Furnace Optimization;
Meeting the Need to Reduce Cost

Stephen L. Feldbauer, Ph.D.
Abbott Furnace Company
St. Marys, PA 15857

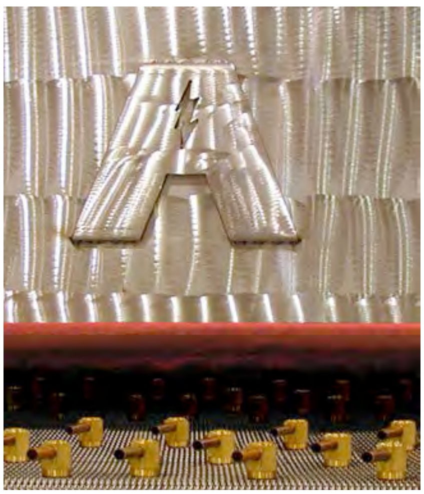

Figure 1. Parts Entering a Continuous Brazing Furnace.

Abstract

Reducing operating costs is a major focus of part producers as the costs of energy, manpower and materials increase. The continuous brazing furnace is one area where there are opportunities to reduce cost. Typically, production requirements and the chemistry of the brazing process dictate the operational characteristics and costs during normal production. However, significant savings can be achieved through the optimization of the furnace parameters during those times when the furnace is not in production. A review of these parameters and the impact that each has on the cost of the brazing furnace is reviewed.

Where is the cost?

Many variables influence the economics of operating a continuous brazing furnace. Energy to heat the product in the form of electricity or natural gas is usually the first variable that comes to mind. Some cost models indicate that up to 50% of the operational cost of a continuous brazing furnace is from the utilities. However, it is generally forgotten that the utilities used in the furnace are not limited to those used to produce heat. The atmosphere inside of the furnace is also a utility. Atmosphere costs can account for a significant portion of the total cost of all utilities. Optimizing utility consumption is the key to controlling cost.

The definition of an optimized furnace is one that is operating at the lowest brazing temperature, with the lowest cost atmosphere composition, and the lowest atmosphere flow rate, at the fastest belt speed while producing acceptable quality parts. Once the optimal production conditions are determined for a brazed product, little can be changed that will not affect the quality of the part or the rate of production. This leaves only those times when the furnace is not in production as an opportunity for altering the operational characteristics of the furnace to reduce cost.

The question must then be asked; what are the true sources of the cost to maintain the furnace at normal operating conditions without production? To determine this, one must start by looking at the total daily cost of allowing the furnace to continue to run under normal operating conditions while not being loaded. A typical continuous furnace for stainless steel brazing would have normal operating conditions of:

- 24 inch Wide 314 Stainless Steel Belt
- 2080^{o}F Brazing Temperature (Copper Filler Metal)
- 17 inches / minute Belt Speed
- 75% Hydrogen / 25% Nitrogen Furnace Atmosphere
- Electric Heating

With utility cost in late 2008 of approximately:

- $0.80 / 100 standard cubic feet of Hydrogen
- $0.40 / 100 standard cubic feet of Nitrogen
- $0.07 / Kw – Hr of Electricity

Assuming labor and maintenance time can be neglected because they can be used in other areas while the furnace is not producing, the cost to allow the furnace to be maintained at normal operating conditions without production is ~$437 per day. Figure 2 illustrates the relative contributors to this cost. Note that the cost of the furnace atmosphere accounts for more than ~74% of the overall daily cost. Next most important is the energy needed to heat the belt as it passes through the furnace. Interestingly, the contribution from the loss of energy through the insulation of the furnace and the shell is less than 4% of the total daily cost.

