Profiling Coffee / the hidden formula

Which goes to show how little we know

Introduction

Caffeine may be the substance that lures you back to that cup of coffee, but once you have acquired the taste of *specialty* coffee which has been grown, harvested, dried, selected, transported, roasted, ground and extracted with care, dedication and fine equipment, it's the subtle and rich quality of the beverage that provides you with a blissful experience, again and again.

Figure 1. Enjoying Espresso

Several processes assist the bean to develop into the best it can be.

Roasting, for instance, can be done slowly or in a hurry, with a steadily rising temperature or with a 'profile' that is continuously changing in intensity, first enveloping the bean in heat energy and then ever more slowly adding to the temperature, almost teasing the bean to finally yield its aromas in a softly crackling volumetric boost.

And luckily, deep in there, the best roast profile can be defined as a single math formula and the software that controls the roasting at my home has a TEX typesetting method built in to display that formula.

As common as grinders are, very few people know enough about it to explain the effect of the profile of cutting edges one finds on the burrs. Even though everyone can take out the burrs and look at them, their secrets are hiding in plain sight.

Extracting then, at last, an espresso from fine grinds

Figure 2. My londinium li-p home machine

packed into a puck, involves at least three kinds of profile: temperature, pressure and flow.

All these work together to create the satisfaction that coffee can bring to your palate and mind.

Even though coffee is one of the most common drinks we know, there's still a lot of invention going on and it's a great pleasure to be friends with a few of the original minds working at innovation.

Simple recipe

For espresso, we take a dose of beans, say 14g, grind them fine into a basket, tamp with some pressure but not too firmly, lock the basket into a brew group, let water flow in at about 93°c, wait a few moments to let the coffee puck get all wet and apply a pressure between 4 and 9 bar to extract about 20g of delicious brew, dissolving between 18-22 percent of the coffee grinds. The high pressure can come from a little motor but I love the hand powered or spring powered lever machines. Hand power allows you to change the pressure as you go, just like you use a fine fountain pen, pressing for more flow, pulling light for a fine stream of ink or, in this case, coffee. A spring lever, once released by hand, applies a specific and beautiful pressure profile on the coffee puck and while the cooling brew head causes the temperature to slowly fall, so do the first droplets fall under high pressure and as the flow increases, pressure declines. The effect is, if all else goes well, a wonderful spectrum of taste unfolding like a fan being spread to show all the intricate patterns.

Figure 3. Coffee refractometer

A coffee refractometer can be used to test what percentage of the grinds have been dissolved in the water. Some like the brew with sugar, some with milk, others prefer it pure, with a tiger skin of mottled crema covering the blackness.

All very simple, it seems. But taken from the start it is quite a journey, and a pleasant one. Although I would like to be a guide, I have gradually learned that with every revealed fact there are a few more that remain elusive. All we know about coffee, all that we try to measure and pin down is the shadow of something that passed by at high speed, too fast to really see and fully understand.

Figure 4. Conical burrs out of a grinder

Figure 5. Grinding

Tamping

When the grinds have fallen into the espresso filter basket, they are nearly ready to be rained on with hot water, but not just yet. First a tamper is used to carefully level the grinds into a firm *coffee puck* which will be firm enough to stay in place once the water hits it, but also leaving enough room for the water to quickly immerse all of the grinds which then change to become a flexible and permeable mass yielding the most pleasant coffee solubles to the water that passes through. It is important to know what tamper to use.

Jan van der Weel, a friend of mine and I do a lot of research together, and one of the projects we did for KTC, a Dutch coffee trade magazine, was about tampers. A close fitted flat tamper will do fine.

Figure 6. Article about tampers

Figure 7. Espresso

Flow

Using a dedicated scale for coffee, one can monitor the flow of the extraction into the cup. At the start of the extraction, the pressure on the water above the puck is high but just a few droplets are falling from the filter basket. Then there is more of a flow and an increasing stream is landing in the cup. As the flow rate increases, the concentration of solubles is declining and you can see the color going from deep brown towards yellow. The richest concentration of taste is in the early very salty moments, but it needs the dilution of later, more watery fluids to reveal the most of itself in the most pleasant way. When using a spring powered lever, the pressure is highest at the start and as the spring expands and relaxes, the extraction pressure decreases; which has the advantage of working towards a mild extraction once the coffee puck is nearly spent. Many of the most expensive modern espressomachines have electronic controls to emulate more or less this pressure profile of the classic lever machines.

