GIESEN
coffee-roasters

COFFEE ROASTING & EMISSION CONTROL

In this guide, written by Giesen Coffee Roasters, we research the emissions caused specifically by roasting coffee and the dangers to our environment.

Industrieweg 13 - 15
7071CK Ulft
The Netherlands

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www.giesen.com

BULLETPOINTS

Coffee Roasting

Coffee beans contain over 1000 chemicals compounds but most are not toxic. A green bean goes through different phases while being roasted. Those are the drying phase, maillard phase and the development phase. The heat from the coffee roaster causes a reaction between the carbohydrates and amino acids in the coffee beans. This reaction creates gases like CO_2, water vapor and volatile organic compounds (VOCs).

Chemical compounds

The term nitrogen oxide (NOx) is used to describe nitrogen monoxides (NO) and nitrogen dioxides (NO_2). In the air, NOx reacts with other particles to form particulate matter. Particulate matter contains microscopic solids or liquid droplets that are so small that they can be inhaled and cause serious health problems. CO and CO_2 are produced during the roasting process itself and during the storage of the roasted beans. When CO is emitted into the atmosphere, it affects the number of greenhouse gases, which are linked to climate change and global warming.

The environment

A common environmental issue is acid deposition. There are two forms of acid deposition, wet and dry. Among other things, acid deposition causes damage to the forests, acidification of lakes and a decrease in agricultural yield. The formation of 'bad' ozone at ground-level is also caused by unwanted emissions. The bad ozone is created by a chemical reaction between NOx and VOCs in the presence of sunlight. This leads to smog.

Difference between catalytic and thermal emission cleaners

Catalytic systems use a lot less heat than thermal afterburners and produce a lot less NOx. Compared to thermal afterburners, catalytic emission cleaners are more sustainable.

CONTENTS

CHEATSHEET

Because we don't expect you to know all the terms that are being used in this document, we listed them down below:

- **Amino acids** - Amino acids are organic compounds that combine to form proteins. When proteins are digested or broken down, amino acids are left.
- **Carbohydrates** - Carbohydrates are the sugars, starches and fibers found in fruits, grains, vegetables and milk products.
- **Carbon dioxide (CO_2)** - Carbon dioxide is a chemical compound composed of one carbon and two oxygen atoms.
- **Catalyst** - A catalyst is material that speeds up chemical reactions. With a helping hand from a catalyst, molecules that might take years to interact, can now do so in seconds.
- **Chaff** - During the roasting process, coffee beans lose their outer skin which we call chaff.
- **Chemical compound** - A chemical compound is a chemical substance consisting of two or more different chemically bonded chemical elements, with a fixed ratio determining the composition.
- **Cyclone** - A cyclone collects the chaff that comes from the roasted beans. Because of this, the beans that come into the cooling sieve are separated from the chaff and after cooling down the beans can be processed immediately.
- **Dioxins** - Dioxins are a group of chemically-related compounds that are persistent environmental pollutants (POPs).
- **Endothermic reactions** - Endothermic reactions absorb energy from the surroundings and lower the temperature.
- **Exothermic reactions** - Exothermic reactions are chemical reactions that produce heat.
- **Formaldehyde (CH_2O)** - Formaldehyde is a simple chemical compound made of hydrogen, oxygen and carbon. All life forms – bacteria, plants, fish, animals and humans – naturally produce formaldehyde as part of cell metabolism.
- **Greenhouse gas** - Gases that trap heat in the atmosphere are called greenhouse gases. Examples: carbon dioxide, methane, nitrous oxide, fluorinated gases.
- **Halogenated compounds** - Organic halogen compounds are a large class of natural and synthetic chemicals that contain one or more halogens (fluorine, chlorine, bromine, or iodine) combined with carbon and other elements.
- **Maillard reaction** - The maillard reaction is a chemical reaction between an amino acid and reducing sugar, usually requiring the addition of heat. Like caramelization, it is a form of non-enzymatic browning.
- **Nitrogen Dioxide (NO_2)** - Nitrogen Dioxide (NO_2) is one of a group of highly reactive gases known as oxides of nitrogen or nitrogen oxides (NO_x). Other nitrogen oxides include nitrous acid and nitric acid. NO_2 is used as the indicator for the larger group of nitrogen oxides.
- **Oxides** - Oxides are chemical compounds with one or more oxygen atoms combined with another element.
- **Oxidize** - Oxidation is the loss of electrons during a reaction by a molecule, atom or ion. Oxidation occurs when the oxidation state of a molecule, atom or ion is increased.
- **Ozone (O_3)** - Ozone (O_3) is a highly reactive gas composed of three oxygen atoms. It is both a natural and a man-made product that occurs in the Earth's upper atmosphere (the stratosphere) and lower atmosphere (the troposphere). Depending on where it is in the atmosphere, ozone affects life on Earth in either good or bad ways.
- **Palladium (Pd)** - Palladium is a shiny metal used in many electronic and industrial products. Along with platinum, rhodium, ruthenium, iridium, and osmium, the metal is part of a group known as platinum group metals.
- **Particular Matter (PM)** - Particulate matter, also known as particle pollution or PM, is a complex mixture of extremely small particles and liquid droplets. Particle pollution is made up of a number of components, including acids (such as nitrates and sulfates), organic chemicals, metals, and soil or dust particles.
- **Thermal afterburner** - In an afterburner, the air from the coffee roaster will be heated up a second time.
- **Volatile organic compounds** - Volatile organic compounds (VOCs) are emitted as gases from certain solids or liquids. VOCs include a variety of chemicals, some of which may have short- and long-term adverse health effects.

