Roaster Design, Process Controls, and Flavor Development

One and two bag roasters come in a very wide range of designs. Probably more than any other size range, these are machines that have their designs firmly planted in both the specialty and commercial markets. Designs can vary from single wall drum, double wall drum, solid cylinders, perforated cylinders, drum-less fixed chamber air roasters, fluid bed style without agitators, air roasters with agitators, oven pack burners, gas jet burners, radiant flame burners, multi-style burners, high velocity air, medium velocity air, fixed air speeds, adjustable air speeds, cooling with water quench, cooling without water quench, sample extraction during roasting, no sample extraction during roasting, fast roast times, medium roast times, conventional roast times, manual controls, semi automatic controls, fully automatic controls, profile controls with five set points, with 30 set points, roasters with aroma valves, roasters without aroma valves, downdraft coolers, updraft coolers, and I'm sure I must have left out a few things.

Just writing the list reminds of me being a child and spinning in circles until you get so dizzy you have to sit down and watch the world spin around you. Hey, with this many possibilities it's got to be fun. How about we take six coffees and roast them on every design with every configure permutation and cup all of the results? What? Is that too much work? It will take too long? I thought that's what five-year government grants were made for. Think of the travel, the adventure, think of the great contribution to knowledge and science. Hey, I can make time in my schedule; we can do this! If you, dear reader, get the grant thing going I am on your list, right? Right?!

"Hey Hensley, buckle down and get back to the job at hand." OK, please excuse the exuberance, must have been the double espresso I had before lunch. All right, let's get serious. One of the wonderful things about coffee is how responsive it is to all the nuances and variations in growing, processing, roasting and brewing. In the roasting especially, these touches have a magic all their own. Enough to make us love the process, think big thoughts, and want to dive in again and again. Understanding the gross and subtle variations in aroma and flavor, and relating this to the variables of roaster performance controls is the essence of profile roasting.

Unlike other food products, the goal in coffee roasting is to produce a uniform result from the outer layer of the bean through to the inner heart of the bean. No dark, caramel-y outside, soft and chewing inside for coffee. In specialty coffee, the roast master is generally trying to maximize flavor development, and, along with this, perhaps, impart a "signature" style to the roast as part of creating a brand identity. Commercial coffees, on the other hand, are often approached with the objective of minimizing or eliminating taints and achieving "acceptable" flavor. Commercial roasters may also focus on imparting a signature roasting style, which generally includes keeping an eye on minimizing weight loss. Minimizing weight loss usually means keeping roast degrees in the lighter end of the spectrum.

Ideally, a master roaster (or a roaster operator with aspirations of mastery) should be adept at both approaches and can become so by developing a thorough knowledge of bean variations and equipment design and adjustments.

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The art of constructing roasting machines lies in the design selection and control of such variable factors as time, temperature, air flow, energy input, roast chamber packing density of coffee to air space, bean motion within the roasting chamber, heat transfer ratios, drum or roasting chamber materials, amount of BTU input per quantity of coffee, etc. Each of these factors, are important in the roasting process. The art and science of profile roasting lies in the ability to individually select or adjust, some or all, of these elements within the complicated web of heat transfer technology that will guarantee the best possible roasting results for a targeted purpose, and as efficiently as possible in terms of technological and economic factors. The ability to reliably and consistently produce these targeted results is what sets apart great equipment and great roast master skills.

Every roaster recognizes the vital importance of green coffee selection in achieving specific coffee flavors. But just as "tainted" green beans can produce tainted flavors, so too the wrong choice of construction materials, poor burner performance, inadequate air- flow, or an "unclean" roaster can also impart tainted flavors. The most well known example of this is the "dirty" roaster. If the roaster is not kept clean, causing a restriction in airflow, or if dampers or air flu's are positioned in such a way that airflow is inadequate, smoldering of chaff inside the roasting chamber can result. Smoldering chaff will result in bitter taints to any coffee.