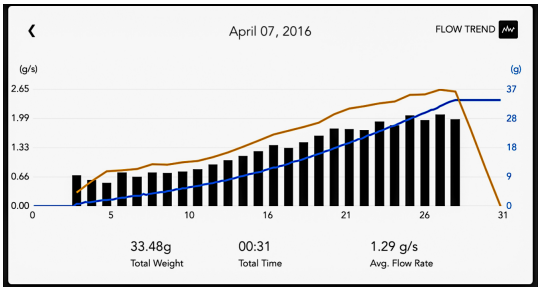

Figure 8. Flow

Extraction temperature

As the hot water hits the coffee puck, the grinds quickly get wet and hot, then cool down a moment until the pressure builds up and more hot water starts to flow through the puck, dissolving (hopefully) the best compounds of the grinds, and moving out to make room for more hot water. Inserting a tiny temperature probe inside the coffee grinds we managed to log the typical temperature profile of an extraction.

The espresso machine needs to be built in a way to have hot water from the boiler to always keep the brew group at a temperature that is ideal to start the next extraction, without getting too hot or cooling down during idle hours. As simple as the copper tubing looks inside a classic espresso machine, the proper dimension of these pipes secretly enable both the right extraction temperature and the correct post-extraction temperature.

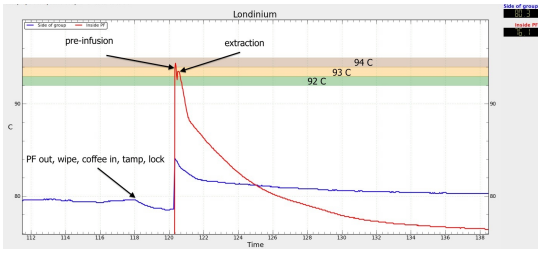

Figure 9. Extraction temperature profile

Coffee plantation

I've had a few coffee plants, but in our climate they look rather boring. Deep green leathery leaves. Some friends even had flowers and then coffee cherries on theirs.

Most coffee varieties originate from Ethiopia, but today they grow in many tropical and subtropical countries; preferably around 1500m above sea level with not too much sun and some mist in the early morning.

Harvest of the coffee cherries can be once or twice a year. Picking the ripe berries is the most crucial moment in the entire journey from plantation to cup, but it is also the worst paying job to have. For as little as $ 12 a day, a picker must select only the best looking ripe red or yellow berries and leave the unripe green ones for the next round, but one gets paid per full basket so there is an incentive to be less critical and also pick some unripe berries in order to fill the basket quicker.

Next, a truckload of berries is washed in water. Any unripe or damaged beans tend to float whare they are scooped off and thrown out. The thin layer of fruit flesh around the coffee bean is partly removed by pressing

the berries though the narrow of a roller mill. The rest can be washed off with lots of water after the wet mass has been left to ferment for about 24 hours. Then the wet beans are dried in the sun for a number of days until the internal moisture in the beans is about 9–11 percent.

From the moment of picking all the way to the last moments of the espresso served to you, the quality can never be improved but only damaged by any faults in the process. So harvesting is as important to our coffee as it is far away from our coffee pot.

The wet processing needs care because beans must not be damaged and fermentation may not be overdone, but a riskier method of dry processing is used in regions where water is scarce. Here the complete berries are dried in the sun during the day, covered during the night and meanwhile any bad looking berries can be sorted out and discarded. After about four weeks, the beans are finaly separated from the dried flesh. You can imagine how fruit drying in the open air in a hot climate can attract all kinds of bad luck, from birds and insects to fungi, but if all goes well, the reward can be a superior complex sweetness in the beans and an higher market value.

The dried beans are often intensely sorted and sorted again to remove any odd, damaged, discolored or insect bitten beans. It is quite incredible how much time and effort is spent on the beans by people who have never even tasted the kind of espresso that we casually order at a bar. In some countries this sorting is not done at the farm but at a washing station where less time and care is spent on selection, and then you have to sort the beans yourself before roasting. The result can be absolutely superior. It is worth all the extra work, and it makes you respect the people who do this every working day.

