TITLE: **A 50 Year History of Contract Refractory Dryout / Heatup Services**

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Abstract:

Contract refractory dryout / heatup services have played an important role in practically all refractory consuming industries and particularly in the quality assurance of monolithic refractory lining installations. Since the invention of the High Velocity excess air burner in the UK in the early 1960's and the subsequent use of that equipment to impart controlled uniform heating of refractory lined furnaces and vessels, the technology has been accepted as "best practice" for initial dryout / heatup of refractory linings. This best practice has been demonstrated for both the uniform heating of pre-fired refractory brick linings and the moisture removal and thermal treatment of monolithic linings. In conjunction with the development of high density, low moisture monolithic refractory products, the ability to perform closely controlled uniform heating using a professional refractory dryout contractor has had a significant impact on the life cycle of monolithic refractory linings and the ever increasing use of such products in today's refractory consuming industries.

This paper discusses the invention of the high velocity burner, the role it played in the founding of Hotwork UK (1962) and subsequently Hotwork-USA (1965) as the companies who brought refractory dryout services to the world. Also discussed are the various monolithic refractory binder systems encountered over the years, dryout curves, and the challenges encountered in bringing refractory linings into service in a manner conducive to providing maximum service life in the applications for which they were designed.

Background:

In discussing the history of contract refractory dryout / heatup services it is appropriate to first discuss the invention of the combustion equipment that made it possible. Without this equipment, the contract dryout industry of today would not exist.

Invented in the United Kingdom in the early 1960's by Trevor Ward, Combustion Engineer with the North Eastern Gas Board, the High Velocity Burner ultimately changed the approach to the heating of furnaces in many industrial applications. It has become the burner of choice for the effective and efficient dryout / heatup of refractory linings in practically all refractory consuming applications. The internal mechanism of the burner was so configured that no matter the volume of air or gas passing through the burner, there was always a region within the burner where the mixture of air to gas remained near stoichiometric ratio (a mixture capable of perfect combustion with no unused fuel or air). Until this invention, the best available burner had a turndown ratio (maximum to minimum input rate) of approximately 10:1 while this new invention exhibited a turndown ratio of 100:1. This invention provided the ability to stay lit, while passing high volumes of excess air thus achieving excellent temperature control even at very low fuel input. It was immediately recognized that the ability for low temperature control, high discharge velocity at the burner nozzle (450ft./ sec), combined with the ability to operate under positive or negative pressure, was very useful in refractory applications. This burner positively affected the coefficient of heat transfer within the furnace structure allowing much more efficient and effective heating of refractory than was ever possible in the past. The high turbulence created by the high velocity air combined with close temperature control also permitted faster more uniform heating thereby minimizing downtime and faster return of the unit back into service than was possible by any other means of heating. An additional benefit of the burner was its ability to also burn other gaseous fuels such as propane or butane as effectively and efficiently as natural gas. In the early 1970's a burner with the same characteristics as the gas burner was developed to burn 100% fuel oil (diesel or kerosene) and which continues to be utilized around the world when gaseous fuel is not readily available on a project site.