This has been one factor that has led some to extol the virtues of "air" roasters. Of course, what is usually meant by "air roasters", are "non-drum" roasters, but that argument will show its Achilles heel to anyone familiar enough with well designed drum roasters with adequate air-flow. The truth is most modern roasters can be thought of as primarily air roasters. Many modern drum roaster designs utilize convection heat ratios of 85% or more as a percentage of the kind of heat transferred to the beans during the roasting process. Furthermore, convincing arguments can be made in regards to the virtues of keeping mixing functions and airflow adjustments as independently controllable variables. Each independent adjustment variable adds to the scope of choices available to the roast master.

The best and brightest of roasting equipment designs have long recognized that flavor development variations will occur according to the choices made in the complex balancing of conduction, radiant, and convection heat transfer, air speeds, bean blending functions, roasting and cooling times, and a whole host of related features. This understanding has been a driving force in the selection of what mechanical features of a given design remain fixed and what features are variable. Together these fixed and variable features are the tools by which the roast master can apply his/her skill and artistry. Just as artists who know their craft can create compelling art with charcoal and paper, but with added colors and canvas, can bring whole worlds to life, so too the knowledgeable roast master is empowered to create greater results with more tools at his or her command.

One key set of tools, are the temperature readouts from a roaster. These are most useful when they show the greatest amount of dynamic change during the roasting cycle. Therefore, placement of thermometers and thermocouples are extremely important. Wrong placement can result in a very shallow range of change or a range whose non-linear response will give the

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operator very little useful information. Like trying to read the depth of field with one eye closed, errors in perception can lead us very far astray from our chosen objective.

Because differing bean characteristics, due to fiber density, which generally follows growing altitude, will respond differently to the absorption of heat being transferred to the heart of the bean. For temperature readings to be most useful they should be positioned to give an accurate reflection of this absorption. The beans themselves will also give obvious clues in the varied texture at the bean surface when comparing low density and high-density beans. After the initial heating of moisture trapped in the cell structure of the bean, beans begin to expand in size due to pressure increases as the roast level approaches the first crack. Denser coffees will show more prominent ridges and valleys on the surface as the more tightly bound bean fiber resists expansion. Low-density coffees will be noticeably smoother with less fiber strength to resist the inevitable volume expansion. At the same time this lower fiber density allows heat transfer to more easily penetrate to the interior of the bean. This effect informs the roaster operator to adjust the level of thermal energy being applied to the bean. Here a variety of choices can be made, including adjustment of the flame and therefore altering the ramping of temperature in the roaster. Other control choices might include adjustments of the velocity of air passing through the roasting chamber and the levels of gas pressure being delivered to the burner. The last item is distinct from a single flame adjustment as it will raise or lower the amount of BTU energy being delivered into the roasting chamber independent of the specific temperature reading of either the bean surface temperature or exiting air temperature.

The slope of the time/temperature curve can be steep, gentle, simple or quite complex. The selection of what path to follow is always a complex formula that must include the equipment, green beans, roast degree targets, batch sizes and ambient conditions. But as wide as this playing field is, there are also some general principles and telltale roast results that define the limits when roast imperfections are certain to occur.

Although the exact temperature and time concerned will certainly vary with the design construction and materials used in different roasting equipment – the roast results themselves inform us when we've gone too far afield.

So, briefly, here are four key roasting imperfections to avoid:

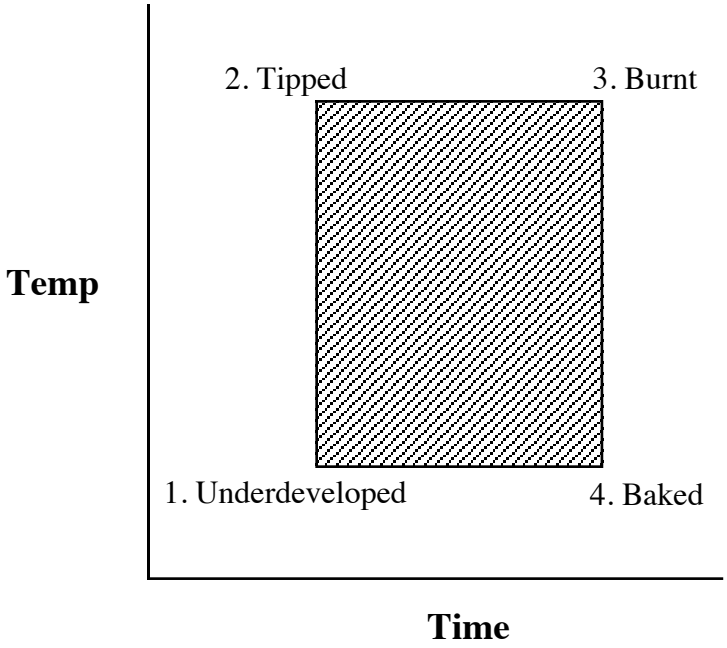
1. Temperatures too low, time too short. Result – underdeveloped flavor characterized by roasted beans which have not fully expanded in volume, exceedingly light roast color, grassy, grainy, raw nut like flavor.