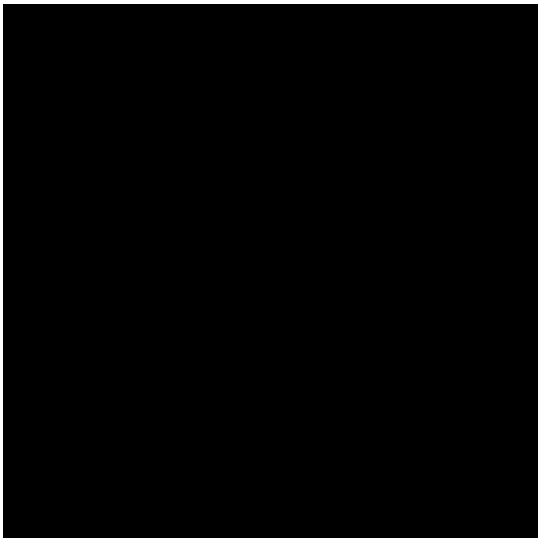

Figure 10. Sorting Mandheling beans

Trading

The next step, selling the beans, is dependent on the options that are open to the farmer or the collective of farmers. In some countries, the state tries to regulate all trade and the harvest is sold in bulk, naturally with some kickbacks to the powerful and corrupt people involved. An excellent harvest can be indifferently mixed with inferior truckloads, and, in those cases, we never discover that lone farmer producing miraculous beans. Elsewhere, international traders manage the collection, testing, branding and transportation to huge warehouses, and the commodity is offered, sold and resold by people on computers who never see any of the product they move on their screens. The volume can differ immensely from a number of sea containers to a hundred 60k bags or microlots of a dozen bags or less.

Luckily there is a growing network of roasters and coffee businesses who connect with farmers directly. Buyers and sellers work together to improve coffee quality, and to ensure that the farmers and their workers get better pay. Investments are made to help the community, and in some regions to improve the way the small family businesses are organized. In a macho culture, for instance, just paying more for the harvest can be useless if the father goes to town to sell his beans and then when he has more money, he stays in town longer to party, returning home a poor as he left. Also, some farmers fly out themselves and visit buyers and roasters to hand out samples and book direct orders. Last year, Marianela Montero of Costa Rica visted me in Amsterdam. Her family owns a coffee plantation, and she has travelled most of the world in between harvests to learn about the international trade. Travelling the world is not new to Marianela since she has competed intranationally as a swimmer. Her father, coffee producer Don Carlos Montero, is also a swimming coach and when Marianela was younger, he built her a competition grade swimming pool at home so she had perfect training facilities. At a trade convention in Seattle she noticed that some big international volume traders took her presence very seriously as she was one of the first from her region to connect directly with many buyers on the other end of the long and complex trade trajectory.

Figure 11. Marianela Montero visiting the author

Roasters reaching out to farmers and helping them improve their life and business is not merely a fair trade move by the roasters. It also builds some protection against the big brands who might otherwise buy up complete harvests of the farms that a small roaster has discovered. Nespresso for instance make so much money on their cups, they can easily afford to pay whatever the currently popular beans would cost, if only just to prevent any comptetition from growing to a significant size.

Cupping

At several moments along the itinerary of the beans, the quality and market value has to be established, and because sophisticated roasting devices, grinders and espresso machines are scarce in most producing parts of the world, this is done by a ritual called *cupping*. First the green beans are roasted in a small, somewhat crude roaster and the next day these beans are ground coarsely.

Figure 12. A cupping session

Figure 13. Late night cupping discussion hosted by Kees Kraakman (r) in Amsterdam. Center is Adam Craig from New York, presently coffee enrepeneur in Amsterdam

The grinds are smelled, distributed over cups and immersed in hot water. The freshly roasted coffee grinds emanate carbon dioxide and come floating on top of the hot water. This crust is broken and the aroma rising from the water is sniffed and noted by all in attendance.

Next, the floating coffee particles are scooped off and removed and deep spoons are used to slurp the coffee. It takes much training to be able to uniformly taste and evaluate the coffee this way.

This process called *grading* has been more or less standardized and there are over 3,500 licensed *Q graders* who provide credible and internationally accepted descriptions of taste and quality. A coffee that scores higher than 90 is considered excellent.

Monsooned

On their way, the beans are mostly packed in sealed plastic food safe bags in a coat of burlap bag with the basic information about trader and origin stamped on the burlap. This wrapping ensures that the beans retain the freshness they had when leaving the farm.

