Refractory Lining Configurations for Aluminum Process Vessels: The Keys to Long Thermal Effective Lifetime

Part 2 of 2

Dr. Ken McGowan, President
Westmoreland Advanced Materials, Inc.
Monessen, Pennsylvania

This article is a continuation of the article Refractory Lining Configurations for Aluminum Process Vessels: The Keys to Long Thermal Effective Lifetime - Part 1 of 2, which appeared in the January 2015 issue of Die Casting Engineer magazine. Part 1 will also be available in the online version of this March 2015 issue of *Die Casting Engineer* magazine. **All Figures from this article will only be available online.**

Discussion – Practical Service Applications

In the aluminum processing industry the old adage "Simpler is Better" holds very true. Basically the fewer things that can go wrong the better. Therefore;

- Rule #1 is to design a refractory lining configuration with the least number of layers possible.
- Rule #2, we have already discussed in length, and that is to put the freeze plane of the alloy in the working lining below metal line if at all possible.
- Rule #3 is to always use inert refractory materials below metal line and other areas in contact with the metal. Also, use insulating versions wherever operationally possible.
- Rule #4 is to insulate above metal line as much as possible based on operational conditions.

The last rule is important since in most actively heated vessels the temperature above the metal is much higher than the metal temperature. Because there is no need to consider a freeze plane, this area offers the greatest opportunity for energy savings. Furthermore, the use of lightweight materials potentially allows vessel manufactures to reduce the bulk of the steel support structures necessary to support dense, heavy refractory. This should reduce the overall cost of the vessel. Finally, the volume of lightweight materials required is significantly lower than their dense counter parts. This means less material is required which will offset their often higher prices. However, keep in mind there is a point of diminishing return.

Also keep in mind that the goal is to reduce heat flow through the lining configuration as a function of time. This 'rate' is usually reflected in the shell temperature. However that may not be the case when the shell is actively being cooled by wind or a fan, for example. Also to consider is the differences a melting process may have on overall efficiency. For example, much of the initial energy put into the system until it reaches a thermal equilibrium condition is absorbed by the refractory lining and shell, its 'thermal mass'. The amount of energy stored is equivalent to thermal capacitance or heat capacity, basically the ability of a body to store thermal energy. In a wet hearth process the furnace and hence lining are heated up one time and then run continuously. In a dry hearth the process is a batch process where the furnace is heated and then cooled in each process cycle. Dry hearth process vessels usually have thick, dense, refractory linings. As a result, they also have large thermal masses and hence a significant amount of the energy generated to melt metal is also going into the furnace refractory and structure. In order to minimize energy requirements, dry hearth processors must cycle quickly, before the energy absorbed by the refractory is dissipated to the environment.

The following examples are several permutations with different alloys, temperatures, vessels and vessel areas. These are used as examples but they are not necessarily the only available options. Variations can be driven by desired shell temperatures, desired lining thickness/vessel volume, cost/availability, and construction method. These will be performed in English Units.

Example 1: Holding furnace Specifications:

- 6" maximum lining thickness
- A360 Alloy; MP range 1060-1090˚F
- Avg. head space temp = 1250˚F
- Avg. metal temp = 1150˚F
- Target shell temp = <180˚F

This furnace is rather small with only 3" of head space to the top of the shell. The exposed surface area is 54 ft^2. This is electrically heated with SiC elements contained in a lid or bonnet which is lined with a medium density board. We will discount the thermal contribution of the bonnet from our evaluation assuming it to be equivalent in all situations. A necessary function of the vessel is to maintain the temperature of the metal at casting temperature. A loss of thermal efficiency causes an increase in recovery time of the temperature of liquid metal and reduces metal throughput.

Because this is a relatively small, rectangular furnace the most cost effective construction option would be to configure the lining with a castable refractory hotface backed up by insulating board. For construction ease this configuration should be uniform on all sides and the floor. The weight of the metal and refractory will not be large enough to compress the board in the floor of this vessel. Figure 16 shows one solution for a side wall that incorporates 4" of insulating inert refractory backed up by 2" of a 2300 LD board.

