Explosive Spalling of Low Cement Castable Refractories - A Dryout Service Company's Experiences, Observations and Recommendations.

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Abstract:

Since calcium aluminate bonded Low Cement Castable Refractories were first developed, explosive spalling during dryout has been an ongoing problem for refractory manufacturers, installers, the end user and the service company hired to perform the initial dryout. As this family of refractory products has evolved, raw material grain sizing, binder systems and manufacturing processes have improved and water content has been dramatically reduced or eliminated in some cases. The net result is that the raw materials in these products are packed together much tighter, resulting in higher bulk densities, lower permeability and improved physical properties that provide superior service life vs their counterparts of just a few years ago. However, in the process of improving the physical properties of these products to enhance service life, manufacturers have brought to the end user, products that now require much more care and attention during their manufacture, installation and dryout if they are to survive the initial dryout process.

This paper discusses some of the experiences Hotwork-USA has had with explosive spalling of low cement castables in various industrial applications as well as the company's observations and recommendations to lower the risk of such incidents and including a practical approach to refractory dryout curves provided by the refractory manufacturers.

Background:

Hotwork has been offering refractory dryout / furnace heatup services to refractory consumers since 1965 and has carried out in excess of 20,000 projects in its history. The company currently averages approximately 400 projects annually and has personnel and equipment strategically located throughout the world to serve its diverse customer base.

In the late 1970's, shortly after the first family of low cement castable refractories were introduced to the refractory consuming industries, Hotwork had it 's first experience with explosive spalling in a vertical pour channel induction furnace in a Milwaukee, WI iron foundry. In that incident, Hotwork had an employee seriously injured as the result of a high-energy refractory explosion in a confined area that blew refractory debris and the Hotwork equipment out the only access door on the furnace, injuring the technician and destroying the furnace in the process. This incident happened during a very cold winter period when environmental temperatures were sub-zero, and it was later determined that cold weather installation was the contributing factor to that explosion and brought a greater awareness to the potential problem.

However, while cold weather installation remains as a factor that can result in explosive spalling, it is by no means the only cause. Hotwork, in recent years, has had significantly more incidents of explosive spalling in situations where low cement castables have been installed during hot summer months in locations, where environmental temperatures remained in the 95°F - 110°F range for extended periods of time and when the refractory materials sat for several months under such conditions before the dryout commenced. On average, Hotwork experiences 2-3 incidents annually of explosive spalling during dryout and which represents less than 0.75% of the total dryout projects the company undertakes annually.

While there has been much research undertaken, technical papers written and presented by the refractory manufacturers and others, the fact is that explosive spalling during initial dryout remains a serious problem that continues to have significant financial consequences for all parties involved. The cost of diagnosing, replacing, re-installing and drying out another installation after a failure can and has amounted to hundreds of thousands of dollars and can become a confrontational situation involving lawyers and insurance companies to determine who has the responsibility for the failure. The refractory dryout contractor, being the party with the "match in hand" when the bomb goes off, is generally considered guilty until proven innocent even though it is faced with a pre-existing condition upon arrival at site and had no control over the circumstances that created those conditions. Payment for dryout services generally goes on hold until cause has been determined and assigned and which can be several months after such an incident occurs.

Actual Refractory Explosions:

Figure 1 - an explosive spall in a cyclone of an Alumina Calciner.

Figure 2 - the hearth of an Aluminum Melter destroyed as the result of an explosive spall.

Figure 3 - explosive spall in feed hopper of an iro reduction facility.

Figure 4 - explosive spall in a gas duct of an iron reduction facility**.**

Factors Contributing to Explosive Spalling:

- Temperature of the refractory mix during installation not maintained within the manufacturers prescribed guidelines.
- Lack of polypropylene burnout fibers not installed at point of manufacture, not installed in the field prior to installation, not installed in the proper volume or not uniformly dispersed within the refractory mix.
- Environmental conditions that result in too low or too high curing temperatures immediately after installation.
- Failure to protect a new installation from the elements after installation and pre- dryout.
- Improper mixing during installation.
- Improper water addition.