There are some exceptions. More than a century ago, beans from the Malabar coast in the British Indies were transported to Europe by ship, and during the journey of several months, rainstorms would wet the beans and hot spells would dry the cargo. This resulted in the beans arriving in a weathered state a bit pale and larger than normal. Everyone learned to love their specific roasted taste quality of musty spice and chocolate so much that nowadays, when transportation is fast and sophisticated, the beans are purposely exposed to monsoon rains and drying cycles in order to acquire that *Monsooned Malabar* finesse.

Figure 14. Monsooned Malabar beans from India

After a short stay in warehouses in harbor cities, the beans are delivered to the roasters and that's where the real fun begins for us. Typically, roasting can take any time between 3 and 20 minutes, and during that time a dazzling amount of changes take place inside the bean, most of these in the last 25 percent of the roast.

Figure 15. Green bean before roast

Roasting machines

You can roast the beans in several ways. The basic thing is to carefully add head, and keep the mass of beans in motion so every bean is getting an equal heat treatment.

Heat and movement can be delivered to the beans in several ways.

Most machines have a metal outer drum that is heated by flame or electrical heating elements. An inner drum, similar to that in a washing machine, continually tumbles the beans. The heavy mass of the metal radiates heat into the bean mass of several kilograms or even dozens of kilograms that is sloshing around in the inner drum and air is blown through the middle drum to clear out smoke and to remove the chaff of silver skin that comes off the beans during the roast.

With *fluid bed roasting* the magic comes in the form of hot air flowing into a vertical roast chamber from the bottom up, pushing through the beans, with the beans dancing around on top of the bed of hot air. This needs a lot of energy from the heat source (gas or electricity) and enough *push* in the flow to keep the beans aloft without blowing them out of the chimney altogether. For instance, when my friend Tije de Jong and I tried to build such a roaster, we used a leaf blower and it blew the beans all through the building, but when we fixed the heat nozzle on it, the blower pushed mostly backwards. The blower had more speed than push.

Mike Sivetz, a North-American legend of the coffee world, built a first fluid bed roaster in 1975 and many of his machines are still in use. Today, the Fracino factories in Birmingham build a small fluid bed roaster for home use and that is what I have today, with some home made extensions.

Figure 16. Roastilino *fluid bed* roaster

More than a century ago, in the early morning, the smell of freshly roasted coffee flowed throught the narrow streets of fast growing cities. Then industrial roasters took over, and home roasting became all but obsolete. Today, the art and craft of coffee roasting is recalled and innovated.

Modern roasting machines mix elements of fluid bed and rolling drum but in 2015, Tije de Jong in Amsterdam came up with a radical new and amazingly simple idea. He built a roaster out of scrap parts with a household sieve to hold and shake the beans in and a paint stripper to heat the beans, using a probe inside the beans to monitor the bean temperature. This roaster is cheap and easy to copy, and it could enable many home roasters to rediscover the art of roasting.

A paint stripper serves as a heat source and a little electric motor does the shaking. We tried several paint strippers and the simple one performed just as well as an expensive one with digital display. Reading the bean temperature and watching a timer, Tije notes the roast values in a matrix printed on paper and at the end of the roast he connects the dots to reveal the profile.

It was not the first time Tije used his extensive workshop for a coffee project. In 2014, Tije built a *transparent*

portafilter, a little compartment that enabled us to see what happens to the coffee grinds during the extraction. Quite a challenge to find and combine synthetic and metal parts to hold together under vast changes in pressure and temperature with sudden variance of nearly 100°C and shocks from atmospheric pressure to 9 bar. Roemer Overdiep, a Dutch designer and cameraman, rented a *high speed camera* and filmed the events in detail. The video clips were an instant hit on the coffee channels with tens of thousands of views as no one had been able to visualize at such resolution what actually happens inside the normally hermetic brew head.