The temperature of the freeze plane is the lowest liquidus temperature. The shell temperature is within the target at 169°F. The metal temperature was used as the specified 'hot temperature' because calculating the freeze plane placement is only important below the metal line. This configuration gives a freeze plane placement of 2.3" into the hotface which is about half the thickness of this lining. The heat loss below metal line is 209 BTU/hr/ft^2. In order to protect the lining from wear due to opening and closing and inadvertent damage due to levering against the top edge we will cap the sidewalls with 3" of a dense inert refractory material. Normally the insulating backup would be extended to within 1" of the surface. Assuming a rough surface area of 54 ft^2 this would indicate a heat loss of 11,286 BTU/hr and assuming constant operation over one month or 720 hours this calculates to 8.1 MBTU/mo or 97.5 MBTU/yr in energy just lost through the lining, not what is required to hold the metal at temperature. Figure 17 shows an alternative configuration maximizing energy efficiency. In this case the hotface lining is 5" of inert insulating refractory and the backup lining is now 1" of micro-porous board. The shell temperature in this configuration is reduced to 144°F with the freeze plane at 3.4" into the surface. This results in a heat loss of 143 BTU/hr/ft^2. Running the same calculations this is 66.7 MBTU/yr. The processor must determine if the energy savings and its associated impacts cover the increased cost of the micro-porous board relative to the 2300 LD board. The associated impacts are faster metal temperature recovery times, faster metal throughput, faster production rates, to name a few. All of these lower the $/lb of metal processed.

Example 2: Floor of Melting Furnace

- 15" maximum lining thickness
- A360 Alloy; MP range 1060-1090°F
- Avg. metal temp = 1150°F
- Target shell temp = <180°F

Assuming the same alloy and hence solidification temperature as Example 1, we would be looking to place the freeze plane in the working lining. Also assume this is a large vessel with 80,000 lb of metal. In this case two options are offered. Figure 18 shows a floor of 9" of inert insulating refractory castable with 6" of a 2300°F IFB as backup. This gives freeze plane 3.5" into the lining and a shell temperature of 158°F. Figure 19 is a configuration with the same 9" of inert insulating refractory castable with 6" of a 1900°F board product. In this case the freeze plane is 4.9" in the working lining and the configuration offers a shell temperature of 139°F. The logic of Example 1 would seem to indicate the appropriate choice to be the configuration shown in Figure 19. However, although this choice offers the best thermal insulating character, in the long term its TEL will likely be less than the option in Figure 18. The reason for this is apparent by examining data sheets for board and similar insulations. You will note under strength data or physical properties that compression strength is offered for a fixed deformation percentage. What this means is that the material is subject to deformation due to compression over a range of applied pressure. In the case of a large furnace holding a large mass of metal as well as the structure of the furnace, it is likely that the loads will begin to compress the board. When this occurs the hard refractory working lining begins to undergo tensile and compressive forces that often lead to cracking of the floor or opening of the joints between the lower wall and floor. These openings can become large enough, even with proper freeze plane placement, to allow metal into the hearth. Therefore, it is never advisable to place deformable materials in the floors of vessels supporting large masses. Instead use materials with known, fixed compressive strengths that do not deform. This is a case where TEL is improved with a lining configuration less insulating than an alternative.

Example 3: Lower and Upper Side Walls of Melting Furnace

- 12" maximum lining thickness
- A390 Alloy; MP range 950-1200°F
- Avg. head space temp = 1350°F
- Avg. metal temp = 1250°F
- Target shell temp = <180°F

In this example we are using an alloy with a lower liquidus temperature but a higher average metal temperature. Figure 20 shows one possible configuration below the metal line with a freeze plane at 8.2" into a 10" hot face of inert insulating refractory. This has 2" of 1900°F board backup resulting in a shell temperature below metal line of 167°F. Figure 21 shows a possible configuration of the upper sidewall using 8" of inert insulating refractory and 4" of 1900°F board. In this case the freeze plane is 9" into the hot face or within the first inch of the insulating board. However, since we are now above metal line the freeze plane need not be considered and we can now opt for insulating capability. Note that the hot side temperature has increased 100°F since we are in the head space area. However, doubling the insulation has allowed the shell temperature to be reduced to 148°F, thereby reducing heat flow in the upper side walls by 25%.

