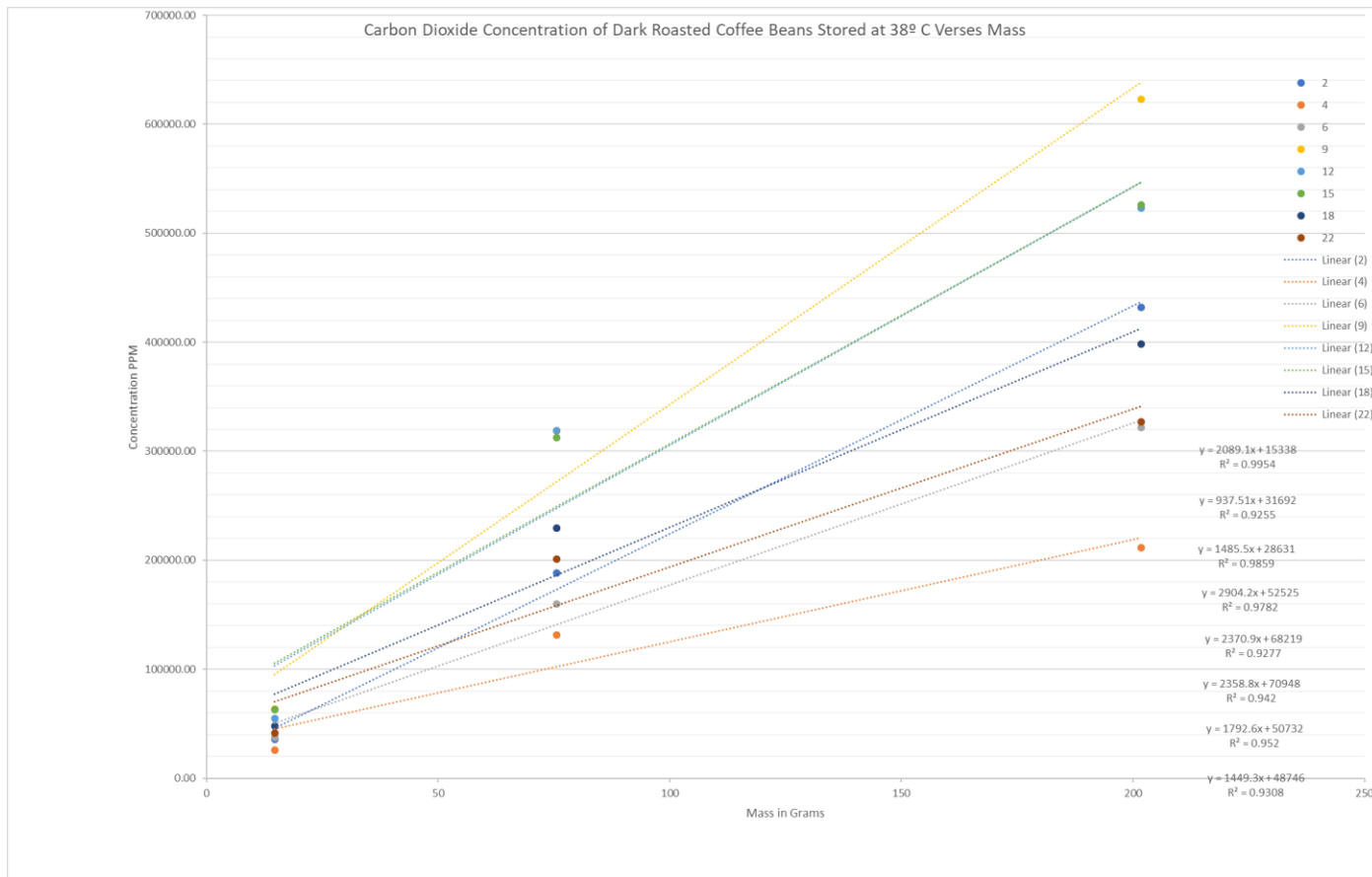


Figure 54: CO₂ Concentration of Dark Roasted Coffee Beans Stored at 38° C Verses Mass