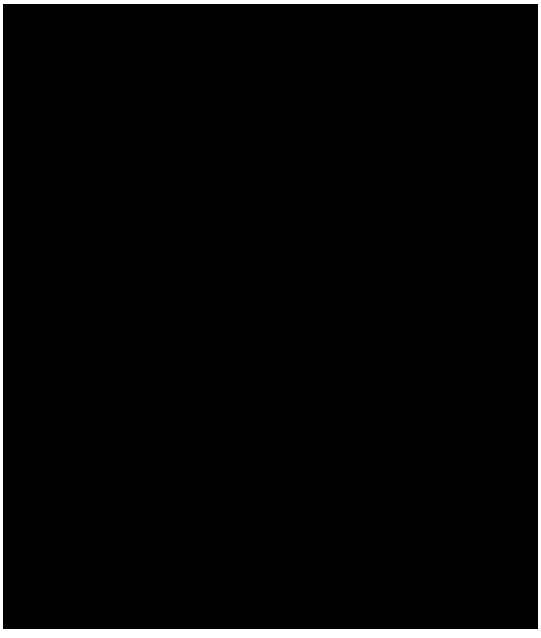

Figure 17. Tije's roaster featured in an online coffee magazine

Figure 18. Gábor and Attila, coffee friends from Budapest, next to version 2.0 of Tije's *Shake, Not Stir* roaster

Roasting

Inside any type of roaster the beans go through a basic experience, a kind of roller coaster ride of an ever increasing temperature, but the rate at which the temperature increases, the so called *Rate of Rise*, can vary depending on the ideas of the roast operator.

You can divide the roast trip of the beans in three phases.

The first and easy part of a roast track is the ramp up to around 150°C. Not much is happening yet besides the beans losing moisture to the hot air, so this is called the *Drying phase*. With some imagination, if you smell the air coming out of the roaster, you are reminded of freshly cut grass, hay, a horse's stable, sometimes even a sweaty horse brought in on a hot summer's evening when a thunderstorm has broke through. The beans change from green to yellowish in color.

If this first part is kept too short and intense, the resulting coffee may be winning in clarity or lacking in body, tasting a bit sour. If it is done more slowly, a more full bodied coffee might be won, but if overdone the brew could taste dull.

Then you raise the heat enough for the beans to gradually start to change color. Browning can be seen in the *Maillard phase*; which is the same event involving amino acids and sugars that gives flavor to steaks, cookies and bread.

If kept short, this might contribute to a simple bright coffee and if prolonged, this phase may bring about a more complex coffee; which could be a good thing if you were expecting much from the deliciously fragrant green beans.

The smell in this middle phase is like toasted bread. During this time, more and more subtle changes take place inside the bean, but it all builds up towards the most spectacular moments at the start of phase three:

The *Development phase* begins with an audible *first crack*. The remaining moisture inside the cells of the coffee bean is heated above boiling point, and all these cells become microscopically small pressure cookers kickstarting a large number of chemical reactions that contribute to the tastes and aromas we associate with coffee. Almost like minuscule popcorn, first a few and then many of these immensely small cells inside the bean begin to pop, and much of the built up pressure and heat bursts out.

Imagine a hot room in a turkish sauna bath where it has become unbearably hot and suddenly the doors and windows fly open and hot steam is blowing out. Standing outside, you'd feel the heat rush coming at you and you could think that the little hut got very hot all of a sudden, when in fact the build up of heat was gradual and only now it is flowing outward.

You might smell *coffee* even though it's more of a sharp smell that I associate with *coffee roastery*. There

can also be a *Second Crack* later on but that is less audible and if you roast that far, you also approach the phase of full carbonization of the bean, and you are basically roasting charcoal and starting a fire.

During this third phase after *First Crack*, The beans are turning a darker brown and many different volatile compounds are carried from the beans and out of the roaster. The roastmaster often takes samples during this time, looking at the bean colour, smelling the beans, trying to decide about the best moment to stop the roast and cool the beans. Overall, this *development phase* takes around 25 percent of the total time, so if he knows when *First Crack* started, he will roughly be able to estimate when the beans will have the desired roasted quality, but this also depends on the heat applied towards the end, on the airflow through the bean mass and the motion of the beans inside the roast chamber.

If this phase is lengthened, a more wonderful complexity and a creamy mouthfeel could be the result but if overdone, you have wasted the beans and the coffee will taste flat. Kept too short, this phase would allow more sweetness, possibly at the cost of being just simpler in taste of maybe even like chewing on grass instead of coffee.

Then the door is opened, and the fuming hot beans rush out to be cooled. It's important to get enough cool air on the beans to make the roast stop, but a thermal shock to room temperature is not needed. The mass of beans can be stirred or left resting, some roastmasters even spray water or water with sugar on the beans. All that is done will affect the taste of the coffee later on.