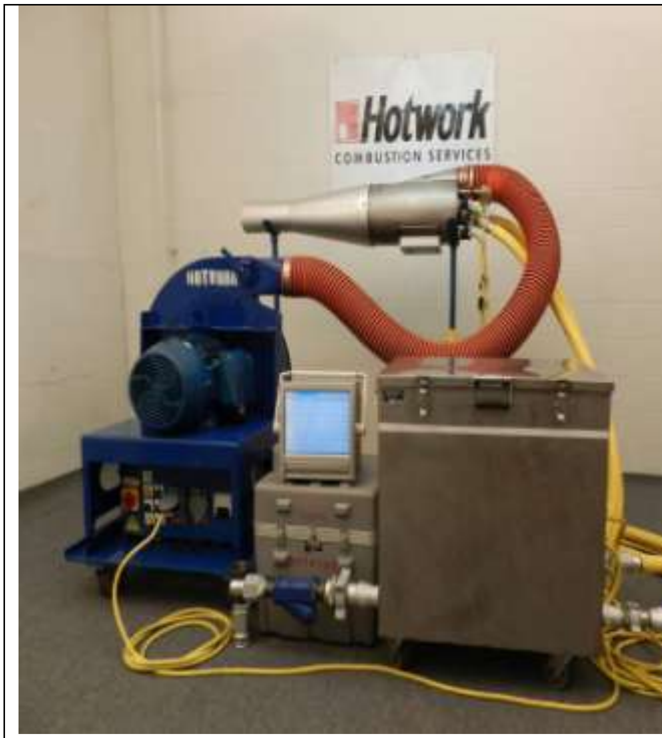

Figure 1: *Portable combustion set*

Figure 2:*10M BTU / hr High Velocity Burner*

Figure 3: *Radiant flame*

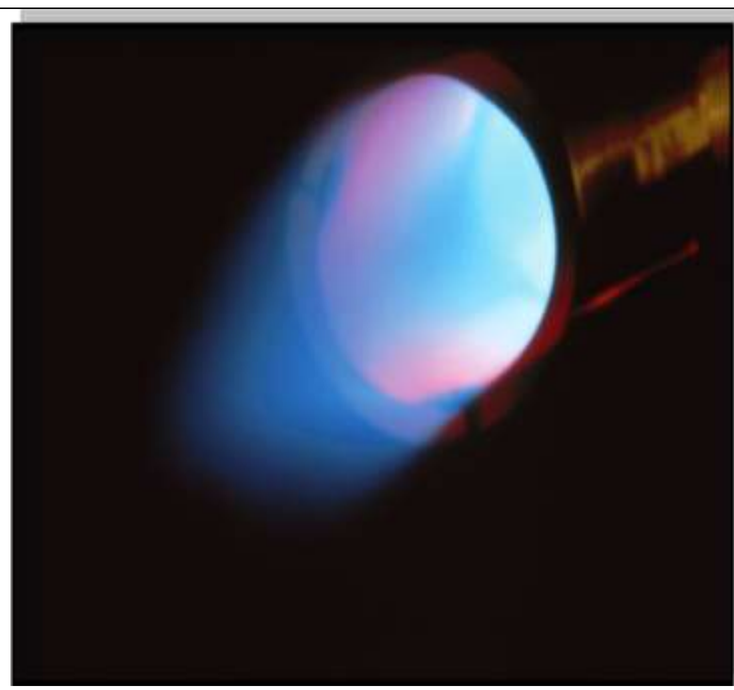

Figure 4: *High velocity flame*

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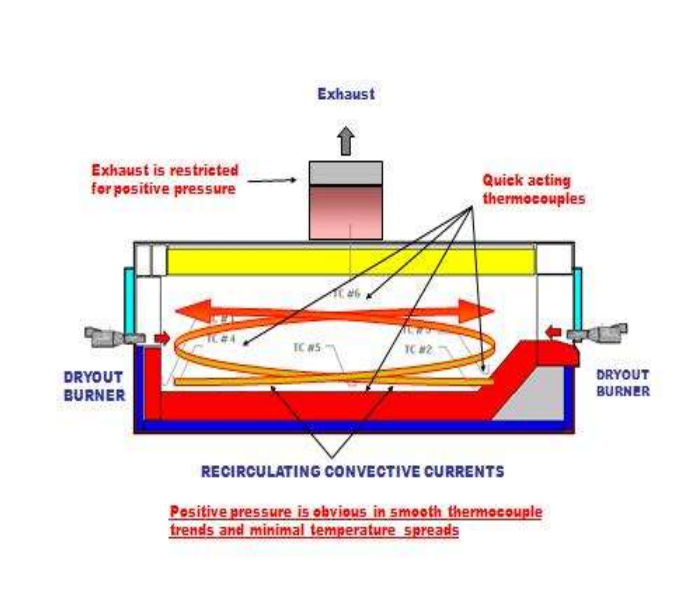