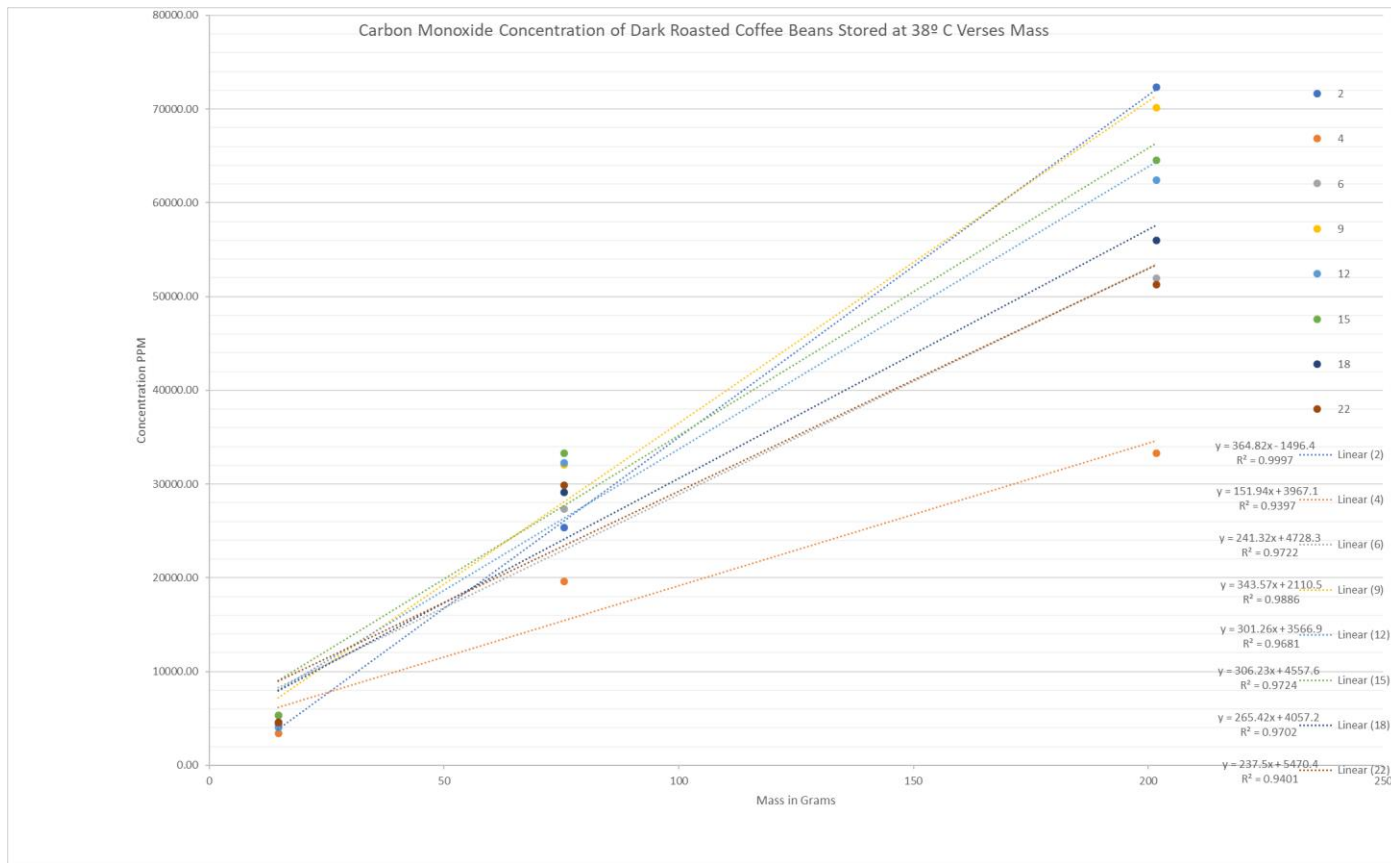


Figure 55: CO Concentration of Dark Roasted Coffee Beans Stored at 38° C Verses Mass