INTRODUCTION

There is no denying that our climate is changing and that it will continue to change. What can we, as professional coffee roasters do about this? As long as ‘emission’ is an abstract term, it is impossible to do anything about it.

This guide, written by Giesen Coffee Roasters, explains what emission is, how it is caused and what the consequences for our environment are. We describe the ways you can approach emission control and what accessories you might need for that. This guide is aimed at roasters who are interested in or have a coffee roaster which roasts larger batches of coffee.

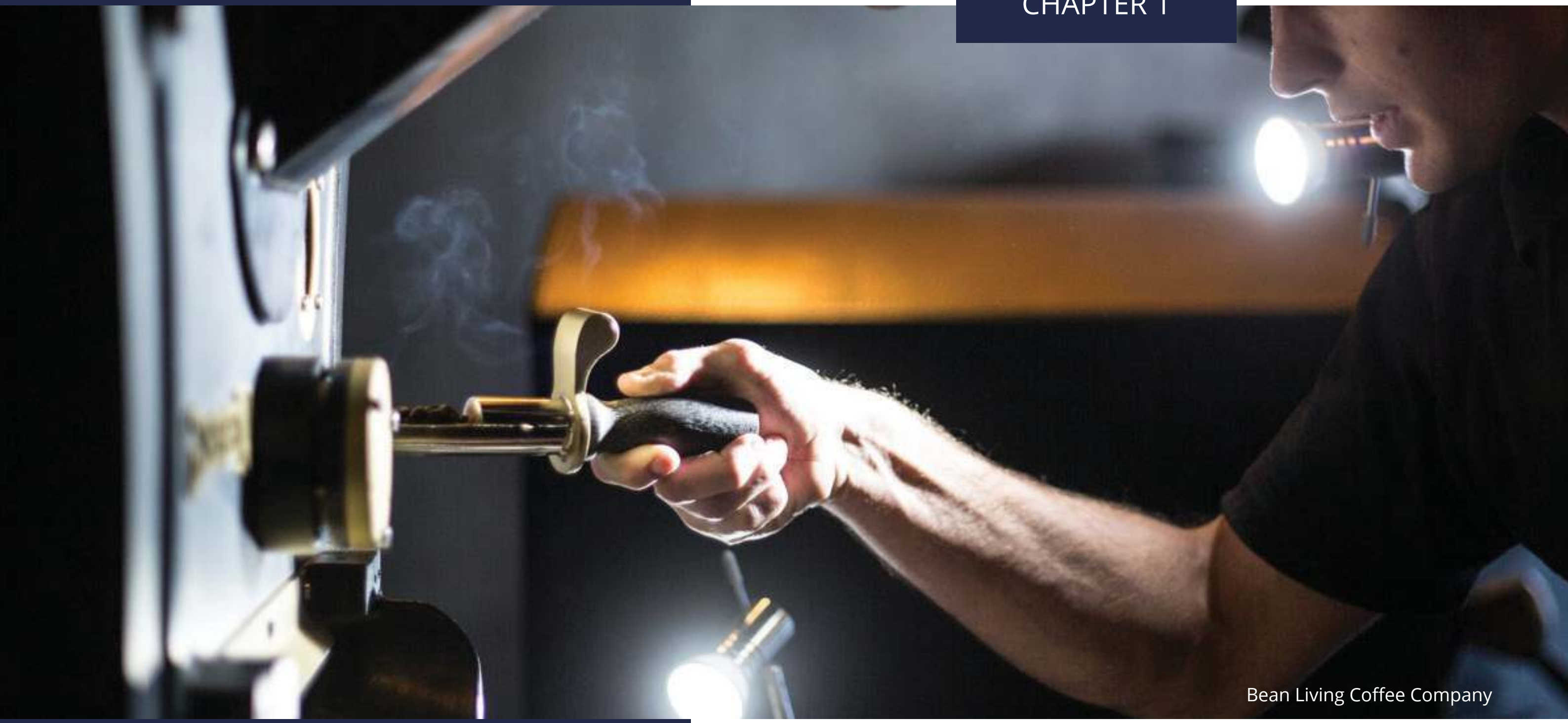
You will learn:

- the process of coffee roasting
- which chemical compounds are released during roasting
- the difference between these compounds
- how to prevent chemicals from polluting the environment
- the advantages of a catalytic cleaning system

If you have any questions about this guide,
please let us know at sales@giesen.com

Team Giesen Coffee Roasters

CHAPTER 1



Bean Living Coffee Company

STARTING AT THE BEGINNING...

Roasting is the most important step in coffee making because it develops the flavours in a bean. This happens because of multiple chemical reactions during this process. You might be surprised to learn that some of these chemicals contribute to environment damages.

There are more than 1000 different chemical compounds in coffee, only a few of which could cause problems for the environment[1]. These compounds make sure the flavour in coffee gets developed. Each different roast profile can activate different aroma blends and determine the flavour of the coffee.

During coffee roasting, green coffee beans change due to the endothermic and exothermic reactions. The beans change in color, mass, and volume. And most important of all, they are much closer to becoming the beverage we all love.

To understand the environmental impact of the coffee roasting process, we start by explaining what happens during the different stages of roasting coffee.

DRYING PHASE

Before roasting, quality green beans contain around 8-12,5% moisture.[2] This first phase of coffee roasting is driving as much water out of the bean as possible, so that the flavor can be developed at a later stage.

This phase begins when the green beans are charged in the coffee roaster and ends when the beans have reached a temperature of 160˚C. You are basically preparing your beans for the rest of the phases by building up pressure inside the bean. The beans are collecting energy from their surroundings.

MAILLARD PHASE

After the drying phase, the beans will then begin to change color. Even though this stage follows up on the drying stage, the beans haven't completed the drying process. The green bean will become yellow and will smell like toasted bread or hay.