These factors alone do not cause explosive spalling. However, the published literature deals in depth with the chemical reactions that occur under certain conditions and their affect on the physical properties of the refractory products involved and specifically the affect on porosity and permeability, which in turn dictates the rate at which the dryout temperature can be increased to avoid explosive spalling. The fact is that ***low permeability and rate of temperature increase on initial dryout are the primary factors controlling whether or not low cement refractory castables will explode during initial dryout.***

As the refractory castable is heated, a volume expansion takes place within the lining as water turns to steam, causing pressure to build and the permeability of the material then dictates the rate at which the dryout can proceed if explosive spalling is to be avoided. There is no definitive temperature at which an explosive spall will occur as the permeability and rate of temperature increase as well as the mechanical strength of the refractory involved will dictate exactly when an explosive spall will occur or if it will do so at all. However, in incidents Hotwork has been involved with, explosive spalling has typically occurred at approximately 800°F. When the stress generated by the steam pressure exceeds the mechanical strength of the refractory material, an explosive spall is inevitable.

Dryout Curves:

The dryout curve utilized for any refractory dryout is, in combination with the permeability of the installed refractory material, the single key ingredient contributing to explosive spalling of refractory castables. The lower the permeability the slower the rate of temperature increase must be to avoid explosive spalling as steam pressure develops. In no instance where explosive spalling has been experienced, has Hotwork not been able to complete a dryout, and it has simply been an issue of finding the proper rate of temperature increase that would permit the moisture to transfer without resulting in an explosive spall to relieve the buildup of steam pressure. In one particular incident four (4) different dryout curves were attempted before one was found that permitted the completion of the dryout without further explosive spalling taking place. At that point the temperature ramp rate was down to 3°F / hr.

Refractory manufacturers typically provide the end user of their products with a time / temperature curve for dryout of their products. Such dryout curves are generally developed under controlled laboratory conditions and tend to be generic in nature in that they may cover a broad range of products within a refractory category i.e. low cement castables. Historically, dryout curves have incorporated a ramp and hold philosophy that calls for hold times as certain temperatures are reached. The duration of such hold periods is typically dictated by refractory thickness i.e. a 1-hour or 0.5-hour hold per inch of thickness. Little if any consideration is given to:

(a) The type of heat being applied and whether convective or radiant.

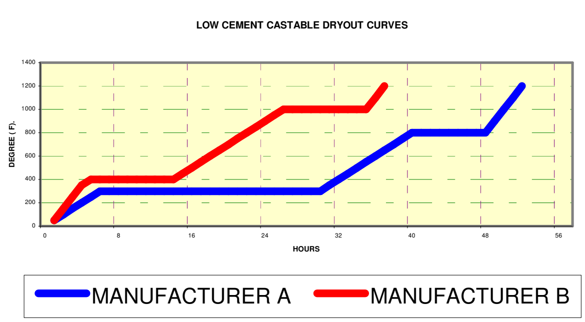
(b) The conditions that the lining has been subjected to during and after installation and pre-dryout.

(c) The complexity or configuration of the unit under dryout and access for dryout burners.

(d) The feasibility of achieving uniformity of temperature within a refractory lined structure during dryout.

(e) The provision of guidelines to adhere to when temperature differentials are unavoidable within a structure during dryout.

Further confusing the issue is a lack of standardization within the refractory manufacturing community in regards to dryout curves for various refractory categories. As a refractory dryout contractor, Hotwork is exposed to dryout curves from virtually every major refractory manufacturer in the world, and what we experience is that every manufacturer has established their own set of rules for dryout curves and which can vary dramatically from company to company. Two low cement castables will have similar if not virtually identical chemical and physical properties but the similarities stop there when it comes to dryout curves.



This graph indicates the dryout curves provided to Hotwork for two 70% alumina low cement castables from two different suppliers competing for a project in a cement producing facility this past January and demonstrates the difference in dryout curves between refractory producers. Note the difference in ramp rates, hold periods and total time involved.

Due to the liability associated with specifying dryout curves, Hotwork resists doing so and requires that the customer provide the required curve. However, when a customer requests a recommendation from Hotwork, we always recommend a linear curve versus one that incorporates ramp and hold periods as it is our firm belief, gained in over 35 years of experience and 20,000 plus refractory dryout projects, that such a curve imparts much less stress on the lining than a curve that ramps then holds temperature at certain plateaus during the dryout process. We further contend that should there be a sound technical argument for holding temperatures on the refractory hotface, then that same reasoning should apply as the heat transfers through the refractory thickness and not just at the hotface. It is important here to note that while not the case in every instance of explosive spalling that Hotwork has been involved with, explosive spalling has more often than not occurred within a short period after a hold in the prescribed dryout curve has been completed and temperature begins to ramp again.