A4.2 Carbon Monoxide versus Carbon Dioxide Emission Rates

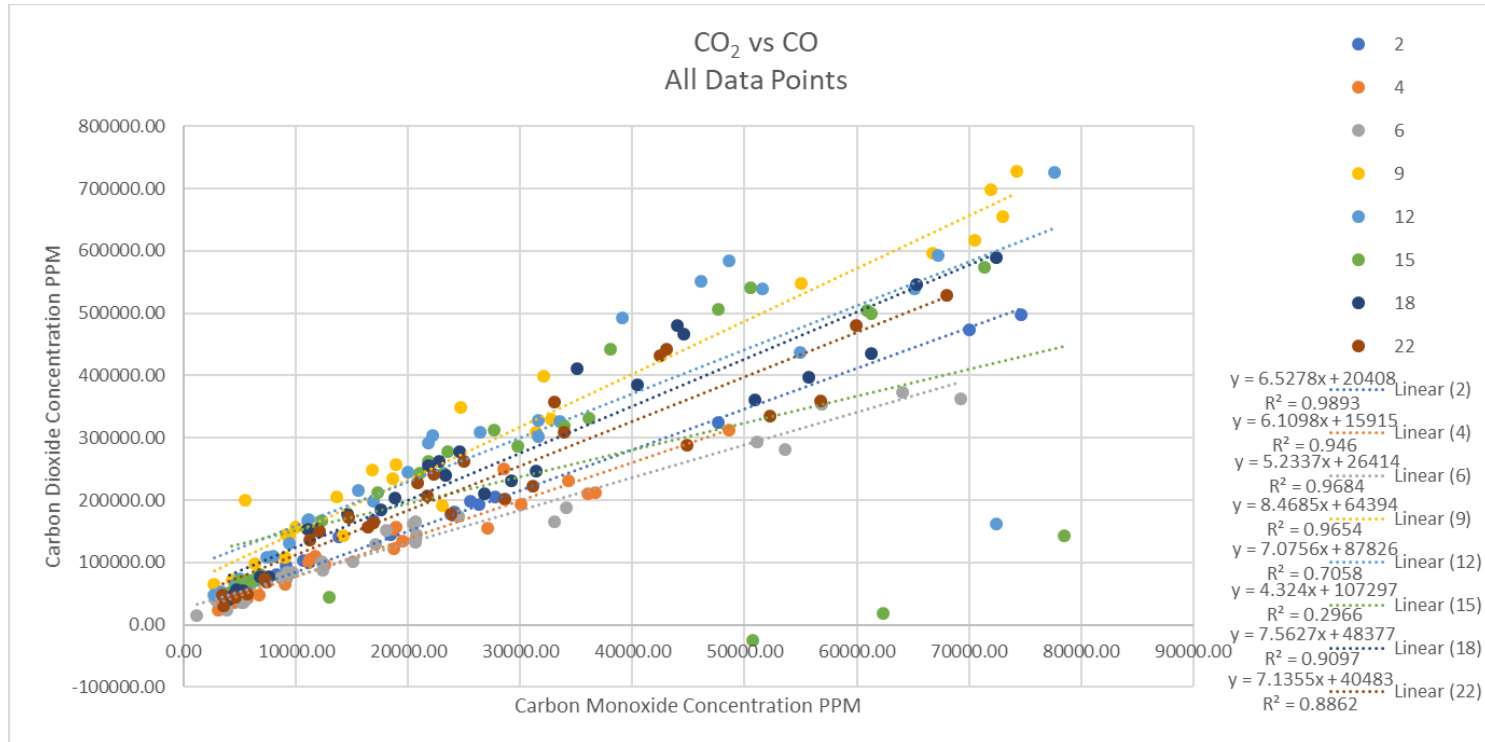


Figure 56: CO₂ vs CO emission comparison

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