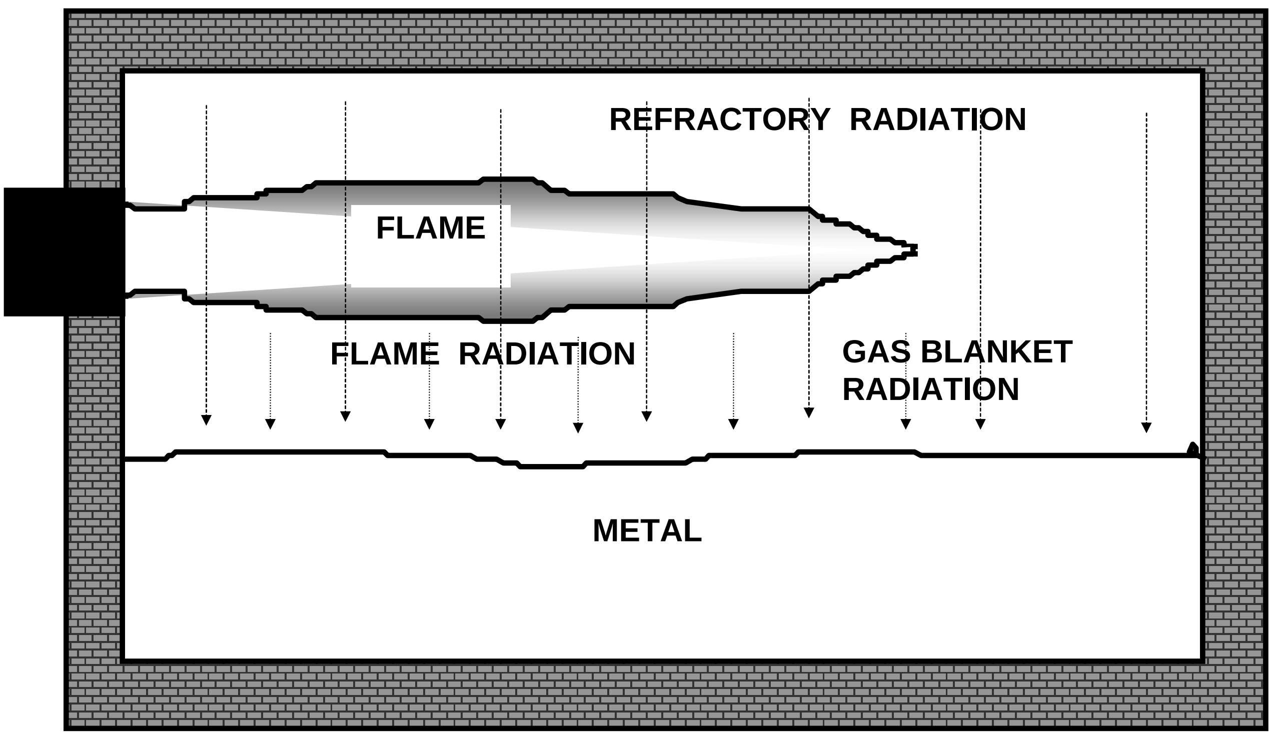
A CONTROL STRATEGY FOR HIGH PRODUCTION ALUMINUM FURNACES

In general, the major sources of heat transferred in an flat bath aluminum furnace is from radiation. The sources being reradiation from the refractory, radiation from the gas blanket (POC) and from the flame envelope. The magnitude of the heat transferred is dependent on the temperature difference between the surface areas of the source and receiver.

FIGURE A



In an aluminum holding furnace, the area of the receiver is limited to square footage of bath surface. The ability of the surface area to absorb heat is complicated by the dross formed on the surface. A thin layer being preferable to a shiny reflective surface.

As the layer of dross thickens, it begins to act as an insulator and the amount of heat transferred to the metal begins to decrease. To maintain heat transfer levels, higher and higher differential temperatures are required between the radiating sources and the bath surface.