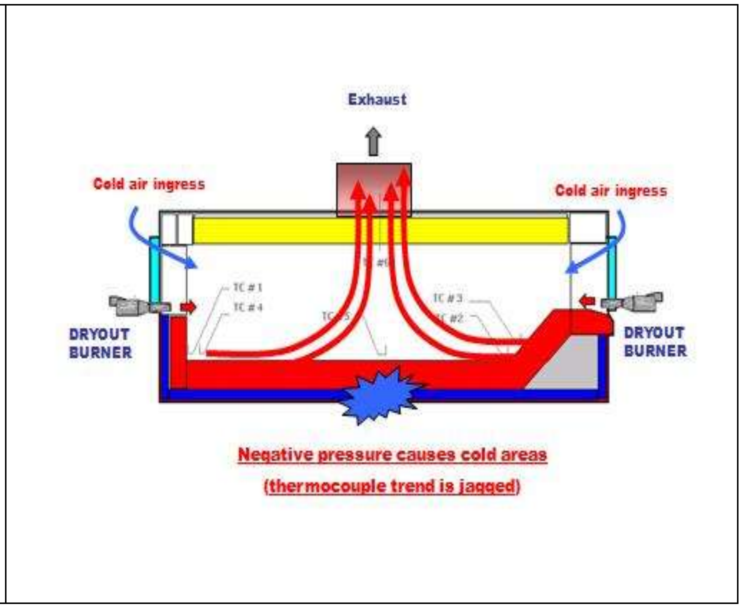
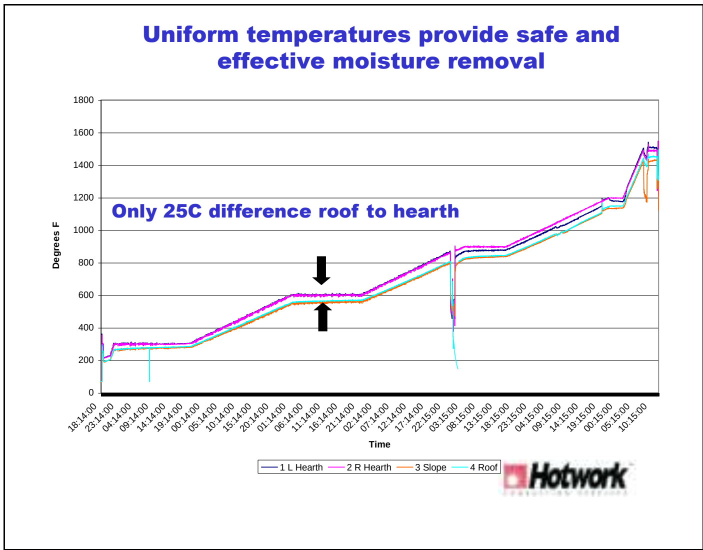


Figure 5: *Convective heating - positive pressure*. **Figure 6**: *Effect of negative pressure.*