2. Temperature too high, short roasting time. Result – disparity in roast levels between the outer bean layer and the inner bean. Extreme examples show a burnt outer layer and raw underdeveloped inner layer. This is the classic case of "tipped" coffee. Taste results are a combination of charred, grassy and grainy. Decidedly unpleasant.

3. Too high temperature, too long roast. Result – Burnt coffee. The flavor has crossed the line from a coffee flavor with carbony overtones, to a pure charcoal taste.

4. Too low temperature, too long roast. Result – Visually, this coffee may look just fine, good bean size, surface texture and even roast color all through the bean. Flavor and fragrance, however, are "missing in action". Very bland, lifeless boring brown liquid. This is the classic "baked" coffee.

Quality roast profiles must keep inside the boundaries set by these four imperfections.



The good news is we still have a wide range of possibilities inside these limitations. What our profiles can further define is what path to take to get the best results for any given target within this zone. Fortunately, we have some guide lines that will suggest to us which possibilities are most likely to give is the results we want. The first guideline is the transformation of flavor that occurs as we move from lighter to darker roasts. That transformation can generally be characterized like this:

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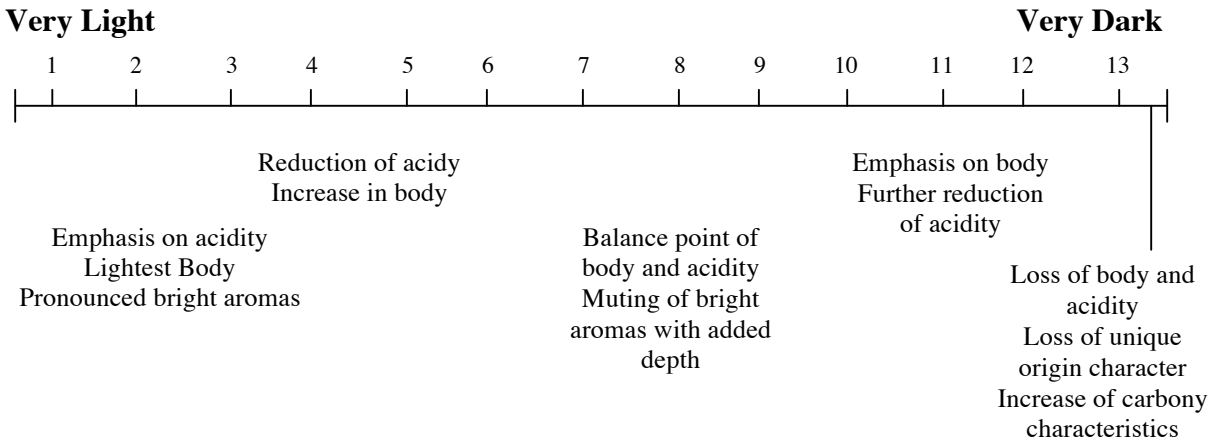

Although this general transformation will be true of all coffees, the scale is in no way linear. For example, the balance point between body and acidity for one coffee may be at level 4, for another level 7 and yet another level 10. Likewise, although our greatest coffee may produce superb flavors and aromas throughout the entire scale, lesser coffees may find only one or two points where they yield excellent flavor and anywhere else they simply fall apart and have nothing special to offer.

Therefore selecting the roast profile is usually well served by starting with understanding the beans' potential through a range of roast degrees.

With this formulation the roast master can begin to "fine tune" the overall time/temperature curve.