Increasing temperature above certain levels becomes self defeating. As the surface temperature increase above 1430°F (alloy dependent), the formation of oxides (dross) increases rapidly. (The chemistry of dross formation being a separate subject.) As the dross layer increases, greater and greater temperatures are necessary. Naturally as the temperatures run higher, the fuel efficiency decreases, metal loss increases and the potential for hydrogen absorption increase. To avoid these problems, it is necessary to:

a) Maintain as low furnace temperature as possible to transfer the heat required. Keep the bath surface, the point of oxidation, at the minimum possible temperature.
b) Minimize free oxygen in the furnace.
c) Radiate energy equally to entire bath surface. Avoid areas of localized overheating. This requires even refractory temperature and avoiding hot spots due to burner flame radiation or impingement.
d) Hold metal temperature below 1400°F until just before casting or tapping. The longer the metal is at tapping temperature, the greater potential for dross. This requires a heating system capable of raising the metal rapidly without overheating.

The major contributor to heat transferred is the reradiation from the refractory to the bath surface. Typically there is effectively 1.5-2 times the refractory surface to bath area. Compared to the area under a flame, the heat transfer potential is for higher from the refractory.

The goal is to bring the refractory to operating temperature as uniformly as possible. This will insure maximizing the heart transfer to the entire bath surface available without localize hot spots.

Radiation from the flame envelope to the bath is appreciable, but when the heat release produces areas of intense heat transfer localized overheating occurs. The surface under the flame is raised to a temperature well above the average surface temperature. In addition, it is the flame envelope that contains free oxygen. Therefore, the areas most conducive to oxidizing have the greatest source of available oxygen and potentially H_2 pickup. Minimizing localized overheating from the flame envelope will reduce oxidation of the metal as well as the potential for Hydrogen pick up.

Heat transfer from the gas blanket is also a significant source; however, this is very dependent on furnace design and the fuel fired.

The goal of the combustion system is to raise the temperature of the refractory rapidly and uniformly to provide maximum and uniform heat transfer to the bath.

If the combustion system can produce an uniform refractory temperature without significant localized hot spotting of the metal surface then the uniformity of the metal temperature is dependent on the dross formation on the surface. If the bath can accept the heat transfer uniformly, the bath will be uniform. In actual operation, this is difficult or impossible to achieve. Conductance of heat from one area to another is necessary to achieve uniformity. However, if the combustion system can provide uniform refractory temperature without areas of significant higher temperatures on the metal surface, it has produced an environment conducive to uniform heat transfer.

As discussed before, it is often necessary to have a combustion system that when needed raises the bath temperature rapidly to casting or tapping temperatures. This is an added burden to the system design. This requires burner with greater input than necessary for holding but with the turndown to provide efficient holding, minimizing oxidation (on ratio) and maintaining uniformity. The task becomes a combustion system design problem as well as selecting the right burner.

Choosing a burner involves selecting a burner that will -

a) have sufficient input to raise the furnace temperature rapidly
b) have sufficient turndown for holding
c) provide uniform heating while avoiding areas of intense overheating
d) operate on ratios to avoid excess oxygen in the furnace