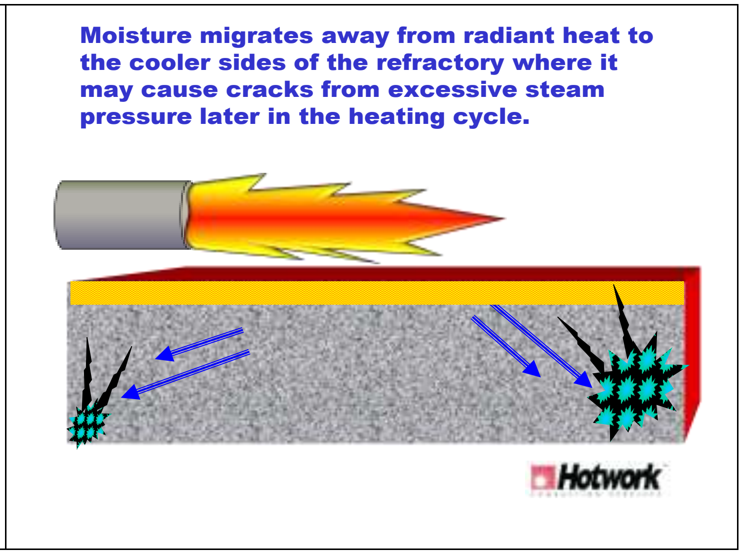


Figure 7: *Uniform temperatures with convective heating - Aluminum melter.*

Figure 8: *Effect o*f radiant *heating with process burners.*

In 1962, Mr. Ward founded Hotwork Limited in Earlsheaton (Dewsbury) UK. Shortly thereafter, the High Velocity Burner found its first application in the Glass Industry where, prior to the introduction of the High Velocity Burner, glass container furnaces took up to 3 weeks and float glass furnaces took up to 3 months to heatup to operating temperatures. Such durations were required to cater for the expansion of the silica brick crowns exposed to uneven heating using wood, coal, and gas lances. The Hotwork High Velocity Burner system enabled the same container glass furnaces to be heated in 3 - 4 days and the typical float glass furnace in 2 - 3 weeks. The ability to reduce downtime while imparting better temperature control and uniform heating of such furnaces quickly lead to a very fast acceptance of the technology by many container and float glass manufacturers in Europe including such companies (to name just a few) as:

Pilkington Glass	Redfearn Glass	Canning Town Glass	Euroglass	Glaverbel
Rockware Glass	St. Gobain	Irish Glass Bottle	Vetrotek	Trakya Cam

Following the early success of Hotwork Limited, Mr. Ward decided to expand outside of the UK and Europe by licensing the technology to others.

K. Robert (Bob) Burger began his career with Knox Glass, Knox, PA after graduating with a BS degree in Ceramics from Alfred University in 1960. Mr. Burger then joined the Corhart Refractories Division of Corning Glass, Louisville, KY. While on a trip to England in 1965, Mr. Burger met Trevor Ward and recognized the potential the Hotwork technology offered in the Americas. As a result, he became the licensee for the Western Hemisphere and first licensee of the technology outside of the UK. Mr. Burger established Hotwork Inc (now Hotwork-USA) in Hillside, NJ in Oct 1965 and operated from that location until 1975 when the company moved to its present location in Lexington, Kentucky.

The first glass furnace heatup was undertaken by Hotwork Inc for Johns Manville, Vienna, WV in November 1965 and was followed by a furnace in December of that year at Owens Illinois, Gas City, Indiana. As was the case in Europe, the technology became accepted quickly in the USA and Hotwork Inc's list of clients soon included such companies as:

Anchor Hocking	Corning Glass	Wheaton Glass	Libby Glass	OCF
Gallo Glass	Liberty Glass	PPG	Glenshaw Glass	Foster Forbes Glass
Ford Glass	Ball Glass	Kerr Glass	Thatcher Glass	Pilkington Glass N.A.

Mr. Ward continued to license the technology in other areas of the world including mainland Europe, Asia, and Africa. Many of these licensees later fell on hard times and eventually the original Hotwork Ltd company in the UK (1998) as well as Hotwork Australia Pty. Ltd (2000) were acquired by Hotwork-USA.

Figure 9: *Hotwork Ltd, Dewsbury UK 1962.*

Figure 10: *Typical pipe burners used for glass melting furnace heatup pre Hotwork 1962.*

Monolithic Refractory Dryout / Heatup:
Following the success of the technology in the Glass Industry in the mid to late 1960's by Hotwork Ltd in Europe and Hotwork Inc in the Americas, both companies began to explore other opportunities for application of their services. The same controlled heating demonstrated in glass melting furnaces was provided to dryout / heatup refractory lined furnaces and vessels in a diverse group of industries including Steel & Iron, Aluminum, Hydrocarbon Processing, Waste Incineration,

Minerals Processing, Iron Foundry, Power Generation, Metallurgical Coke Manufacturing and others.

The first contract dryout of a monolithic refractory lining was carried out by Hotwork Inc in North America on an iron ladle at Great Lakes Steel, Detroit, Michigan (Zug Island) in June 1970. A conventional cement bonded castable was utilized vs the then standard practice of using brick linings. Due to the ability to eliminate joints, which were the typical weak point in a brick lining, and also due to the speed of installation vs brick linings, monolithic linings began to find acceptance in many industrial applications. However, it was realized early in their introduction to potential consumers, that these products required special attention not only during installation but also during the initial dryout / heatup.

