Coffee roasting optimization focusing on afterburning optimization and energy saving

Celso Ricardo Bertinotti

Natural Gas Engineer at Gas Brasiliano Distribuidora, Marketing and Customer Support

ABSTRACT

The purpose of this research is to evaluate technical parameters involved in coffee roasting process in order to optimize the roaster operation, reducing gas consumption and at the same time meeting environmental concerns. According to roasters' manufacturers, there are many parameters to be mitigated and optimized without changing the coffee characteristics as proposed by the coffee producer in terms of taste and smell. A coffee roaster is composed of: hot air generator; a furnace; a blower; a drum; control system; dampers; and in the most of cases an additional burner to the afterburning procedures. Heated air goes into the drum from a combustion system while the drum rotates continuously to ensure roast process uniformity. The intensity of the bean heating and batch time depends on the taste and smell pre-defined by the desired degree of roasting. The last phase of the batch roasting process consists of injecting cold water directly to the bean, interrupting the temperature increase inside the bean and finishing the process. Nearly the end of the coffee roasting process, beans release VOC (volatile organic compounds) and odors that have to be incinerated before being vented through a chimney. The amount of energy spent to incinerate these harmful components and odors is said to be higher than the energy spent to roast the bean. This research aims to evaluate an afterburning stage then propose some measures to optimize the energy consumption. Some measure to optimize the coffee roasting process as a whole will be proposed as well.

OBJECTIVE

This technical research aims to publicize some details of the coffee roasting process, highlighting the afterburning stage. Finally, it proposes technical measures to optimize the natural gas usage, leading to energy saving.

MOTIVATION

Nearly 75% of heat input to the roaster leaves through the chimney, indicating great potential of recovering this energy. The pollutants gases generated by the process that in most industrialized countries must be incinerated before vented to the environment according to local legislation. The lack of information about coffee roasting optimization by Brazilians' manufactures.

METHODOLOGY

For this research, we used the following method:

Consultation with manufacturers of coffee roasting equipments and their advices towards energy saving measures. The evaluation of a roasting process for one month (the case study), application of energy saving measures whenever possible, and measurement of the gains. Some Instrumentation installed in the roaster system, which was used to provide the input information for energy balance and the chemical composition of the stack gas, based on roaster gas mass spectroscopy. Creation of a ranking of energy saving measures based on the case study or on estimated results when the measure was not implemented.

Case study: A batch roaster of 420 kg.

INTRODUCTION

According to Brazilian Coffee Association, the list with the top five producers and consumers of coffee in 2013 were composed of:

TOP 5 PER CAPITA CONSUMERS	TOP 5 PRODUCERS
1. **Netherlands**	1. **Brazil**
2. **Finland**	2. **Vietnam**
3. **Sweden**	3. **Indonesia**
4. **Denmark**	4. **Colombia**
5. **Germany**	5. **Ethiopia**

What is Coffee Roasting?

Roasting is a heat process that brings out the aroma and flavor that is locked inside the green coffee beans. There are hundreds of flavors and aromas that can be extracted from the coffee bean, depending on the temperature and the time the bean is exposed to the hot air flow.

Pollutants originated from roasting process occur at every step of the process, increasing rapidly at the end of the batch, when the desired degree of roasting is reached. Environmental control has significant impact on coffee roasters, which are subject to fines for violating local regulation. This concern can translated in overuse of energy at the afterburner stage when it is not optimized.

Coffee Roasting Phases

Coffee roasting process is divided into three distinctive phases:

<u>Drying phase:</u> which aims to eliminate moisture completely inside the bean. It is a less time sensitive phase.

Pyrolysis phase: when coffee beans develop their specific aromas and flavors, which can produce a very complex taste profile. It is an accurate phase where the temperature is increased gradually inside de bean.

Cooling phase: when water is injected into the drum, interrupting the temperature increase, in order to reach the desired degree of roasting. This is when the gases and vapors emission reaches its peak.