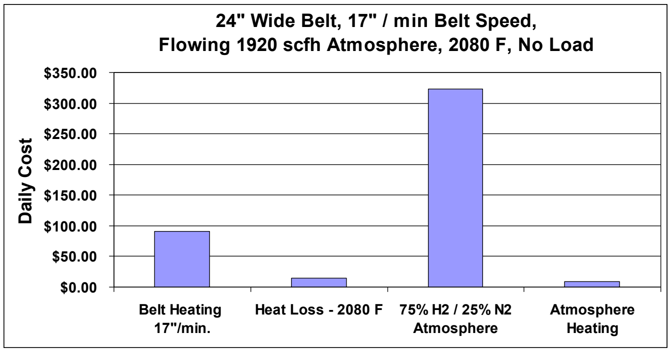

Figure 2. Relative Contribution to Daily Idling Cost

Choices

Knowing the primary sources of cost is only the first step in reducing overall furnace cost. The next and most difficult step is determining the most efficient way to control these sources.

Furnace Atmosphere

Since the furnace atmosphere is the largest contributor to the daily idling cost, let us consider ways in which to reduce this cost. Two approaches can be taken. The first is to reduce the amount of total gas flow. While idling, the flow rate of the atmosphere is purely a function of the total open area of the front door and rear curtains that must be blocked from the ingress of air into the furnace.

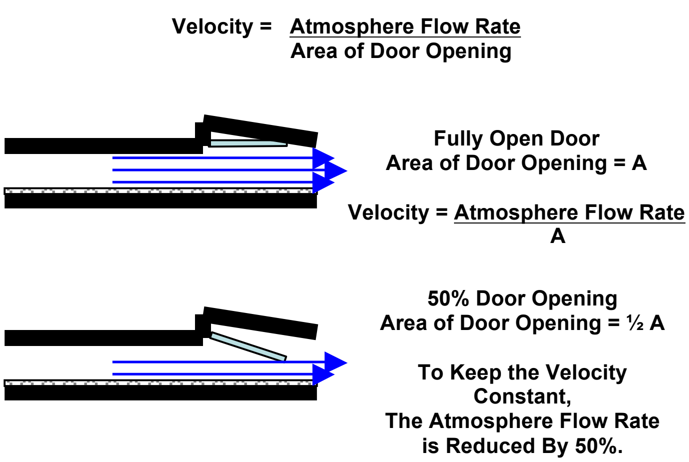

Figure 3. Effect of Door Position on Atmosphere Flow Rate

As figure 3 illustrates, the area that must be blocked and thus the amount of atmosphere that must flow is directly proportional to the door position. This has a two fold beneficial effect on cost. First, closing the front door by 80% can result in an 80% reduction in the atmosphere needed. Second, only the reduced amount of atmosphere must be heated to the operating temperature. Together this results in a ~60% reduction in the total daily cost.

The second approach to reducing the atmosphere component of the cost is to optimize the composition of the atmosphere. Since the only reactionary function of the atmosphere is to react with any small amount of oxygen that may enter the furnace as the result of a leak, the amount of Hydrogen in the furnace atmosphere during idle can be reduced and less expensive Nitrogen can be substituted.

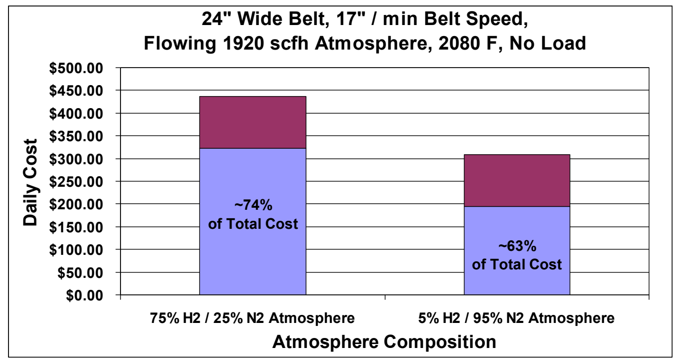

Figure 4. Effect of Atmosphere Composition on Daily Cost

Because Nitrogen is typically half the price of Hydrogen, a change from a 75% / 25% Hydrogen to Nitrogen ratio to 5% / 95% results in an ~30% reduction in the total daily cost.

Door Opening	Hydrogen / Nitrogen Ratio	
	75% / 25%	**5% / 95%**
100%	$437	$309
20%	$172	$146

Figure 5. Combined Affect of Atmosphere Composition and Door Position on Daily Idling Cost

Optimizing the atmosphere cost by using both approaches is very effective. Combining an 80% reduction in flow and a shift to a 5% / 95% Hydrogen to Nitrogen ratio can result in an 88% reduction in the daily atmosphere cost and an ~66% reduction in the total daily cost of idling to ~$146 per day.