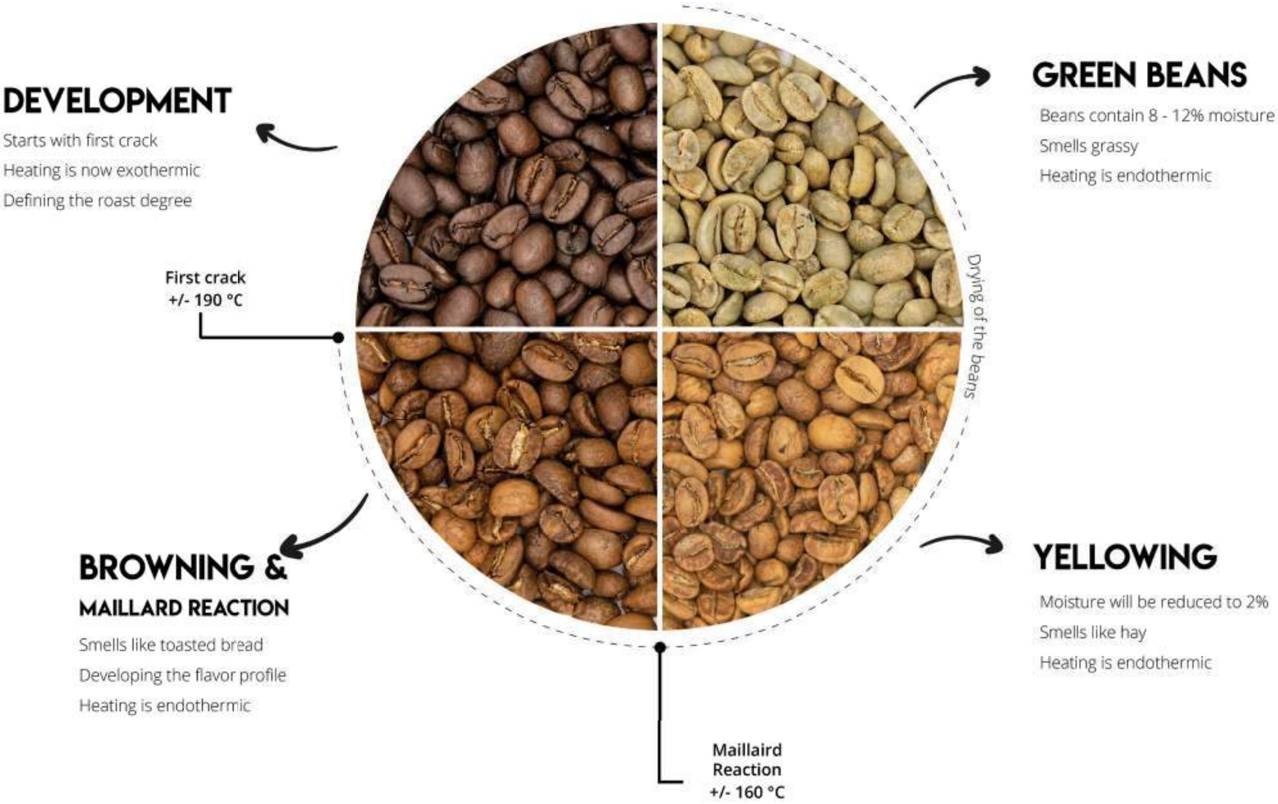
The maillard phase begins at around 160˚C. It is named so because of the sugars that are broken down due to their exposure to high temperatures. The beans are still absorbing heat endothermically, which means they are absorbing the heat from the drum.

DEVELOPMENT PHASE

When the beans have hit the first crack, they expand. Releasing all the heat that has been built up inside it during the previous phases. This is exothermic heating.

As the beans expand, they harden and release the parchment otherwise known as chaff, that was trapped in the groove of the beans. Roasting can trigger over 800 identified reaction products and a lot of intermediate compounds.

The heat from the coffee roaster causes a reaction between the carbohydrates and amino acids in the coffee beans. This reaction creates gases like CO_2, water vapor, NO_x and volatile organic compounds (VOCs).



AFTER THE ROAST

All the matter that's previously described passes through the exhaust and the cyclone.[3] The cyclone takes care of the chaff of the coffee beans that came lose during roasting. Then the gas including the pollutants will go through the chimney.

What can we do to keep roasting coffee but also keep the environment in mind? Some roasters use a catalytic or thermal afterburner, so the gas will pass through an afterburner. What a catalytic emission cleaner is will be explained in a later chapter.

Summary:

- Coffee beans contain over 1000 chemicals compounds but most are not toxic;
- A coffee bean goes through different roasting stages;
- A coffee roaster emits gases like CO2, water vapor, NOx and volatile organic compounds.