Unlike refractory brick that are manufactured in a closely controlled factory environment, the quality assurance of monolithic linings was now subject to field installation procedures and in situ initial dryout / heatup. In many cases futile attempts were made to utilize process heat, gas torches, and even wood and coal to dryout new monolithic linings. These initial attempts often resulted in catastrophic failure or less than expected service life due to the damage that was done during initial dryout / heatup. By working closely with refractory manufacturers and installers as well as the end users of the products, the Hotwork dryout / heatup process has played a key role in the transition from use of refractory brick to monolithic linings. Today, these monolithic linings can (if manufactured, installed, and dried out properly during initial startup) exhibit superior physical properties, resistance to chemical attack and in service performance exceeding that of brick linings previously utilized in many difficult refractory applications.

Figure 11: *Heatup of a 60 oven heat-recovery coke battery in India in 60 plus days using coal.*

Figure 12: *Heatup of an 80 oven heat-recovery coke battery in USA in 15 days (80 burners).*

Refractory manufacturers have done an excellent job of engineering products and binder systems to enhance monolithic refractory performance. Since the early 1970's Hotwork has witnessed and has been an integral part of the transition from conventional calcium aluminate bonded castables to low cement, ultra low cement, no cement and more recently the advent of Sol-Gel bonded nanotechnology products. Method of product placement has also changed substantially over the years and has included casting, pumping, gunning, shotcreting and, with plastic refractories, ramming in place. Regardless of binder system or method of placement the desired end result is a combination of:

a) the selection of the proper material for the intended application (for compatibility with the intended process, chemical & physical requirements must be understood)
b) the quality assurance of the product throughout its manufacturing process
c) close adherence to established installation practices
d) attention to temperature control and uniform distribution of heat particularly in the lower temperature range of the dryout / heatup curve.

Once all of these criteria are implemented then the refractory lining can be expected to provide optimum performance. On the other hand, if any one of these criteria is lacking, then it stands to reason that something less than desirable campaign life can be expected.

As manufacturers developed refractories with better grain size distribution that resulted in high bulk density, low permeability, and low porosity combined with low moisture content to permit mixing and placement, these products presented a greater challenge to dryout. While such products provided excellent service life once installed and dried out properly under controlled heating conditions, they were not as forgiving as their earlier counterparts (conventional castables). When subjected to poorly controlled process heat, gas lances or other means of heating that were not conducive to providing gradual and uniform dryout / heatup conditions, they reacted poorly. The result was numerous failures due to explosive spalling from steam pressure buildup within the lining. As these products became more prevalent due to their superior in-service performance, the need for professional contract dryout became more apparent. As a result, the Hotwork dryout process became accepted as being an integral part of the total quality assurance for the installation of such products. However, even under closely controlled heating and uniform temperature conditions, explosive spalling of these products has occurred. Typically, the root causes for these failures usually exist before the contract dryout company ever shows up on site.

Figure 13: *Explosive spall in a refractory lined duct*.

Figure 14: *Explosive spall in the hearth of an aluminum melting furnace.*

To date Hotwork has had limited exposure to the newer generation of Sol-Gel bonded refractory products that have started to appear in various industries over the past few years. While controlled and uniform dryout / heatup of these products is still desirable for removal of water (while no water

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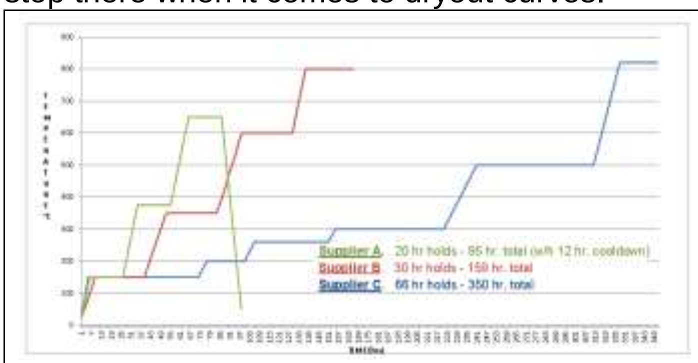
is added for mixing or bond reaction, water is created through a chemical reaction) the dryout process is typically much faster than that possible with calcium aluminate bonded products due to the absence of chemically combined water and permeability values that are promoted as being significantly higher than calcium aluminate bonded products.