Belt Speed

As the belt travels into the furnace, energy is pulled from the furnace to raise the cold belt up to the furnace temperature. Additional energy must be added to the system to maintain the furnace temperature. The amount of energy that must be replaced is directly proportional to the amount of belt that enters the furnace over a day. If the speed of the belt is fast, more belt material enters the furnace over a day than if the belt speed were slow. Slowing the belt speed down during idling will result in a savings in electricity and a reduction in the total daily idling cost.

The normal production belt speed is 17 inches / minute. At this rate approximately 765 pounds of material are entering the furnace each hour. The power required to bring the belt temperature up to the furnace temperature is ~54 Kw per hour. Only ~19 Kw per hour are required to heat the belt when it is traveling at 6 inches / minute. Slowing the belt speed can result in a more than 65% reduction in the cost to heating the belt. The result is an ~$59 per day reduction in cost.

Depending on the type of cooling system that is installed in the facility, the reduction in belt speed may produce another savings. The amount of cooling water needed to cool the belt as it travels through the cooling section may also be significantly reduced. Under normal operating conditions, ~36 gallons / minute of water are needed to cool the belt from 2080°F to 70°F. Since, at 6 inches / minute belt speed, less mass is traveling through the system at a given time, the cooling water may be reduced by as much as 65%. Depending on plant location and water supply, the water cost savings may or may not be significant.

Furnace Temperature

When thinking about furnace utility cost, the electricity cost due to temperature loss may be one of the first items that comes to mind. But, a reduction in the furnace temperature produces the least amount of savings and the most risk of issues due to thermal stress from large temperature changes.

The daily cost due to thermal losses through the insulation and shell of the furnace at a temperature of 2080°F is ~$15. If the temperature is turned down to 1450°F, the daily cost is reduced to ~$8. This is only a savings of ~$7 per day.

Since the atmosphere and belt must only be heated to 1450°F instead of 2080°F, an additional savings of ~$13 per day can be realized, bring the total daily savings to ~20. This does not consider peak demand charges for electricity that may occur when bringing the temperature back up. Also, if the equipment is not capable of automatically ramping the temperature at a rate that is no more than 100°F per hour, additional labor cost will be incurred to gradually bring the furnace back to temperature at the maximum recommended ramp rate. Figure 6 shows that the risk does not justify changing the temperature of the furnace unless the intended idle time is very long. Even then, it may not be worth the risk.

1 → 3 Days	4 → 9 Days	10 → 30 Days
IDLE AT 2080°F Max. Savings ~$59 Risks: Thermal Cycling, Increased Maintenance	**IDLE AT 2080°F** Max. Savings ~$176 Risks: Thermal Cycling, Increased Maintenance	**???** Max. Savings ~$586 Risks: Thermal Cycling, Increased Maintenance

CAUTION: Calculation DOES NOT Consider Peak Charges.

Figure 6. When to Turn Down the Furnace Temperature?

Optimized in the Idling Condition

The ideal condition for any furnace is to be producing product. However, scheduling and economic conditions often require the furnace to sit empty. The cost of idling under normal operating conditions for our test case is ~$437 per day. This can be greatly reduced if all of the tools of optimization are used in combination.

The flow rate of the furnace atmosphere can be reduced by closing the front door. It can not be closed 100% of the way since clearance must be made for the belt to pass under the door. Considering an 80% closure of the door, the savings from the reduced flow of atmosphere and the energy to heat that atmosphere would reduce the idling cost to ~$172 per day.

The chemistry of the furnace atmosphere can be optimized. If the normal 75% Hydrogen and 25% Nitrogen is changed to a blend of 5% Hydrogen and 95% Nitrogen, the idling cost would now be ~$147 per day.

The final cost saving measure is to turn the belt speed down from 17"/ minute. Since the slowest belt speed that our test case furnace can achieve is 6" / minute, the optimized cost of idling is ~$88 per day. This is a net savings of ~$350 per day or ~80%.