2

CHEMICAL COMPOUNDS PRODUCED DURING COFFEE ROASTING

In the previous chapter we described some chemical compounds which are released when roasting coffee, but what are they and what is their impact on your health or the environment?

NOx, NO AND NO2?

Nitrogen gas (N2) is formed when two nitrogen (N) atoms bond together. You can't smell, see or taste nitrogen gas. Next to being not able to notice this gas, it is also non-flammable and will not support combustion[4]. About 78% of Earth's atmosphere is nitrogen.

Oxygen (O) is an oxidizing agent that creates oxides with most elements and other compounds. As described, nitrogen is a very inactive gas. But when this gas meets oxygen in the presence of lightning or a spark, it combines the two to form several different oxides.

The difference between NOx, NO & NO2...

NOx

The term nitrogen oxide (NOx) is used to describe nitrogen monoxides (NO) and nitrogen dioxides (NO_2). The impacts of NOx on our health include damage to the lung tissue, breathing, and respiratory problems.

NO

Nitrogen monoxide (NO) is a colorless gas and one of the principal oxides of nitrogen. Nitric oxide is not considered to be hazardous to health at typical ambient conditions.

NO_2

Nitrogen dioxide (NO_2) is a reddish-brown gas with a pungent, acrid odor and one of the several oxides of nitrogen. Nitrogen dioxide (NO_2) at high concentrations causes inflammation of the airways.[5]

Some particles less than **10** μm ∅ can end up in your lungs

PARTICULATE MATTER (PM 2.5)

In the air, NOx reacts with other particles to form particulate matter. With a little help from the wind these particles can travel hundreds of kilometers before they settle somewhere. Some particles, such as dust, dirt, soot, or smoke, are large or dark enough to be seen with the naked eye.

Particulate matter contains microscopic solids or liquid droplets that are so small that they can be inhaled and cause serious health problems. Some particles less than 10 micrometers in diameter can get deep into your lungs and some may even get into your bloodstream. In 2013, the World Health Organisation (WHO) classified PM (Particulate Matter) as carcinogenic to humans.

CO and CO2 are byproducts of chemical reactions within the coffee beans

CARBON MONOXIDE (CO) & CARBON DIOXIDE (CO2)

CO is a colorless, odorless gas.[6] CO is a byproduct of the incomplete combustion of hydrocarbons.

When CO is emitted into the atmosphere it affects the number of greenhouse gases, which are linked to climate change and global warming. This increases changes to the ecosystem such as increased storm activity and other extreme weather events. You can get ill if you get exposed to a high level of carbon monoxide (for example during bush fires).

CO and CO_2 are produced during the roasting process itself and during the storage of the roasted beans.[7] During roasting, CO and CO_2 are the by-products of chemical reactions within the coffee beans. The high temperature raises the beans above their glass transition temperature.[8] This is the temperature at or above which molecules start to move and change in structure.

VOLATILE ORGANIC COMPOUNDS (VOCS)

VOCs are emitted as gases from solids or liquids. Common examples of other sources of VOCs are paints, varnishes, cosmetics, air fresheners, formaldehyde, and gasoline.[9]

Formaldehyde is a colorless gas with a pungent smell. It results from incomplete combustion of hydrocarbons. Formaldehyde is quickly broken down in the air – generally within hours.

Volatile organic compounds contribute to a number of environmental problems. VOCs include a variety of chemicals that can cause eye, nose and throat irritation, shortness of breath, headaches, fatigue, nausea, dizziness and skin problems.

Summary:

- NOx is the collection name for NO and NO2;
- NO2 is hazardous at high concentrations;
- Particulate matter is harmful to your lungs;
- CO affects the greenhouse gases in the atmosphere;
- VOCs contribute to environmental problems.

3 Environmental issues

This chapter dives in deeper on some of the environmental issues that are caused by the previously described chemical compounds.

Wind makes acid deposition a global problem, not just restricted locally.