Coffee Roasting Schematic:

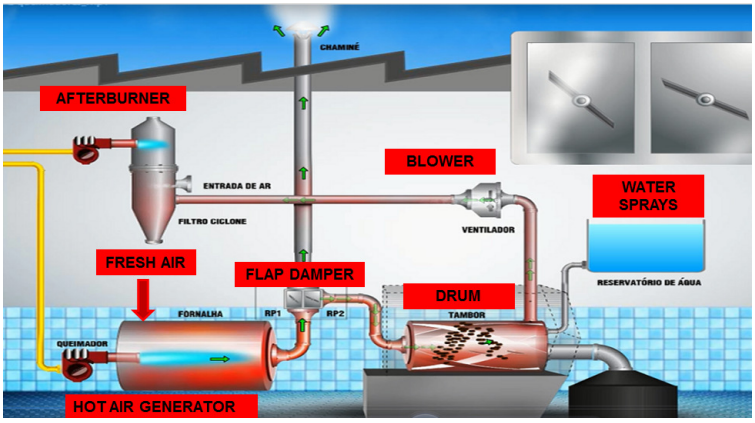


Figure 1

- Hot air generator: Composed of a furnace and a combustion system. The hot air is mixed with fresh air that reaches the furnace at ambient temperature.
- Drum: it is a rotating metal cylinder where the green coffee bean is kept and roasted.
- Flap damper: Mechanical device responsible for the controlling the amount of thermal energy going into the drum and keeping the correct hot air pressure.
- Blower: Forces the air circulation in the system.
- Afterburner: a specific burner used to incinerate the harmful gases, smoke, particulate matter and odor from roasting process.
- Water spray: The water reservoir that injects cold water at the end of the process straight to the drum interrupting the temperature increase inside the bean to halt the desired degree of roasting.

AFTERBURNER ANALYSIS AND OPTIMIZATION

As mentioned before, roasted coffee releases VOC (volatile organic compound) and odor in different levels. The peak emission occurs near the end of the roasting process. Based on the case study and the available literature we can draw some conclusions about the afterburning process:

- The afterburner uses more energy than the roasting process itself: 60% of input energy on afterburner and 40% of the input energy on coffee roasting.

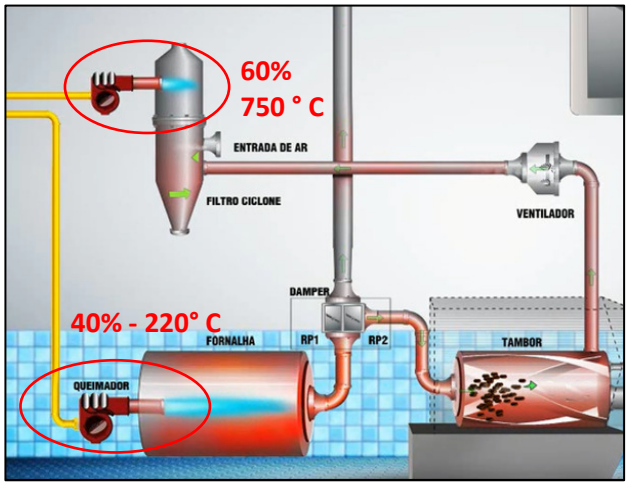
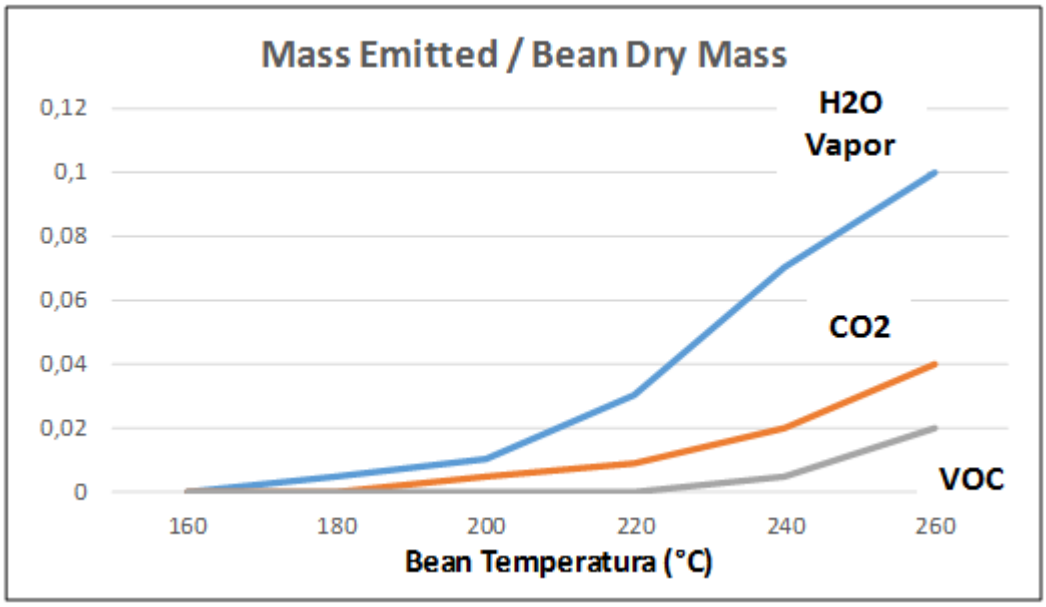


