“Smart” Thermal Processing: Hot Air in Three Dimensions

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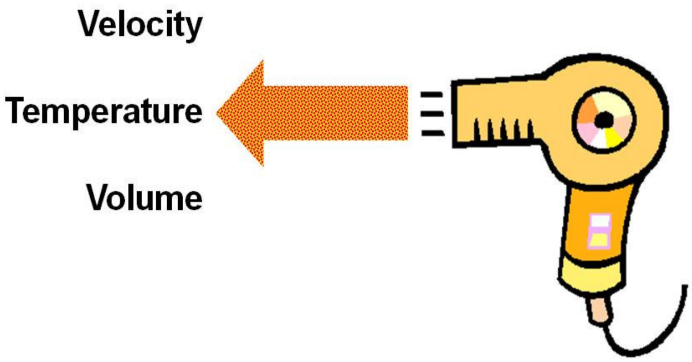
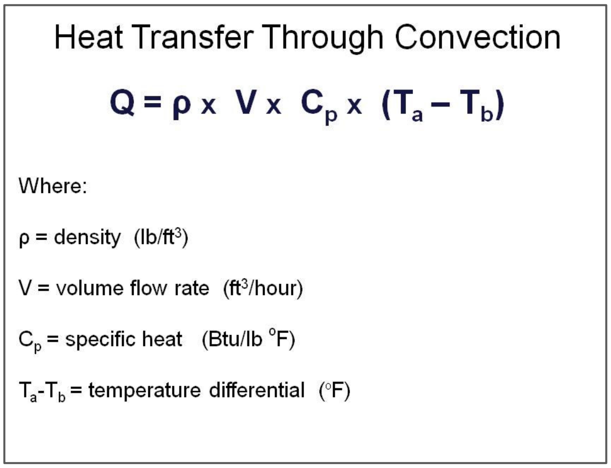
To better appreciate the state of hot-air thermal process heating and recent developments, visualize a simple model. For those that still have their hair, imagine blow drying your hair. (For those without hair, flash back the appropriate number of years.) Now imagine instead that you have an incredibly massive, huge head, piled high with sopping wet hair. Does that change your image of the blow dryer you would need?



It’s readily understood that hot-air processing cannot be accomplished with an industrial one-size-fits-all dryer. But just as importantly, effective, optimized heating design requires not only the right sized heat source, but a more precise level of control. Reflecting back on our hair drying example, the ***temperature*** of the airstream is not enough to provide efficient drying. Imagine a teeny tiny, thimble-sized dryer struggling against that massive mane of soaked hair. Even a very hot, but miniature air stream would amount to a proverbial drop in the ocean. As well as temperature, we need a large enough ***volume*** of air to do the job. But those of us in a rush know also that hair drying is also more than just an exercise of defined by temperature and volume. That’s because drying is not just about the heat, but about the efficiency of heat transfer. That’s why your hair dryer has a low-medium-high switch in the handle. The ***velocity*** of hot heated air can have a large impact on many processes. Sometimes we want very fast moving air. Sometimes, depending on the product, the material being heated or other particulars, high velocity can be a bad thing. Like Goldilocks – often the answer is not too hot and not too cool but instead getting it “just right”. But finding that sweet spot with most conventional hot air equipment is a daunting task. Without proper controls it’s darn near impossible - like trying to use cruise control by controlling the brakes alone.



Heat Transfer Through Convection

$$Q = \rho \times V \times C_p \times (T_a - T_b)$$

Where:

ρ = density (lb/ft^3)

V = volume flow rate (ft^3/hour)

C_p = specific heat (Btu/lb °F)

T_a-T_b = temperature differential (°F)

The underlying arithmetic of this heat transfer is given by the familiar heat flux equation shown in Figure 2 which illustrates the dependence of transfer, or heat flux (Q), on temperature and the volume flow rate of the airstream. This paper examines the benefits of thinking of hot air process heating not just in the singular dimension of temperature as has been the custom – but in the three dimensions of temperature, volume and velocity. These three parameters, which are inter-related by the physics of thermodynamics, can be relied on to work effectively together to improve the efficiency of process heating using modern control technology. This is important for a wide range of applications from the sensitive heat staking operations in electronic goods, or shrinking of delicate packaging films to more robust operations like food or timber drying where optimum drying can save a great deal of time and money.