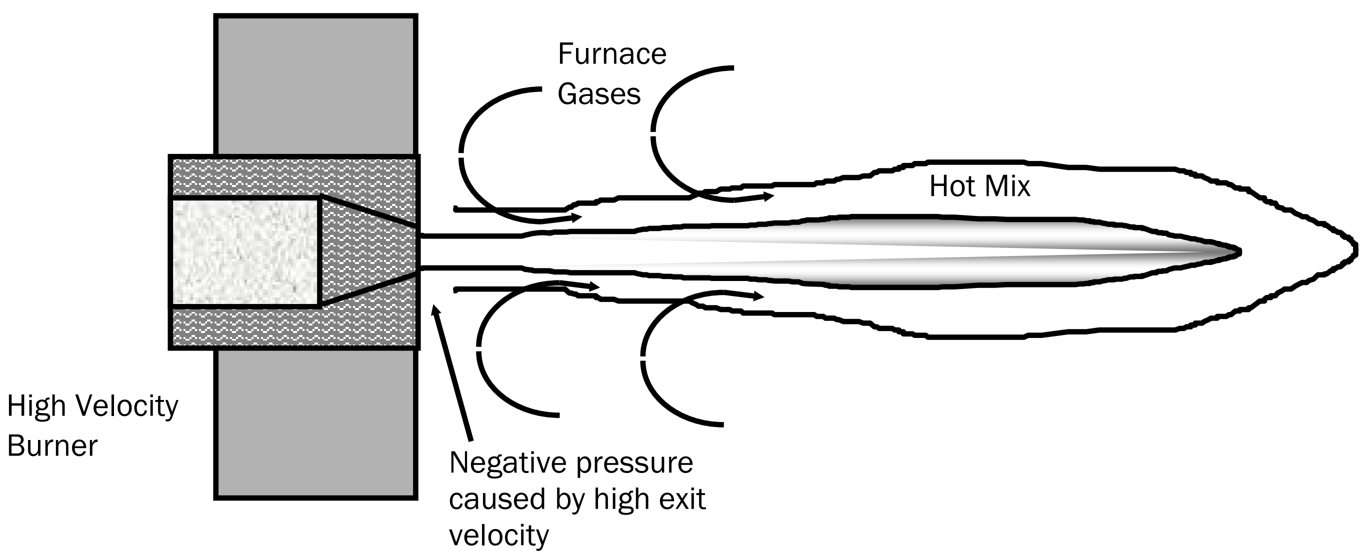
To raise the metal temperature rapidly, all the heat transfer mechanisms need to be employed remembering that hot spots on the bath surface need to be avoided. This means maximize radiation and convective heat transfer. The best option is to use high velocity burners.

The actual burner input is dependent on the furnace capacity/size. (At this point, metal depth may be part of the discussion but a separate subject.) Once the input is known, the burner selection question becomes effective heat transfer and turndown while maintaining ratio. High velocity burners become the choice especially when applied with a STEPFIRE control and cascade temperature control. HiVelocity burners provide the optimum in net transfer and uniformity.

It has been well established in many industries that hi velocity burners provide exceptional uniformity within a furnace. The uniformity comes from the delayed or staged release of heat as well as the rapid circulation of gases throughout the furnace. The delayed combustion and massive circulation are due to the reduced port design of the burner.

The burner tile is designed with minimal tile volume and a reduced exit port. Very little combustion actually occurs in the burner tile. What does occur causes an expansion in gas volume which in turn causes a very high exit velocity of the POC and unreacted air/gas mixture. This hi velocity stream causes a negative pressure at the face of the burner tile - SEE FIGURE B. Subsequently (POC) or furnace gases are pulled into the flame envelop. As they flow into the negative area, these gases act the same as a flue gas recirculation (NOx reduction technique) which retards the combustion process (effectively staged combustion) while increasing the gas recirculation rate by six to seven times in the furnace.

FIGURE B



The effect is greater heat release in the furnace not at the tile or at its immediate outlet (reduces hot spot at tile outlet). The burner flame temperature is homogenized eliminating the pockets of intense heat release which reduces areas of over temperature in areas around the flame and as an added benefit a significant reduction in NOx. The movement of gases in the furnace eliminates stagnant areas insuring uniform heating and maximum convective heat transfer.

The problem here is how to maintain the benefits of hi velocity burners while providing adequate on ratio turndown to maintain furnace temperature. As hi velocity burner turndown, the outlet velocities decrease and the overall effectiveness decrease. Using the hi velocity burners in conjunction with a modified pulse fire controls system eliminates this problem.

Pulse fire control is a system that fires the burners at high fire on a time bases that depends on the difference between the set point and the process variable (PV). If the furnace temperature is considerably lower than the set point, the burners are on at high fire 100% of the time. As the PV nears the set point the on time of the burners is reduced for the stop time period. As an example, if the step time period is one minute then the control system will address the burner on time every minute. If the set point and process variable are far apart , then the control system tells the burners to stay on for the full 60 seconds or one minute. If in the next minute the S.P. and P.V. come into the control range, the controller will decrease the burner on time for the next minute. Lets say the control stays 90% of on time, then the burner will fire during the next minute only 54 seconds. At 80% only 48 seconds and so on to the minimum on time of 5-7 seconds. Below the minimum, the burner stays in the off condition (air and gas are off).