Controlling

I built the controller for my roaster with the help of Wa'il al-Wohaibi from Ryadh in Saudi Arabia. He sent me many tips and pointers for the hardware. At the heart of the device is a PID module. It is a data bridge beween the computer and the roasting machine. The computer tells the PID controller how to roast, the controller drives the heating element in the roasting machine to stay on track. At the same time the controller measures real time temperature inside the bean mass and communicates these data to the computer where a program called *Artisan* processes the information. *Artisan* displays the roast profile as a graph of temperature over time, and looks ahead on the roast plan to provide the controller with the latest temperature targets. It automatically marks the roast phases, and even uses computer speech over the speakers to alert the operator about the events.

Figure 19. Wa'il al-Wohaibi talking about coffee roasting on a Saudi television talk show

The *Artisan* roast software that I use is written and developed by Marko Luther from Fürstenfeldbruck in Germany. It is the only piece of roasting software that both loggs what happens while, at the same time, controlling the process like an *autopilot* or *cruise control*.

Many players in the coffee world keep their knowledge and methods to themselves or share these in very small portions during expensive training, but there is also a growing network of friends and colleagues who freely share all they do and know. The Artisan software is open source and free, just like TEX and in fact there is a kernel of TEX in the roast program.

Figure 20. Look! TEX sighting in coffee software

Together with a friend, Marko Luther has also built a full-spectrum color sensor with 4 white LEDs, a 7-segment display and an Arduino micro controller to measure the roast color of coffee grinds. Usually these cost several thousands of Euros but they managed to produce this open-source device for a few hundred, using a 3D printer; the result of combining low cost high quality components and many many hours of work.

Figure 21. Tonino roast color meter, hardware and software (open source) by Marko Luther

Designing a roast

Before roasting a new bean, I measure the moisure of the bean, its density, weight and size. This way I can predict if the beans will easily dance on the hot air, or if the airflow might have trouble permeating the bean mass. If, for instance, the beans have a moisture content of 9.7%, I look in my logs to see if I roasted a bean like that before. If so, I can estimate how long the roast could be, at what point *First Crack* might occur, and then the proportions of the phases become apparent.

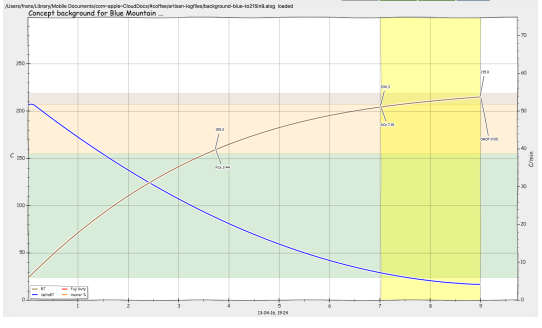

Figure 22. A typical design of a roast profile of mine

In my roaster I aim for a fast start followed by a gradual decline of the *Rate of Rise* (the blue line). The brown curve is the planned *Bean Temperature*. The green area of the temperature is where mostly drying takes place, the pink level is between 155°C and *First Crack* and the grey level is the temperature area where the *development* happens. On the time line, the *development phase* is the vertical yellow bar.

I want a high Rate of Rise at the very start that keeps gradually declining towards the last moments of the roast when it is ideally near zero. This way, there is a constant flow of extra energy towards the beans, even at the moment of *First Crack* when the pores fly open and hot aromatic fumes are squirting out of the popping

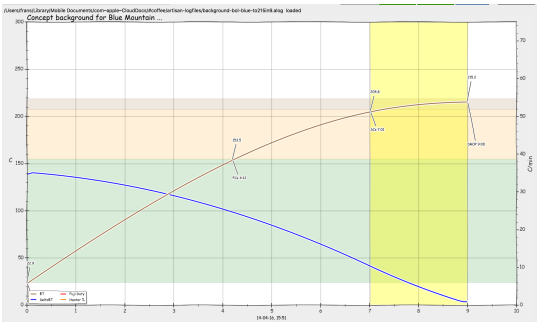

Figure 23. A more *traditional* profile

bean cells. At no time is the energy buildup allowed to sag. It is merely increased ever more gently towards the end to support the process inside the bean during which all the complex taste and aroma is created.