<u>Dryout / Heatup Curves</u>:
Historically Refractory Manufacturers have provided the end user of their products with a time / temperature curve for dryout / heatup of their products which considers the physical and chemical properties and defines the rate of dryout that can safely be achieved to get the lining into service in its best possible condition. Such dryout curves are generally developed under controlled laboratory conditions that are seldom reproducible in the field when dealing with the one sided heating of a refractory lining. Manufacturer's dryout curves tend to be generic in nature in that they may cover a broad range of products within a refractory category i.e. light weight, medium weight, or high density castable. Historically these dryout curves have incorporated a ramp and hold philosophy to cater for poor control or uniformity of temperature i.e. hold to let the cold area catch up with the hot area nearer the heat source. 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. These curves are generic and do not typically consider:

- The type of heat being applied i.e. convective or radiant.
- The controllability of the source of the heat - can it control to 1°F or 200°F per hr?
- The conditions that the lining has been subjected to during and after installation pre-dryout.
- The complexity or configuration of the unit under dryout and access for dryout burners.
- The feasibility of achieving uniformity of temperature within a refractory lined structure during initial dryout. Is the heat concentrated at the burner discharge or is it uniformly dispersed across the lining?
- The provision of guidelines to adhere to when temperature differentials are unavoidable within a structure during dryout. Burner access positions are rarely ideal therefore making perfectly uniform heating impossible. If not possible to achieve perfect uniformity, what guidelines are in place to deal with such a circumstance?

Further confusing the matter 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. What we experience is that every manufacturer has established their own set of rules for dryout curves and these can vary dramatically from company to company for the same or similar product. A number of low cement castable products being proposed for a project will invariably have similar if not virtually identical chemical and physical properties but the similarities typically stop there when it comes to dryout curves.



Aluminum melting furnace dryout:

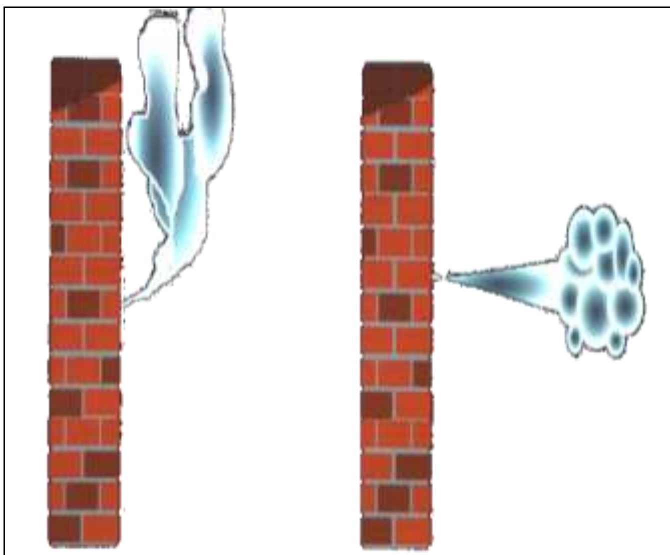
3 different refractory suppliers with 3 dramatically different dryout curves ranging from 95 to 350 hrs. duration and holds ranging from 20 hrs. to 66 hrs. at various temperatures.

In the case of Supplier A, a cooldown was also recommended to permit inspection of the lining for cracks before going into operation.

Figure 15: *Variation in dryout curves - Aluminum melter*

The failure of a refractory lining during dryout results in a "no win" situation for all parties involved including those parties who may have had no responsibility for what occurred. Invariably, all parties get drawn into the dispute once lawyers and insurance companies get involved. In many cases, such occurrences end up with the plant owner facing a situation where three parties, manufacturer, installer and dryout contractor are placing the blame on each other. As the last party involved and the entity with the "match in hand" when the bomb goes off, the contract dryout company is particularly vulnerable and is typically considered guilty until proven innocent. While a poorly controlled un-uniform dryout / heatup carried out using either process heat or an inexperienced refractory dryout contractor can no doubt contribute to a lining failure, seldom is the root cause of an explosive spall during dryout / heatup strictly related to the application of heat to the lining. It has been Hotworks experience that when such incidents have occurred, the heat being applied has acted as the catalyst that starts the failure mechanism in motion as a result of a problem that existed before the dryout / heatup ever commenced.