Figure 2

- VOC levels were acceptably low during 75% of the regular roasting process of 17 minutes – data from Donfer and Henry Schwartzberg

- The beans start releasing VOC at high level only at 225℃.

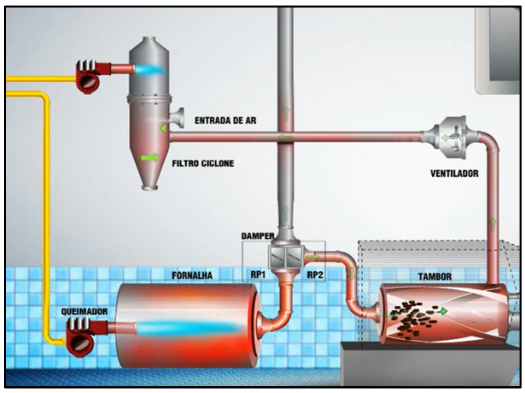
- Drum rotating faster than necessary resulting in higher emissions due to bean fragmentation, so in the case study we had to slow down the drum.



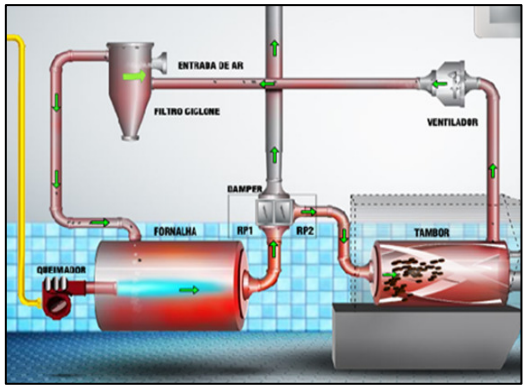
Graphic 1 – VOC emission (qualitative)

The recommendations to optimize the afterburner stage we can turn-off the burner used at afterburning or reduce its power when VOC emission are acceptably low, even bypass the afterburning (when roasting gas recirculation is used), and gradually reduce the bypass intensity as VOC levels rise.

The coffee roasting designed with an exclusive afterburner as figure 3, could be adequate to the figure 4.



The Least Efficient Configuration
Figure 3



The Most Efficient Configuration
Figure 4

The characteristics of the optimal configuration:

- Only 1 burner: Ranging from 220℃ to 750℃, developing two roles: generating hot air to the roasting process and “after” burn the harmful gases. A suitable flap damper ensures that coffee beans do not become over roasted, through the controlling of the amount of heat switched to the drum.

- Duct the harmful compounds returning them to the furnace to be incinerated.

- A Bigger Furnace was required in order to ensure residence time of the gases and its efficient destruction (0.5 second).

Coffee roasting configuration with afterburner (figure 3) is more efficient in terms of VOC destruction, however the return of roasting gas exhaust to the furnace (figure 4) should be pursued.

SIX GENERAL MEASURES TO OPTIMIZE THE ROASTING COFFEE PROCESS

Measure 1: improvement of insulation Quality:

Thicker or higher quality insulation can reduce the heat radiation from roasting system to the environment.