ACID DEPOSITION

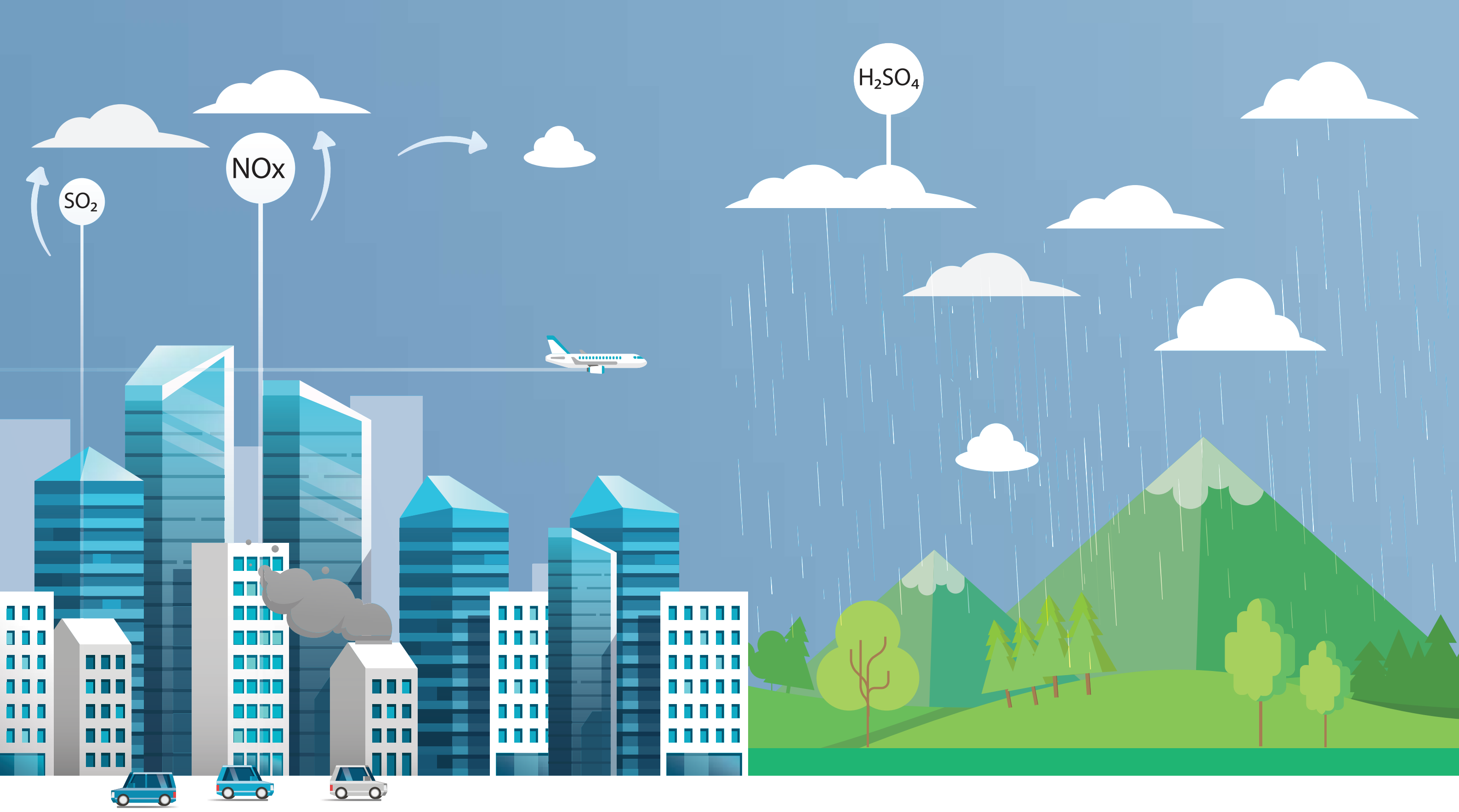
There are two forms of acid deposition.[10] Wet- and dry deposition. The most common wet deposition is acid rain but can also fall to the ground as snow, fog or hail.

Acid rain is caused when sulfur dioxide (SO_2) and NOx are emitted into the atmosphere and transported by the winds and air currents. SO_2 and NOx react with water, oxygen and other chemicals to form sulfuric and nitric acids. They get mixed with water and other materials before falling to the ground.