This system is very effective in many processes but in the case of holders where a very high input is required periodically for heat rate but holding requires considerably less input but uniformity must be maintained, a modification is necessary.

The effectiveness of the burner to circulate gases and maintain uniformity requires on time without overheating. The input requirements holding versus heating are dramatically different requiring two input rates. By reducing the input rate as the set point is achieved increases on time without overheating or temperature spikes. Hi velocity burners lose some effectiveness between a 100% design input and 50% input. However, the losses are no where near as dramatic as turning down a standard burner or hi velocity burner 7:1 or so to maintain temperature. Modifying the pulse fire system to reduce input as the set point is neared from 100% to 50% increases on time and reduces overshoot in temperature. Uniformity is maintained and the heat is still released in the furnace rather than the outlet of the tile.

Once the system is in holding mode, it is important to avoid overheating at the tile outlet. Releasing heat here is not effective in heating the furnace and it causes overheating of the metal in contact with the refractory. This can cause increased build up of dross in that area and depending on alloy premature refractory failure.

Once the metal is at temperature, it is best to avoid over agitation of the bath surface. Reducing the velocity of the burner reduces that agitation and the instantaneous volume of gases with excess O2 scrubbing the surface.

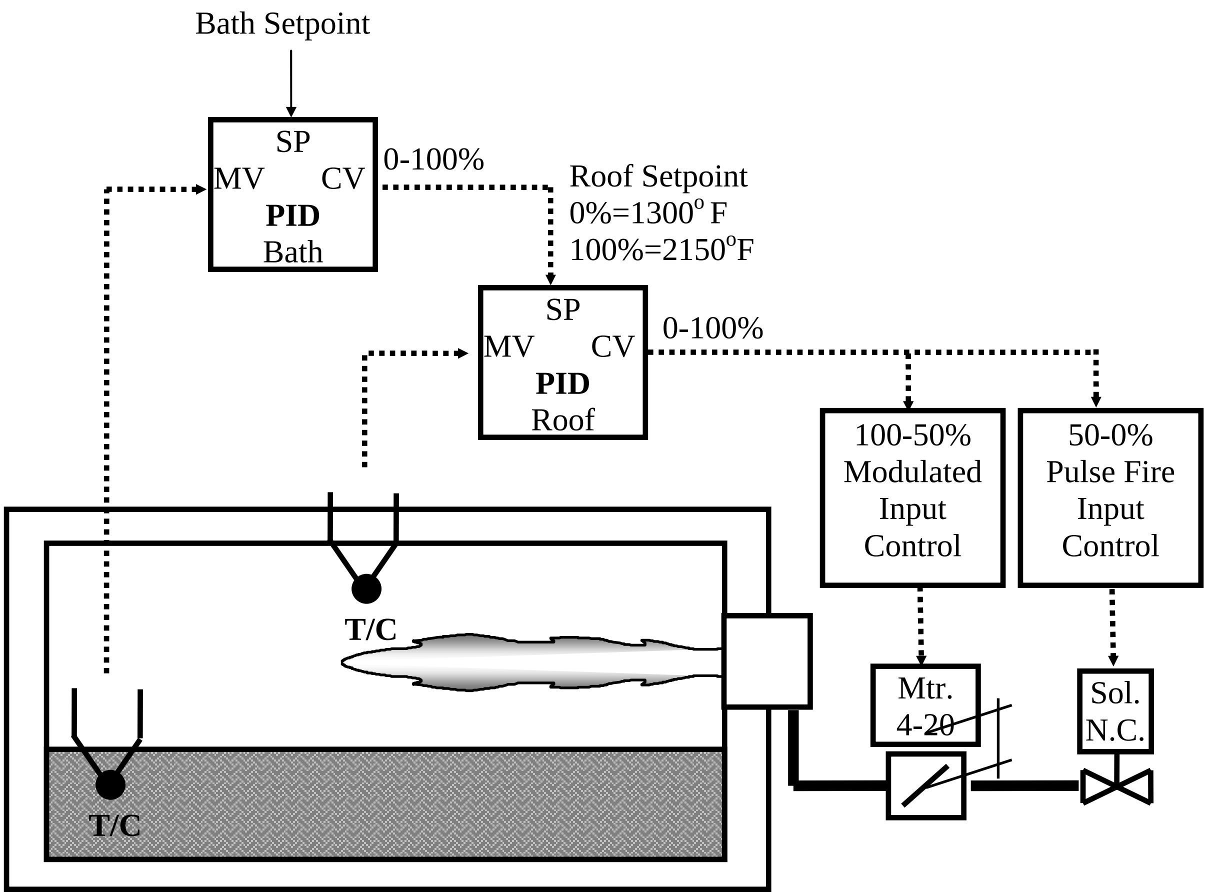
In controlling an aluminum holder, a major problem is control of the heat up rate without overheating if the furnace is driven up in temperature when the metal temperature is raised quickly what happens to the heat built up in the refractory once the metal reaches temperature? Two scenarios are possible with standard types of control system:

1) Metal temperature control - The burner system responds only to metal temperature. The metal comes to temperature faster but there is so much heat built up in the refractory that even with the burners shut off the "fly wheel" effect occurs, heat from the refractory transfers to the metal and the metal surface exceed temperature subsequently increasing dross and metal loss.
2) Roof temperature control - The burner system responds only to the roof thermocouple. The roof S.P. is depressed to avoid overheating of the metal. The time to heat the metal to temperature increases.

CASCADE CONTROLS

Cascade control is a simple system using metal temperature and roof temperature to determine burner firing rate. Figure C shows a 2 loop cascade control system.

FIGURE C



Control Loop 1 - monitors the metal bath temperature and varies the 4-20ma output based on the difference between the bath temperature and the set point. If the metal is at or above set point, the output is 4ma. If the bath temperature decreases, the output increases to a maximum of 20 ma is necessary.

The 4-20ma output from Loop 1 goes to Loop 2 as the set point for Loop 2. The 4-20ma signal is scaled in the Loop 2 controller for a set point range generally around 1300°F (704°C) to 2150°F (1176°C). This means that if the input is at 4 ma, the roof set point is 1300°F (704°C). At 20 ma, the set point is 2150°F (1176°C). The input varies depending on the bath temperature.

Loop 2 monitors the roof temperature and adjust the output 4-20 ma to the firing rate controller based on the deviation of the roof temperature from the set point.

In a pulse fire system, 20 ma signal would hold the burners on at 100% capacity for the entire step time period (burners are on constantly). At 4 ma the burners would be at the 50% capacity and the minimum on time (5-7 sec of every minute).

With bath to roof cascade control, a rapid increase in temperature can be achieved while minimizing the bath surface over temperature condition.

If it is necessary to increase the metal temperature, the set point on control Loop 1 is raised and the output drives up from the holding condition to 20 ma. This in turn drives the roof set point on Loop 2 to 2150°F (1176°C). The burner are driven to 100% of capacity and 100% on time. The burners then modulate to hold the 2150°F temperature.

As the metal temperature increases the control output decreases and subsequently decreasing the roof set point temperature of Loop 2. The output of Loop 2 will begin to decrease the firing rate of the burners to maintain set point. Once the burners reach 50% input, the burners stop modulating and begin stepping. Any further decrease in firing rate will start depressing the on time of the burner within the pulse cycle.

As the metal temperature increases the roof temperature decreases and with proper adjustment of the PID parameters the bath temperature can be raised efficiently and in a timely manner without suffering overheating from “fly wheel”.

Efficient control of holding furnaces and combination melter holders requires an integrated system design using state of the art burners and controls to assure operating efficiency.

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