A linear curve also considers the issue of temperature differentials in complex refractory lined structures where it is virtually impossible to achieve uniformity of temperature as the result of limited access for the portable dryout equipment. Areas where burners are located follow the dryout curve while remote areas can lag considerably. Ramp and hold dryout curves result in decisions having to be made at site as to what differentials in temperature are acceptable or whether the temperature in a remote area must also be held at the designated temperature hold in the prescribed dryout curve once it reaches that plateau. A linear curve on the other hand maintains a slow steady temperature increase where the burner equipment is located and in turn, temperatures in remote areas continue to gradually increase. Should minimum required temperatures not be achieved in remote areas of the system when maximum temperatures have been reached on the hotter control points at end of the dryout cycle, then a decision can be made to either:

(a) Increase the maximum temperature limits in the hotter areas or,

(b) Extend the duration of the final hold period to ensure thorough dryout of the remote lower temperature areas of the facility.

The only time that Hotwork recommends a hold period is at the maximum required temperature and to permit the temperature gradient to stabilize within the refractory thickness thereby ensuring maximum drying before programming the temperature back down.

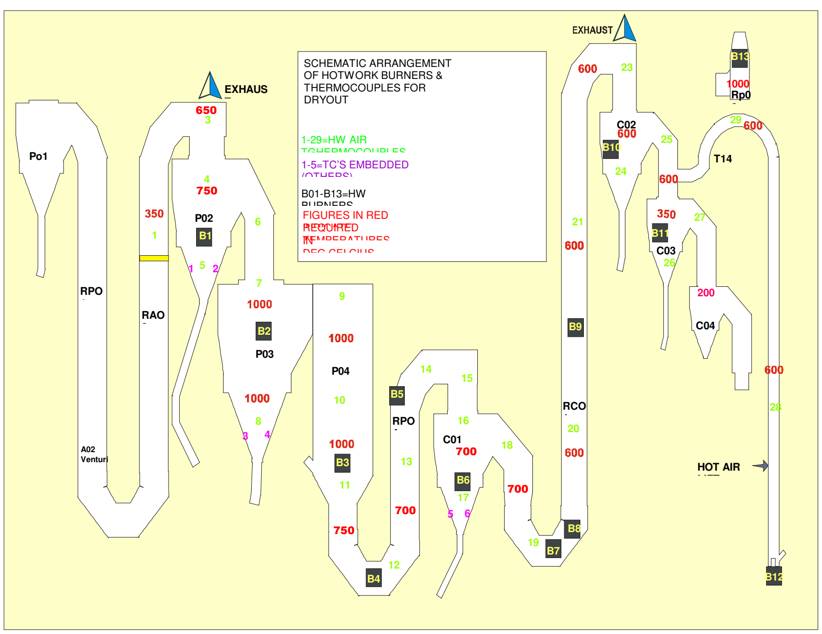
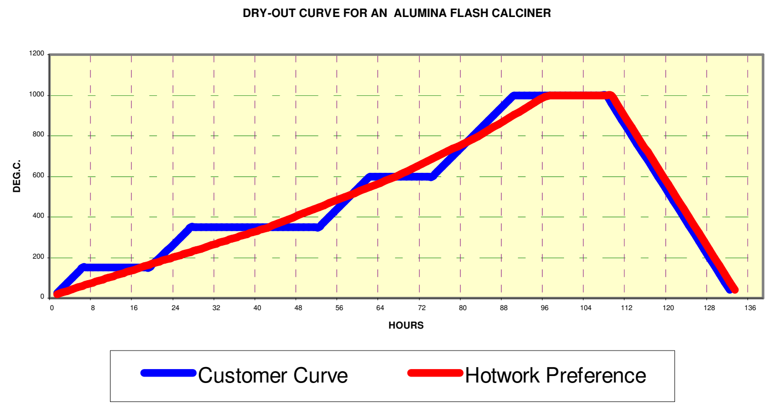


Figure 6

Figure 6 indicates burner, exhaust and thermocouple positions for dryout of an Alumina Flash Calciner with large volumes of high alumina low cement castable hotface lining backed up with insulating castables. It is depicted here as an example of a facility where temperature uniformity is neither practical to expect or possible to achieve and where a linear curve should be given serious consideration. Hotwork's experience in this type of system dates back to the late 1970's when they first came into existence. Since then, Hotwork has performed the dryout of such facilities in a number of countries around the world.



This graph indicates the prescribed ramp and hold dryout curve that Hotwork was required to adhere to on a recent dryout of an Alumina Flash Calciner plus a Hotwork preferred linear curve carried out to the same time duration.

Pressure Steaming:

Regardless of the dryout curve utilized for any refractory dryout, it is important to point out the need for extreme care when pressure steaming is evident during dryout. However, the definition and recognition of pressure steam is where problems begin and difference of opinion can be debated for hours. For these reasons, the issue will not be discussed at length here as a separate technical paper could be written on the subject. However, for purpose of this discussion the following points are relevant:

- Steam is a natural reaction as temperature increases and the water in the refractory mix is driven off.