Acid can also be emitted into the atmosphere without moisture, which is called dry deposition. The particles and gas deposit to surfaces like water, vegetation or buildings. But they can also form another chemical reaction to form larger particles that can be harmful to human health. When the acids are washed off by the rain, the acidic water flows over to the ground and affects plants and wildlife. Wind can blow NOx and SO_2 over long distances and even across borders. This makes acid deposition a global problem, not just restricted locally.

Acid deposition causes:

- damage to the forests;
- acidification of low-lime lakes, resulting in fish mortality;
- acidification of fens which changes the vegetation;
- decrease in agricultural yield;
- damage to monuments and buildings.



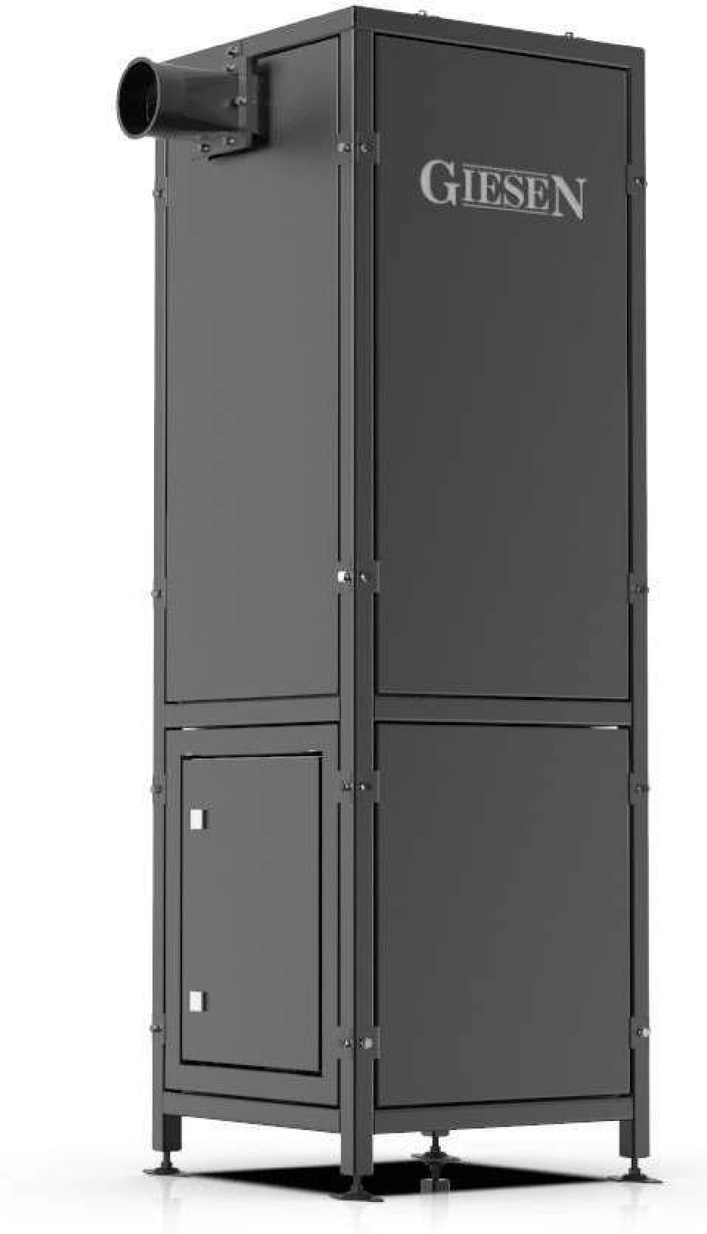
OZONE

Ozone is a gas made of three unstable oxygen atoms (O3) which easily reacts with other substances. In the upper atmosphere, it occurs naturally and protects us from the sun's ultraviolet radiation. Near the surface of the earth, high concentrations of ozone are toxic to people and plants.[11] 'Bad' ozone is created by a chemical reaction between NOx and VOCs in the presence of sunlight. This contributes to the formation of ozone and particulate matter at ground-level, which can lead to smog.