It is important to note that the temperature of the furnace was left at 2080°F. Under this scenario, there is a minimal risk of peak charges for electricity and increased maintenance from thermal cycling. There is also a minimal amount of time that a person must interact with the furnace to put it into the idle condition and restore it to normal operating conditions

When to Turn Off the Furnace?

If the intended idle time is very long, at what point does it make more sense to turn the furnace off? In the off condition, the atmosphere is off, the belt is off and the electricity to maintain the furnace temperature is off.

Turning off the furnace does have other cost. The time to ramp down could take four days. During that time, the furnace can be in an optimized idle condition for atmosphere and belt speed. The cost to cool is ~$39 per day, for a total cost of $155.

Bringing a furnace back on line also has cost. The recommended ramp rate is 100°F per hour. To reach 2080°F, the heat up time will be ~21 hours. The first 14 hours of the heat up time can be done under optimized idling conditions at a total cost of ~$71. The remaining 7 hours will need to be under normal operating condition in an effort to begin conditioning the furnace for production. This cost will be ~$137.

By far, the largest cost to restoring the furnace to normal production capability is that of conditioning the furnace. Each time that air is permitted to infiltrate the furnace, a significant amount of time is required for the furnace atmosphere to react with all of the Oxygen that has filled the pores of the insulation and that has reacted with the metal components in the furnace. All of this Oxygen will continue to compete for the reducing components of the atmosphere and cause issues with the brazing process until they are removed. Once the furnace is at operating temperature, conditioning could take seven to fourteen days under normal operating conditions. In seven days, the cost incurred to recondition the furnace is ~ $3,062. This brings the total cost to turn off the furnace and bring it back on line to ~$3,425.

1 → 39 Days	**30 → Days**
Keep Furnace ON Shut Down and Start-up Cost ~$3,425 Cost to Idle at 2080°F For 39 Days (optimized conditions) ~$3,420	**??** Risks: Thermal Cycling, Increased Maintenance Extended Reconditioning Time

CAUTION: Calculation DOES NOT Consider Peak Charges.

Figure 7. When to Turn the Furnace Off?

If the total cost to turn the furnace off is compared to that of idling in an optimized condition, the furnace can be idled for 39 days before a cost saving may be seen from turning off the furnace. Here too, peak electrical charges are not considered. The break even point could be much longer. For this reason, turning off the furnace should not be considered unless it will not be used for production for 6 weeks or more.

Caution!

Although this has been mentioned earlier, it is important enough to state once more. There are risks that must be considered anytime that a decision to change from the normal operating condition is considered. Thermal cycling must always be considered when a temperature change is contemplated. Thermal stresses can cause a reduction in the life of many components such as Silicon Carbide heating elements and muffles. A 25% reduction in the life of one heating zone of glow bars could result in a loss in excess of $1000 when considering the total cost of the heating elements.

Thermal cycling is only one risk to consider when taking the furnace cold and turning it off. Other risks such as conditioning the furnace to achieve an atmosphere capable of reducing the oxides prior to brazing are common when air is allowed to enter the furnace. Idling the furnace at normal operating conditions for seven to fourteen days before it is possible to resume production is not uncommon. The result could be a $3000 to $6000 total cost to reestablish the furnace atmosphere before production resumes.

Conclusion

Minimizing the cost of a continuous brazing furnace is always a focus of any producer. Once a production process has been optimized for atmosphere, temperature, and belt speed, the only opportunity to reduce the cost of the brazing furnace is when the furnace is not in production. It is at this time when the utilities of the furnace can be optimized to reduce the idling cost by as much as 80%. It has also been shown that only in those cases where the furnace will be down for 6 weeks or more should turning off the furnace be considered. Otherwise, it is best to idle the furnace at the normal operating temperature with optimized atmosphere chemistry, atmosphere flow rates, and belt speed.

Another area that can be considered for optimization and cost savings that must be dealt with on a case by case basis is the use of labor and maintenance during those times of idling or shut-down. These resources can be utilized in other areas or in the case of maintenance, preventative maintenance can be done on the furnace that will be seen as a cost savings in the future due to reduced down time during periods of normal production.