- Steam is subjective and influenced by surrounding environmental conditions.

- Steam is not bad - it is evidence that the dryout is progressing.

- Steam will find its way out even if the refractory is installed in a pressure vessel with no openings for the steam to escape.

- To avoid waste of time and additional financial costs involved with unnecessary holding of temperature due to steam, it is crucial to have experienced and qualified personnel involved with the decision making process as to whether or not additional hold time is really necessary.

- It is not the steam one sees during dryout that causes explosive spalling - it is the unseen steam that does so.

The final point to be made on the subject takes us back to the refractory manufacturers dryout curves where the prescribed curve will carry the warning " ***if pressure steaming occurs temperature should be held until the steaming subsides*****"**. Such warning seldom if ever come with any definition and occasionally the word **"pressure"** is not even included in this statement. Suffice it to say, that were Hotwork to hold temperature every time steaming occurred, the typical dryout would take weeks or even months instead of days were we to wait for steaming to subside.

Whisks of steam are not a problem and is a positive indication that the dryout burners are doing their job.....driving the water out of the refractory.

Summary and Recommendations:

Until such time as refractory manufacturers, installers and the refractory dryout contractors begin to work closer together to evaluate all the variables surrounding the supply, installation and dryout of low cement castables in industrial applications, it is virtually assured that explosive spalling of these products will continue to be a problem for the industry. From the dryout contractors perspective, Hotwork believes that the following points must be considered to limit the risk to all parties involved:

- Refractory manufacturers must take a more pro-active role in the dryout process and must go a step further than producing, selling refractories and providing generic dryout curves. They must work closer with the refractory installers and dryout contractor to understand the installation variables, feasibility and practicality of what can be achieved by the dryout contractor. **Dryout curves should be and must be tailored to what is possible in the field and not what is possible under controlled laboratory conditions**.

- The refractory manufacturing companies must work together to standardize dryout curves based on chemical and physical properties of their products. At present, no such standardization exists. The challenge will be to get manufacturers to collaborate on the issue as everyone wants to believe that they have technology to protect. We would suggest however, that the benefits far outweigh any risk to loss of technology and that a combined effort in regards to standardization of dryout curves brings with it a financial return when each company considers the benefits of less refractory problems to deal with in the field and a more satisfied customer base.

- Linear dryout curves should be given consideration vs a ramp and hold philosophy that is currently prevalent in the industry and is not practical to apply to many large, complex refractory lined structures where it is impossible to adhere to the dryout curve in all areas of the facility.

- Refractory installers must strictly adhere to the manufacturers specifications for installation of their products and recognize that non-compliance changes the physical properties and which in turn requires change to the dryout curve if explosive spalling is to be avoided.

- Immediately prior to dryout, more field testing must be considered on the installed refractory lining to establish that the physical properties are in fact what they are supposed to be and which the dryout curve has been designed to deal with. If different physical properties are evident upon testing and specifically, if permeability is lower than expected, then adjustments need to be made to the dryout curve to accommodate those findings. More than any other, the HPI and Chemical Processing Industries have put in place strict testing procedures and as a result, Hotwork has not experienced a refractory explosion in an Oil Refinery or Petro-Chemical plant in over 20 years.

- The refractory manufacturer, installer and dryout contractor must collaborate on dryouts and after considering all the variables, jointly arrive at a practical and feasible approach to the project at hand. Too often at present, Hotwork is provided a dryout curve during the quoting process or even upon arrival at site and no questions are ever asked or information volunteered until the lining goes "boom" and then, upon post failure analysis, all sorts of relevant information comes to light way too late to make a difference.

In conclusion, the risk of explosive spalling of low cement refractory castables can be significantly reduced if not entirely eliminated. To do so however, will require a different approach from what is happening currently and by all parties involved. Hotwork challenges the refractory manufacturing companies and refractory installers to work closer together and with Hotwork to help solve the problem. Any solution will involve a close working relationship between these three parties and will involve thinking outside the box in regards to such issues as dryout curves. The fact is, when the one sided drying of any refractory installation begins, a very complex heat and mass transfer phenomenon exists and includes constant chemical reactions, changes in conductivity, internal pressure changes, and development of mechanical stresses. However, once all the variables and their affect are fully understood, then the proper steps can be taken to avoid problems and the lining put into operation with the best opportunity to perform to its design capability. That, ultimately, is what the end user expects and is entitled to receive.