Aside from the adverse health implications to humans and animals, the effects of ozone on the environment can include increased chances of plants developing diseases, an inability to fight off pests and environmental stress, reduced growth, and survival of tree seedlings, and reduced agricultural yields. [12]

Especially in the summertime ozone pollution is a concern because sunlight and hot weather result in harmful ozone concentrations.[13]

How do catalytic emission cleaners work?



Catalytic afterburning works quite similar to thermal afterburning, with the difference being that the air after passing the flame, passes through a catalyst.

The catalyst ensures accelerated oxidation at lower temperatures. The polluted air is heated to approximately 320°C, which is a much lower temperature than being used with thermal afterburning.

A catalytic emission cleaner needs four things to make it work: a carrier, special coating, precious metal and heat. The precious metal, acts as a catalyst and encourages and enables a reaction between individual carbon atoms. Catalysts are used to start all kinds of chemical reactions.

This is the chemical reaction that happens with a catalytic emission cleaner: **Hydrocarbon, carbon monoxide, formaldehyde and caffein go into the catalyst, which oxidizes and reduces these compounds.**

NITROGEN DIOXIDE AND CARBON MONOXIDE

As you can see in the chemical reaction, while the catalyst oxidizes a lot of chemical compounds, there are still nitrogen oxides in the air. Nitrogen oxides are generated during the roasting process but also during thermal afterburning. With increasing flame temperatures, the NOx production is increasing. As catalysts use less heat production, less thermically formed NOx is emitted in contrast to thermal afterburning.

To continue to reduce the NOx levels it is possible to attach a tandem catalyst. This makes sure you are compliant with all statutory emission limits (hydrocarbons, carbon monoxide, formaldehyde, and nitrogen oxide).

Carbon monoxide is also produced as VOC oxidizes. CO is emitted by roasting beans, and even more CO can be produced by improperly adjusted burners. Little CO is released during catalytic afterburning.

EFFICIENCY

VOC: The destruction yield for VOCs is 95 - 99% depending on the type of catalyst, the operating temperature and the size of the catalyst bed. The destruction yield for odor is 80 – 95%. The end concentration of VOC is less than 20 mgC/Nm^3.

CO: CO is removed simultaneously with the VOC. In contrast to thermal afterburning, one should not work above a particular temperature. A typical end concentration is less than 50 mg/Nm^3 CO.

PROS & CONS

+ Uses a lower temperature so less insulation is needed;
+ Lower risk of fire compared to thermal afterburning;
+ Reduces the odours that are released while roasting;
+ CO is destroyed at the same time as the other components;
+ Highly consistent and reliable performance;
- Catalysts need to be replaced every 10.000 roast hours if properly maintained;
- The system is sensitive to changes in energy-content in the gas.

WHAT IS THE BEST SOLUTION FOR YOU?

Thank you for reading our 'coffee roasting and emission control' guide. This guide can't provide sufficient information to immediately know what the best solution is for your set-up. If you need guidance with emission management, don't hesitate to reach out directly to our salesteam at sales@giesen.com

Before contacting us, perhaps you can already think about the following questions:

- What is your budget?
- How much coffee do you roast?
- Are your roasts typically light, medium or dark?
- Do you already have a coffee roaster?
- What is your coffee roaster type?
- When was the last maintenance that was performed on your roaster?
- Where is your roastery located? City centre or a remote location?

ENDNOTES

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About Giesen Coffee Roasters

Giesen is an involved and innovating roaster manufacturer. We not only create technologically advanced roasters but also provide guidance into finding the right solution for you. We have years of experience and still we keep focusing on developments in the industry and keeping up with new technology. Innovation is not just a word at Giesen, it's also a company goal that is definitely lived by everyone, by working on every roaster that is made at Giesen.

Founded in The Netherlands, Giesen is established with headquarters in Ulft and distributors all around the world.

GIESEN COFFEE ROASTERS
+31 (0) 315 68 13 77
Industrieweg 15
7071 CK Ulft
The Netherlands

ONLINE
giesen.com
sales@giesen.com

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