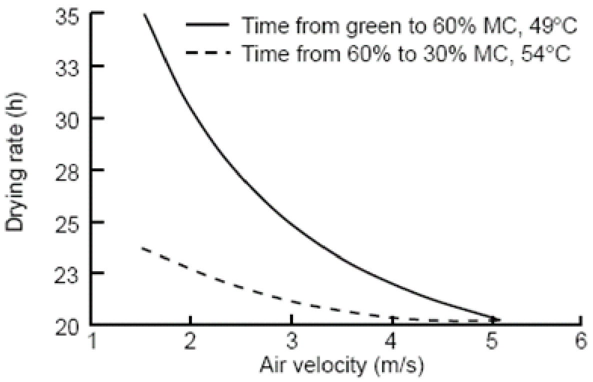
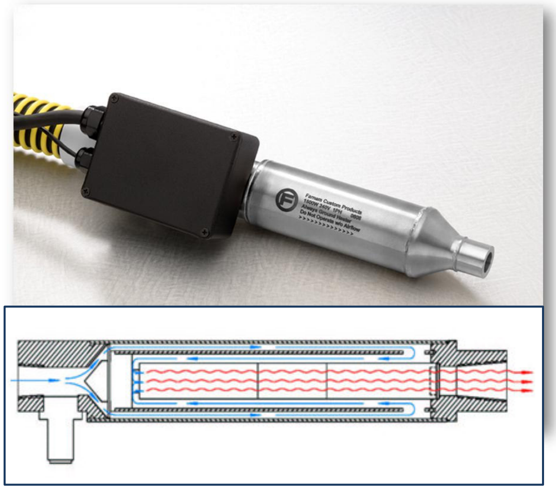


Figure 3 shows the dramatic and practical consequences of increased airflow in the drying of eastern white pine from green to various levels of moisture content (MC). This is a far more urgent example than hair drying of why it's important to focus on the impact of factors other than temperature alone in hot-air processing. Those working in delicate medical, laboratory and other manufacturing operations where errors in process heating can cause untold damage also appreciate the need to achieve a higher degree of consistency and reliability.

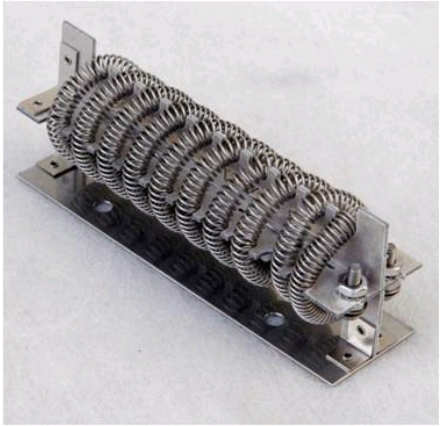
Improved Heat Sources

A typical hot air process heating source is the open-wire resistive heater (Figure 5). Air is blown across heated coils of wire composed of Nichrome or similar metals. The air is heated and exits the nozzle towards the substrate.