Example 4: Scrap Loading Well

- 12" maximum lining thickness
- A356 Alloy; MP range 1040-1130°F
- Avg. head space temp = open vessel area
- Avg. metal temp = 1220°F
- Target shell temp = <180°F

In this instance the alloy is A356. A scrap loading well is the target area. Since this area undergoes a significant amount of physical abuse it is necessary to use a high density, inert refractory composition. Figure 22 shows a possible solution utilizing 11.5" of dense, inert refractory hot face backed up by 0.5" of micro-porous insulation. This results in a freeze plane at 7.8" into the hot face and a shell temperature slightly above our target at 184°F. In this case if we lower the shell temperature by increasing the insulation thickness the freeze plane moves into the backup lining. Therefore we are limited by the overall allowable thickness of 12". Thus the appropriate option to increase TEL is to opt for the proper freeze plane placement and not the lower shell temperature. Another option utilizing less expensive 1900˚F board is shown in Figure 23. This option utilizes 10" of dense, inert hot face refractory and 2" of the board. The freeze plane is appropriately placed at 7.1" into the hot face but the shell temperature is now 192˚F. Figure 24 shows one more interesting option and that is to use only 10" of dense, inert refractory in the hot face with the same 0.5" of micro-porous backup. In this case, an increase in furnace capacity is possible and the savings of installing 2" less of inert, dense refractory becomes possible. The only cost is that the freeze plane is now 7.6" into an overall thinner hot face.

Example 5: Roof of Melter Running

- 10" maximum lining thickness
- A390 Alloy; MP range 950-1200˚F
- Avg. head space temp = 1350˚F
- Avg. metal temp = 1250˚F
- Target shell temp = <180˚F

In this last example we will look at a roof which will not see any metal contact or splash. Therefore we can use non-inert refractory materials. Figure 25 shows a configuration utilizing an insulating castable that is designed with non-clay aggregate in order to avoid shrinkage and hence cracking over time. This is backed up by an 8 lb blanket. In the example the roof is open with no metal shell. The freeze plane is not important. The cold end of the blanket in this example has a temperature of 167˚F with a heat loss of 166 BTU/hr/ft^2. Figure 26 shows a type of configuration often observed in the field. This uses a hot face of a medium density fireclay of 45% alumina content. In this case the cold end temperature is 206˚F with a heat loss of 275 BTU/hr/ft^2.

Conclusion

It is important that processors have a clear understanding of the effect of lining configurations on maintenance requirements, lifetime, cost, and TEL. In all cases, with the exception of vessels with necessarily very short lifetimes, the overall cost of ownership of a vessel lining is much less when providing lining configurations based on these rules. For an appropriately configured lining, the average payback period on an average premium paid at the time of purchase (over the least expensive refractory lining option) is 8-14 months after which the vessel begins to reduce the processors production costs. Processors utilizing these strategies have measured economic advantages in excess of $100,000 annually after the first year of operation based on energy and maintenance savings. None have seen a non-beneficial economic or performance result.

About the Author

Ken McGowan is a founder and the President of Westmoreland Advanced Materials®, Inc. (WAM®). His background and experience encompass Chemistry in which he holds a doctorate, Material Science and Ceramic Science. He holds several patents on inert refractory compositions, refractory compositions for unique processing conditions as well as ceramic based tissue scaffolds for bone growth and regeneration. In addition to the aluminum industry, he and WAM® provide consulting services and products to many industrial technology sectors.

References

1. U.S. Energy Requirements for Aluminum Production, (Washington, D.C.:U.S. Department of Energy, February 2003 v 1.1). The report was prepared for the Energy Efficiency and Renewable Energy Industrial Technologies Program

2. Modern Refractory Practice, J.P Sutton, S.W. Thrower, Pittsburgh, PA. Compass Marketing Services, 1992 5th Ed. pg. dm2-dm13.

3. Corundum formation in Aluminum Processing Vessels; Why? Effects and Practical Solutions, K.A. McGowan, Pittsburgh, PA. 2014. White paper.

4. http://westadmat.com/aliiproducts/

5. http://westadmat.com/wp-content/uploads/2013/12/Comparative-corundum-strength-article.pdf

6. http://westadmat.com/wp-content/uploads/2013/12/Practical-Experience-with-Microporous-castable-article.pdf

7. http://www.epa.gov/ttnchie1/ap42/ch01/final/c01s04.pdf

8. http://www.epa.gov/ttnchie1/ap42/ch01/final/c01s03.pdf