It is usually a good idea to start at the beginning and in roasting that beginning can be defined with three fundamental parameters:

1. Charging temperature
2. Air velocity
3. Burner Output

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Charging Temperature

The range of charging temperatures is usually best narrowed down to a final choice by considering three primary conditions:

A. Batch size

B. Roast Degree Target

C. Bean Density

Secondary conditions that might also be considered, particularly if they are in any way extreme are green bean moisture content and ambient temperature. Finally, if we wish to impart a signature style to the roast, such as more surface oils, less surface oils or extreme volume expansion, these items will also affect the conditions we want (temperature, air speed and burner setting) at the charging of the roast.

At the charging of the roaster our roasting chamber temperatures will drop, eventually leveling off and beginning the upward climb to the final roast level. During this cycle the bean will be undergoing the characteristic changes of color transformation, size expansion, audible first and second cracking and the outgassing of a rich array of fragrances.

This array of fragrances is remarkably revealing of the beans' virtues and possible taints. Understanding these fragrances and the roaster adjustments available in manipulating their development is key in getting the best from each coffee. Here the craft and skills of the roast master guide the mechanical adjustments for burner, air flow and temperature acceleration. Automated roast profile control systems will track these changes and if the roast master is satisfied with the results, can be locked into memory. The same results can be achieved manually by careful notation of settings on all available controls. Automated systems at first glance might seem to take something away from hands on artisan roasting, in practice it honors the efforts made by the roast master by consistently repeating the pattern that was painstakingly analyzed and derived. Of course, as the green beans change over time or a new crop arrives, the profiles might benefit by a bit of tweaking.

The most common profile controls make simple burner adjustments as the roasting process progresses from beginning to end. Set points are typically available for changing temperatures and one, two or three burner adjustments during the roast and quenching and discharge upon reaching the selected final roast temperature.

A key consideration along the time/temperature curve is the build up of internal pressure within the bean throughout the roasting cycle. The pressure factor can be considered independent from measurable ambient and bean temperatures in spite of the fact they are interrelated. Energy input and the speed of its delivery is key to the pressure factor. The two primary adjustments roast masters can use to regulate the pressure factor are burner output and air flow.

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Internal pressure increases first occur from the transformation of trapped moisture content into steam. The climax of this build up is the occurrence of the popcorn like sounds of the first crack. A secondary increase of internal pressure then takes over as CO2 and other gases continue to be generated faster than they can pass through the bean fiber. The continuing escalation of these pressure cycles is responsible for the 100%-plus increase in size from green to roasted bean. Inadequate BTU energy input through the roasting chamber can often be recognized by a restricted size increase from green to roasted bean. This stunted growth will also yield flawed flavor development as well. This is due to a lack of adequate internal bean pressure being generated and sustained through the roasting cycle. This can happen because of inadequate gas pressure to the burner, a premature decrease of burner setting, or excessive lowering of burner output.

Telltale signs of these are excessively long roasting times, excessively long periods from charging to turning point, or turning point to first crack, or an overall drop in roasting chamber temperatures after a burner adjustment. Roasting results under these conditions will usually be a mixture of underdeveloped and baked characteristics. Surprisingly, it is even possible to find the odd occurrence of beans showing a darker degree of roast on the inside while lighter on the outside, due to the air passing over the bean surface, having a cooling effect when an excessive decrease in burner output has occurred. In any case, adjusting the burner and airflow to maintain a steadily increasing ambient temperature, or building to a holding temperature at or above the charging temperature while bean temperatures continue to increase will usually alleviate these problems.

Another key factor is determining the roast profile time/temperature curve is the control of the exothermic phase of pyrolysis. Fundamentally, the exothermic phase can be thought of as the trigger point that once ignited, will begin the rapid release of stored energy inside the bean. The results of this release will be the creation of all of coffee's most desirable aromas and flavors. However, the roaster operator must be cautious in controlling the applied energy of the roaster once the stored energy of the bean begins to be liberated. With too much combined energy, the roast will accelerate out of control, moving past the target degree of roast to well beyond in a matter of moments. To prevent this from occurring, applied energy is usually minimized with roasting chamber temperatures only slightly increasing or leveling off and held steady. The momentum of exothermic processes will then take over and continue to drive the bean temperature higher but with adequate time to allow the operator to observe steady increases in the degree of roast and halt the process when the precise roast degree target is achieved.