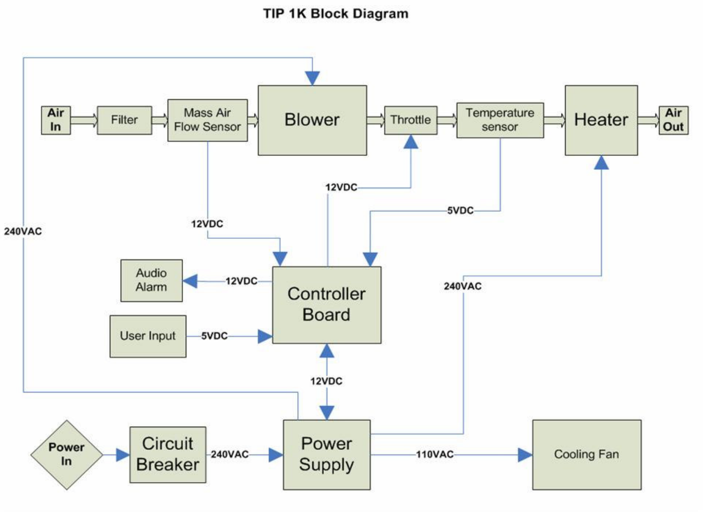
The temperature is determined, and limited, by a few factors; the temperature of the coils, the temperature of the incoming air, the volume of air, and surface area of the coils as well as the amount of time provided for the air to be heated. The temperature of an open wire resistive coil is determined by the electric current applied to it. A 20-gauge Nichrome coil for example produces 400^{o}F temperature when 1.9 amperes are applied and 1200^{o}F as the current increases to 4.6 amps. The heating time of course is related to the speed at which the air moves across the coils on its way through the torch.

Some good engineering has taken place in the last several years to improve the efficiency of these heaters with better coil design. Another welcome improvement has been the development of the Farnam CoolTouch® version of the heat torch which utilizes a triple-pass route for the air inside the torch to provide insulation between the interior chamber of the heat torch and its exterior housing (Figure 4). Since outlet temperatures in excess of 1000°F are not uncommon, those who use these devices realize the value of providing a safe unit that can be handled and integrated.



Many of these heat torch devices rely on a simple thermocouple installed near the outlet nozzle to monitor hot air temperature. This is a poor environment for the measuring device, and failure of the thermocouple is a common occurrence. Finding a suitable location for the sensor is also a bit of a challenge since obstructing the airstream is undesirable.

It is also well acknowledged by manufacturers of heat sources and customers alike, that all-to-common low-air and no-air conditions are by far, the largest single contributing factor to premature failure of these heating devices. To help avoid air-related failures, more advanced models utilize a simple "go-no-go" flow sensor to shut down the heater if the incoming air drops below a preset critical threshold. Frequently however these sensors fail to save the unit before it needs to be replaced or produces poor quality product.



New Integrated Designs

To date, installing an engineered hot air process heating system has placed a burden on most plant engineers and maintenance departments. Systems have been cobbled together with pieces and parts to solve these problems. Separate airflow sensing, electric heater controls, compressed air with traps and filters or regenerative blowers with filtration. Unfortunately even after the effort of integrating such a system it lacks the automated control capability needed to operate simply and efficiently for a range of applications. There just hasn't been the availability of a simple "plug and play" solution.

The schematic in Figure 7 illustrates a new approach to hot air process heating. The unit represented is an integrated system containing 1) an air source 2) the heat torch and 3)a control system which provides simultaneous control of air temperature, velocity and volume.

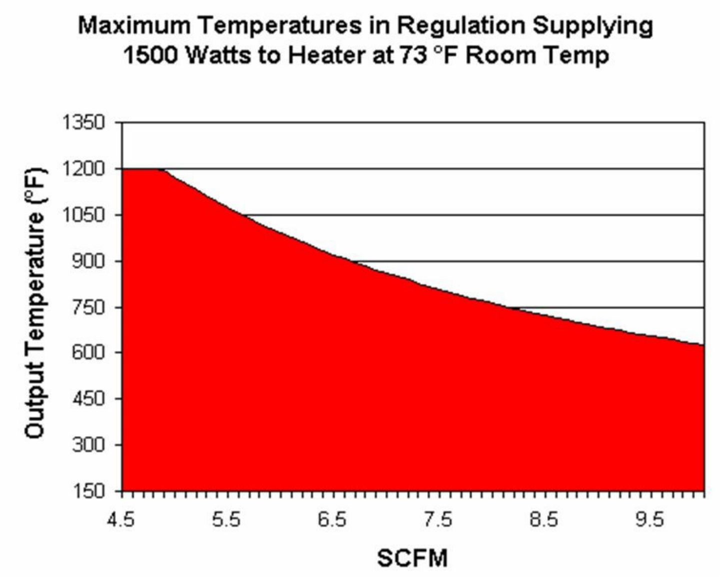
The heat source consists of a HEPA-filtered, regenerative blower capable of supplying a clean, uniform airflow over a wide range of desired air volumes. Note that the blower is accompanied by a mass air flow sensor which is used to regulate the mass of air entering the system (since the volume of air changes with temperature, but the demand for a given volume of air can be computed and controlled.)