In all fairness to the Refractory Manufacturers and their approach to the provision of dryout curves, they often sell their product not knowing how exactly the end user may approach the dryout of their product. They therefore cater for the most severe situation when providing dryout instructions. This then leads to statements in those instructions that are ambiguous at best i.e. *if steaming is observed, hold temperature until it subsides.* The fact is steam will be generated once temperature of the free water in the lining reaches 212°F. Specifying a dryout curve in excess of 212°F and prohibiting steam defies logic and is an impossibility. When steam occurs, it is evidence that the dryout contractor is doing what he was hired to do, which is to remove the moisture from the lining. An interesting fact that is often missed, is that it is not the steam one sees during dryout that creates potential for explosive spalling but rather, the unseen steam that is trapped in the lining.



- Steam is a natural reaction

- Visible steam is subjective and its visibility is influenced by surrounding environmental conditions

- Steam will find its way out – even in pressure vessels with no obvious avenue of escape

"It is not the steam one sees during dryout that causes explosive spalling – it is the unseen trapped steam that does so"

Figure 16: *Steam facts.*

Considerations for avoidance of issues with explosive spalling and suggested actions when it does occur:

- *involve the contract dryout company early in the process so that provisions can be made for such critical decisions as burner access. This ensures the best possible conditions for uniform distribution of heat across the lining surface.*

- *pay close attention to proper installation procedures and methods including material mix temperature, water content, mix time, vibration time etc.*

- *take test samples from each batch as mixed and test for physical properties to ensure they meet or exceed published data. If properties change, then changes to the planned dryout curve may be appropriate.*

- *be cognizant of environmental conditions before, during and after installation and take precautionary measures to ensure the lining is protected from both too cold or too hot environmental temperatures as both can have a negative effect on the outcome of a dryout.*

- *have reasonable dryout curves that take into consideration who will handle it and by what method the dryout will take place. Consider a linear vs ramp and hold approach to dryout when temperature control and uniformity is possible. Dryout with process heat should not be dealt with the same as a dryout with a professional dryout company. Keep in mind that not all dryout contactors are alike - do your homework, understand who you are dealing with and have confidence in their ability to understand what is required and have the experience to deliver the desired end result.*

- *When problems do occur:*

  * *Get the parties (manufacturer, installer, dryout contractor) together and get to the bottom of the issue as quickly and as fairly as possible.*

  * *If responsible, accept that responsibility vs dragging the entire delivery chain into the dispute and ensuing legal action.*

  * *Keep the end user informed and get their furnace / vessel back in operation as quickly as possible.*

  * *If at all possible, keep the lawyers out of it.*

<u>Summary</u>:

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 can be placed into operation with the best opportunity to provide maximum service life.

Since contract refractory dryout was first introduced to the world by Hotwork Ltd in the UK in 1962 and by Hotwork Inc in 1965, thousands of projects have been successfully completed and the technology has continued to expand globally. Hotwork-USA carried out a project in Mongolia's Gobi desert just this past year and continues to expand into less developed countries where the contracting out of such services has not been standard procedure or readily accepted. As Western technology, engineering services and refractory suppliers gain a foothold in such areas of the world, so too will the demand for professional refractory dryout as these clients also come to appreciate the value in such services.

Today a refractory dryout / heatup can range from a simple one burner operation to a project such as the heat-recovery coke battery pictured at Figure 12 with 80 burners. These projects have involved all refractory consuming industries including those depicted here:

Figure 17: *Oil Refinery - 3rd Stage Separator*

Figure 18: *Steel Industry Torpedo Ladle*

Figure 19: *Cement Industry Cooler*

Figure 20: *Iron Induction Melting Furnace*

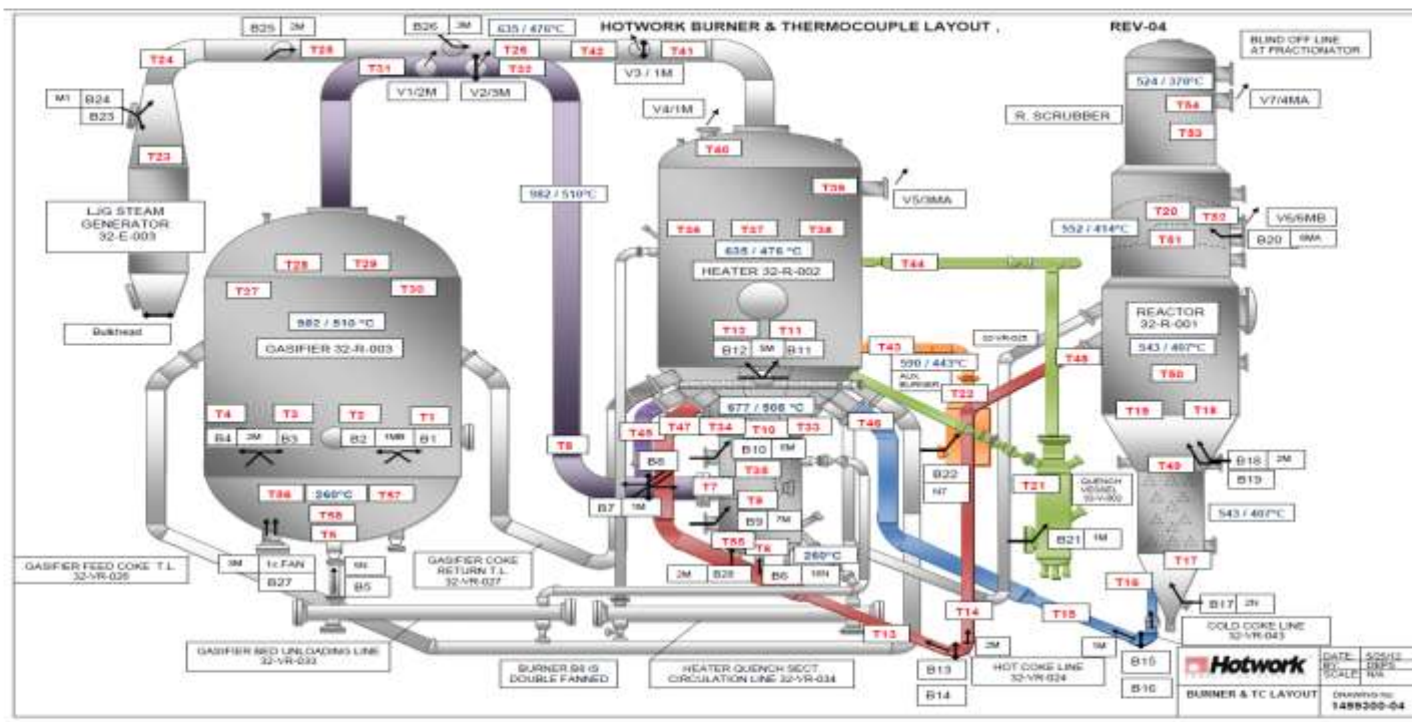


Figure 21: *Oil Refinery (26 burners - 58 thermocuples).*

Figure 22: *Conventional slot oven coke battery*

Figure 23: *Float Glass Furnace heatup.*

Acknowledgements:

In closing, I wish to acknowledge the following and without whom this paper would not have been possible:

- Mr. Trevor Ward (Hotwork Ltd.) and Mr. K. Robert Burger (Hotwork Inc) who collectively were the pioneers of the contract refractory dryout business as it is known today. Their insight, engineering & marketing abilities combined with sound business ethics laid the foundation for what was to follow.

- Those first customers who took the risks and gave us the opportunity to demonstrate the value in the technology that ultimately permitted us to be a successful and reliable service company that provided value to their operation. For those clients and decision makers, we have the utmost respect.

- The refractory manufacturers and installers who, upon recognizing the benefits of a proper dryout / heatup of their products, promoted the need for our services as they developed, sold and installed the products we would ultimately dryout / heatup.

- Those Hotwork-USA employees (past & present) who contributed to the historical facts herein:

  * Norman W. Severin (joined Hotwork USA in 1967 - retired since 2000)
  * R. Michael Flannery (Regional Mgr. Asia Pacific - joined Hotwork Ltd in Feb 1972)
  * George Kopser (VP and Glass Industry Mgr - Hotwork USA employee since Jan 1966)