<u>Energy saving expectation: 4%</u>

Measure 2: Optimization of roasting parameters (trials):

Coffee roasting parameters involve: hot air flow, hot air pressure inside the drum, the velocity that hot air goes across to the drum. These parameter affects the efficiency of heat exchange between hot air and coffee bean. The automation of the flap damper permits more positions of the damper and more refined control of the roasting process. The roaster´s operator must find the perfect setup of the system on tests and simulations.

Energy saving expectation: 7%

Measure 3: Providing greater hot air pressure in the chamber:

Drying phase is a less time-sensitive phase that aims only to eliminate the water in the bean. The recommendation is to increase the hot air pressure inside de drum as much as possible resulting in significant reduction of bath time. At the same time, there is an energy saving effect because, it uses less energy in the afterburner. On that measure, the reduction of batch time is main effect.

Energy saving expectation: 3%

Measure 4: Roasting gas recirculation:

The possible coffee roasting configuration includes a system with afterburner without recirculation, a system with recirculation and no afterburner and finally a system with recirculation and with afterburner. The recommendation is to avoid the system without recirculation so that it will have less energy wasted in the chimney and the energy will be recycled.

Energy saving expectation: 30%

Measure 5: Installation of the heat exchanger on the process cycle

The recommendation is to exploit the energy of the exhaust gases by using them to pre-heat the incoming process air or the green coffee bean. The particulate matter deposit on the exchanger can fairly occur, requiring continuous maintenance

- Pre-heat the fresh air that enters in the furnace that comes originally at ambient temperature.
  Energy saving expectation: 30%

- Pre-heat the primary combustion air, in that case a special burner will be required in order to withstand the high temperature (up to 200℃).
  Energy saving expectation: 7%

- Pre-heat the green coffee bean before dropping them into the drum. It can perform adding a mixing chamber to the system. Green coffee bean can be pre-heat up to 90℃
  Energy saving expectation: 15%

Measure 6: Installation of low temperature catalysts

Today, the large majority of coffee roasting plants in Brazil use a traditional thermic afterburner, which operates at 750° C. However, there are catalytic afterburners that permit the incineration of VOC at lower temperature, 480℃, resulting on less energy usage. It is a catalytic converter based on chemical reaction. This is a more costly solution for environmental protection, but it provides a significant energy reduction. A supplementary blower will be required to overcome the drop pressure caused by the system as well as a pre-filter in order to protect the system from particulate matters. Expectation of catalysts replacement every 3 years.

Energy saving expectation: 25%

CONCLUSIONS

The afterburner stage uses more energy than the roasting process itself when not optimized. The VOC (volatile organic compounds) are completely destroyed at 750℃ while coffee roasting process runs up under 280℃. The excessive use of energy in the afterburner stage normally can occur as far the manufactures of coffee are not aware of their actual emission levels and do not hold technical advices to optimize the afterburner process. Others general measures for energy saving can be applicable in the process as a whole, since these measures are subjected to the evaluation of a specialist in terms of economic and technical feasibility. Increasing the automation level of the roaster, control involving hot air flow, hot air velocity and pressure into the drum, can increase significantly the roaster efficiency, which would be translated into significant energy saving. The measures indicated for roasting process optimization can be deployed in comply with emissions regulation and keeping the coffee flavor and aromas as desired by the producers.

Energy Saving Measure Summarize:

Measure	*Energy Saving
Pre-heat the incoming fresh air (process air).	30%
Exhaust gas recirculation.	30%
Catalytic afterburning instead of thermic afterburning.	25%
Reduce burner power when VOC levels are acceptably low.	20%
Pre-heat green coffee bean before dropping them into the drum.	15%
Pre-heat primary air combustion.	7%
Optimization of roasting parameters (trials).	7%
Improvement of insulation quality.	4%
Provide greater hot air pressure in the chamber at drying phase (Reduction of batch time).	3%

Table 1: Energy Saving Measures - ranking

***The energy saving values are only qualitative and must be studied for each case.**

REFERENCES

Schwartzberg, Batch coffee roasting; roasting energy use; reducing that use.

Dorfner, R. 2004. In-Line TechnikenzurEchtzeitAnalyse von FluchtigenVerbindungen in KaffeeRostgasen.Doctoral Thesis, TechnischenUniversitatMunchen, Germany.

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