For those who have experienced both the cost of instrument quality compressed air as well as the need to properly condition air to remove oil, moisture and other contaminants, a HEPA filtered air source is a welcome and obvious choice.

The heat torch, a CoolTouch (TM or R, need Tutco Farnam name? model described above is selected based on the intended operating range of the unit as well as the air velocity required. The wattage required for the heat torch is approximately given by the empirical formula:

$$\textbf{Watts = Flow Rate (scfm) x } \boldsymbol{\Delta}\textbf{T x 0.3165}$$

So for example, a typical 1500 Watt heater can operate over a convenient temperature range of 600F – 1200F and air velocities ranging from 4.5 to 10.0 SCFM. This provides a convenient source for many industrial applications.

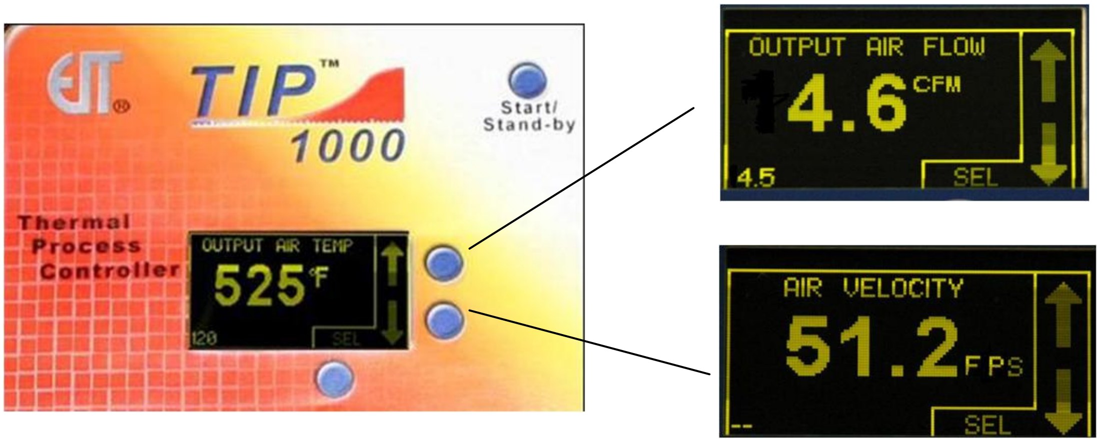


The dependant relationship of air velocity and heat source wattage along with output temperature illustrates graphically what was alluded to earlier. That is, the task of maintaining a pre-set temperature requires adjustment of the air velocity. Of course compounding the difficulty is the complication that the air volume is changing as it is being heated as well. Add to this the idea that the temperature of the heat source is determined by the current running though its electric coils which must be varied proportionately…and it's easy to see that there are a lot of inter-related variables to control… or in many applications are not controlled at all!

Of course this could be done manually – if you have the time, patience, and instrumentation to provide rapid feedback of the effects of each variable upon the others. This iterative process of tweaking is both time consuming and dynamic. (Add to this for example another variable; that the incoming air temperature may be fluctuating as well. In some plants this can range as much as 30 to 40 degrees Fahrenheit or more (Clarify F or C) during the day..

For processes that require consistency, accuracy, or repeatability, monitoring and varying these parameters in real time is simply not possible without a supervisory control system. The schematic shows the “smart” control provided by a PID temperature controller that is interfaced to they system with several sensors. PID controllers, (short for Proportional, Integral, and Differential) use sophisticated mathematical algorithms to make rapid, real-time voltage electrical adjustments to the coil based on observed changes in the process. For example, if the incoming air temperature varies suddenly, or there is a change in line current fluctuation, the PID controller will compensate to maintain a pre-programmed set-point. (PID controllers are also programmed to reach set-point temperatures more rapidly than conventional controls).