Mastery of the roasting art can broadly be thought of in two fundamental categories – 1) understanding of green coffee and 2) understanding of equipment features and controls and how these will affect the green coffee. Useful operational knowledge of each of these can be acquired quickly with a bit of focus and instruction. Mastery of both is only accomplished by those with an enduring passion for understanding the wonderful complexities of the process. Fortunately, their passions are usually met with the joyful response of paying customers. But the learning

curve of the masters is not easily duplicated and consistency of product is generally enhanced with automated control systems that allow production operators to reliably repeat the results of the roast master.

This is precisely what profile controls are for. Among various manufacturers, profiling control systems range from rudimentary, moderately complex, sophisticated cybernetic "intelligent" systems and exotic edge of the art controls. Taken in order, let's consider each type.

I. Rudimentary

Here is a first step beyond manual controls. Rudimentary controllers generally will use a bean temperature profile to track the progression of degree of roast. The target degree of roast is recognized when the bean surface temperature reaches a pre-selected value set by the roast master. The controller will then either sound an alarm for the operator to stop the roast or initiate the quenching (if used) discharge and cooling cycles. All other parameters are typically left for the operator to set or adjust manually.

II. Moderately Complex

These systems are probably the first that genuinely deserve to be called "profile" controls.

Profile controllers in this category allow the roast master to select a multitude of settings and roaster adjustments to closely approximate a desired time/temperature profile. These can include charging temperature with a selected burner output (i.e. 100%, 80%, 60%, etc.) and a selected ramping of airflow volumes in conjunction with burner adjustments as pre-selected bean temperatures are achieved. The final degree of roast ending temperature, selection of water quantity and time duration of water quench (if used), automatic discharge into cooler, cooler fan start up, sweep arm start up and duration of cooling, automated cooler discharge and destoning (if used) are all adjustable within the scope of mid level profile roasting controls.

This level of profile control offers a big step over more rudimentary controls. The beauty of these moderately complex profile controllers is that even though they make their adjustments in relatively few steps, by allowing the control of both burner and airflow at key steps in the roasting process, significant changes in flavor development can be created. These alterations of flavor cannot be accounted for by simple degree of roast management log. It is these fine adjustments that allow the roast master to garner that extra scintilla of flavor great coffees have to offer. Indeed, herein lies a significant part of the "magic" attributed to roaster designs that allow for the independent adjustment of airflow and burner output from the mechanical mixing and tumbling of coffee beans.

Roast masters know that the time and temperature curve followed in reaching an identical degree of roast can produce remarkable differences in flavor profile. These level two profile controls begin to allow the roast master to lock in on these differences and keep their production operators producing them, batch after batch.

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The next step up is where continuous feedback takes on a whole new significance. Here we enter level three – the cybernetic intelligent systems.

III. Cybernetic Intelligent Systems

An evolutionary step up from level two, these profile controls allow the complete integration of the roasting system by creating a continuous feedback loop between sensors and controls. This is the realm of high precision roasting that will execute the roast master's selected profile perfectly while adapting to any changes necessary to master the profile. By continuously monitoring and adjusting burner and airflow, these systems insure that the precise time/temperature curve is followed and degree of roast achieved, regardless of variations in batch weights, green bean moisture content, atmospheric pressure, humidity, or air temperature. This level of profile controls represents a step beyond what most skillful and observant roaster operators can consistently achieve.

Finally, our list would be incomplete if we didn't mention the exotic edge of the art controllers of level four.

IV. Exotic Edge of the Art

First on the scene in expensive ultra designs, these systems represent a benchmark achievement. I'm talking about the fully integrated on line roast degree meters. Like their cupping lab brethren, these are systems that take measurements of the coffee's roast degree. But unlike the lab units, these systems do so inside the roasting chamber during the roasting process. With a precision beyond what the eye can see, on line color reading controls can bring coffee to an exact selected level. Although more likely to be found on roasters larger than 60 or 120 kilos per batch, they are, nevertheless, edge of the art.

Robert Hensley is the founder and chief trainer of the Coffee Training Institute. Anyone interested in learning more may visit his website, www.specialtycoffee.com or contact Mr. Hensley through his office at 650 259-9308.