Most roasters use a profile like the one above. The ramp up to *First Crack* is almost a straight line so the *Rate of Rise* is fairly constant. Most large drum roasters have such a heavy metal mass that it is not very easy to influence once it is going. Like a big heavy truck going up a hill. Around *First Crack* much energy is released from the bean mass and there, the profile mostly turns to a less steep rise. Some roasters boost the energy towards the end to quickly get a certain targeted deep brown color of the beans.

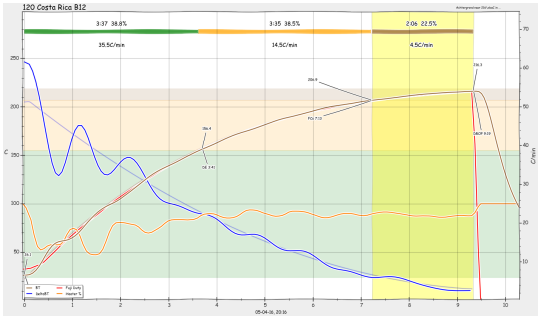

Figure 24. An actual roast log

In figure 24 the brown line of the actual roast is practically covering the red target curve. The orange line shows the intensity of the heater controlled by the PID system and the dark blue line the actual *Rate of Rise* value meanders ever more closely over the light blue target line. *Rate of Rise* was first an average of 35.5°C/min, then 14.5°C/min and a mere 4.5°C/min during the last phase. Both the *Drying phase* and the *Maillard phase* have been about 38% of the total roast and the *Development phase* was 22.5%

After a rest of ten days, the espresso from this roast was boring, but it gradually improved during the week

after that, and then it really spread its wings to be most enjoyable.

In my experience this is a good way to go from bean to cup but who knows, I might think differently later on. Figuring out how to do it is like finding your way in a town house with the floor plan of a different building in your mind. You bump your head often but the more you browse around, the more you discover.

> "After winning, I realized how little I knew" said Gwilym Davies in 2014 when he was interviewed in his barista training centre near Prague, five years after becoming the World Barista Champion. "I realized that none of us knew that much which made me much more confident and I was in the wonderful position where I had proved myself. I was allowed to say *I don't know!* I was allowed to make mistakes because I was the world champion. I'd proved myself and it was okay to say that I'm still learning. I didn't have to feel like my identity was being challenged because I didn't know something, I didn't have to make something up. I could just be honest and go *Hmm, I don't know*... It's fun."

Recently Talor Browne, a very experienced roaster and coffee expert, mentioned in an interview how even some of the most famous coffee gurus are still searching:

> "Even at the top, there is no known knowledge, only trial and error. Everyone, even Tim, is kind of bumbling along in the dark, looking for the light switch. It bothers me to see people be looked up to so much when it's all so unknown. The things I do know are: if your raw coffee is delicious, it's actually pretty hard to mess it up."

Marko Luther commented:

> "Nice quote. I couldn't express this better and share Talor's view fully. I had that impression already in 2013 when I talked to Morten and Tim in person at the European SCAE convention in Nice.
>
> So there seems to be a clear change in taste on modification of the roasting process, but it seems impossible to grab the exact details of this influence and use these to make a tool that brings out what you are looking for in a coffee.
>
> Even worse, I have the feeling that coffee changes dramatically and without much control or predictability during the time after roast and by small modifications of the drink preparation process.
>
> All we have by now are only some rather rough general wisdoms.
>
> Brewing hotter or extracting longer tends to make your brew more bitter, while extracting cooler and extracting shorter tends to move to the bright and sour side.
>
> The same in roasting. Shorter, lighter roasts might be brighter, while darker roasts turn towards bitter. In the middle there must be the *sweet spot*.
>
> Then we know that there is the danger of underdeveloping a roast (still green in the middle), especially with gentle, but short roasts. Hotter short roasts are better developed, as are longer roasts. Too gentle and long roasts could end up boring.
>
> But why are some roasts that tasted horrible a week out of the roaster, excellent if tasted after 3 months?
>
> And why is my grinder choking up the shot every now and then, without me changing anything in bean choice or grind setting.
>
> Sure, changes in humidity might be the reason. But humidity is not changing too much during winter times in my kitchen.
>
> I am lost, but others too."

That is maybe the best: being blissfully lost amidst the most delicious coffee.

Figure 25. Roasted bean

Meanwhile, the roasted bean is smiling at us, mysteriously, with a self satisfied gleam on its cheeks. We will be studying it for a while yet.

Frans Goddijn

Figure 26. Do you like sugar with that?