The integrated controller provides a simple means to do the real-time number crunching of the simultaneous equations of several variables that must be solved to deliver constant uniform air regardless of the velocity, temperature of volume required. (Figure 9)



The operator keypad permits any two of these variables to be entered directly and the system solves for the unknowns and the invisible hand makes the needed adjustment. Figure 10 illustrates a single real world example of how the integrated controller works.

For three different process temperatures, 150F, 250F and 350F it’s clear that to provide a constant volume of hair for a drying application, the air velocity would need to be steadily increased as the ΔT rises. So that air velocity must be raised from 21 feet per second at 150F to 45 FPS at 400F.

We can also see that as the volume of air requirement at any given temperature changes so must the air velocity. If we were to examine instead an application requiring constant velocity, we would have an analogous situation where the air volume (and hence incoming air mass) must be adjusted to keep up with changes. Fortunately the controller does this rapidly for us.

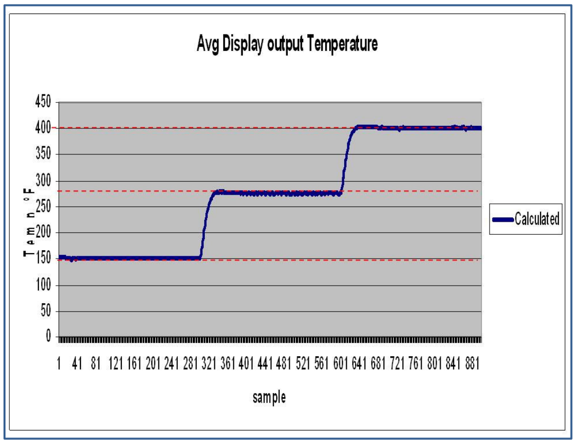
This feature not only enables a process to be defined, set and maintained, but in a laboratory or plant environment where the process must be changed often, for example to accommodate various different parts, for recipes to be developed which can be recalled quickly to provide enormous flexibility as well.

150 F	250 F	400 F
7.0 CFM	7.0 CFM	7.0 CFM
21 FPS	37 FPS	45 FPS
5.5 CFM	5.5 CFM	5.5 CFM
25 FPS	29 FPS	35 FPS
4.5 CFM	4.5 CFM	4.5 CFM
20 FPS	24 FPS	29 FPS

The invisible hand is a steady one. As can be seen in Figure 11, a "smart" controller provides a high degree of stability around programmed set-points as even minor fluctuations in operating conditions are quickly adjusted for.

The Economics of Smart Control

Integrated controls used to come at a premium. They were considered "nice but not necessary" "bells and whistles". But the power and flexibility of today's controls along with the commoditization of digital keypads and readouts has resulted in integrated systems with lower costs than the sum of their separate parts. To duplicate the package shown in figure XXX using conventional components would require providing a regulated and well filtered air source, an airflow switch to provide shutdown in low and no air conditions, separate electronic controls for the heat torch, and temperature monitoring.



Even at a comparable cost this makeshift arrangement would still fall short of the capabilities of “smart” control in terms of air velocity and volume. For too long we have accepted a slower adoption of sensible control technology in our manufacturing plants than we would ordinarily tolerate on our car dashboard or microwave oven. Finally however the gap is being bridged.

Considering that the hidden costs of poor control are more significant in manufacturing production than in popping popcorn this modernization is long overdue. Supervisory control can offer significant immediate improvements in both system downtime and replacement costs of the heat source itself. (The integrated system provides an estimated 2x to 3x improvement in the average heat torch lifetime). Add to this the cost of rework, scrap or other risks of an uncontrolled heat processing and integration of smart hot air process control technology makes all the economic sense in the world.

For Information about the TIP Integrated Heated-Air Processing System contact:

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