A Review of the Refractories Industry

D. A. Jarvis

The historian R. G. Collingwood believed, as do many others, that only by studying the past can the present and perhaps future be better understood. Whilst most people have a good grasp of where they currently are, almost everyone would ideally like to have more information to try to establish where they may be going in the future. It often helps to look back at the past, to see how the present situation has evolved from it and the factors and trends which perhaps may still bear an influence on circumstances in the future. This applies not only on a personal level of course, but also corporate and industry wide. This is particularly relevant even in such a diverse environment as today's the refractories industry and also in future, as it strives to serve the many different end user industries which are often always heavily reliant on it.

Several questions may therefore need to be posed under a number of main headings, to better understand change and more accurately forecast the future of the industry for the benefit of those relying on it. The information, which is available may then be reviewed by readers, who can apply their own filters and use their own perspective to arrive at conclusions which are relevant to each of them personally in their own individual situations.

Introduction

For about the last 2000 years, some people have quoted variations of an old Indian proverb saying essentially that when a finger points at the moon or stars, don't concentrate on the finger. There is of course a large matter of perspective which influences how different people interpret a multitude of information available from diverse sources. A philosopher might proclaim that "change is inevitable" while his chauffeur might add "yes but not from the automatic parking ticket machines found in many city streets".

In considering change it is not only relevant but actually important to consider that readers of any study like this today would in many cases be very different from readers who may have read a similar such report in the past. Even fifty years ago a small refractories plant of which there were very many would have been built virtually on top of, or at least adjacent to a source of raw materials and would draw its personnel from local towns and villages which in some cases might be largely reliant on the company for its existence. Readership would therefore have been drawn mainly from some of the commercial and technical management. There would also have been a readership drawn from some personnel who were employed by end users specifically to work on refractories and some academics in universities and research centres.

Today refractory raw materials are obtained or synthesized globally and transported to many fewer larger manufacturing facilities all of which are highly automated employing relatively few people. Most end users have very many fewer internal specialists and installers dedicated exclusively to refractories in their own organisation. Most refractories installation work is subcontracted to external specialists and is now very highly automated. There will certainly be more academics involved today compared to the number in the past as there is a much greater emphasis on both fundamental and applied research. In addition there will also be many other professionals whose daily remit covers refractories only as a small proportion of their overall corporate responsibilities in the end user industries.

David A. Jarvis

E-mail: dajarvis@btopenworld.com

How essential is the refractories industry and how has it evolved over time?

Many commentators have made the point that without refractories most basic industries such as iron and steel, nonferrous metals, cement, glass, ceramics, incineration and many other utilities like the generation of electricity could not function. Perhaps surprisingly one of the largest refractories companies in the world estimates that refractories costs account for less than 2 % the total production costs in their end user customer industries. In that respect the importance of the refractories industry is not always widely recognised especially by the public as having such a central role in everyday life. PRE – European Refractories Producers Federation has stated that with-

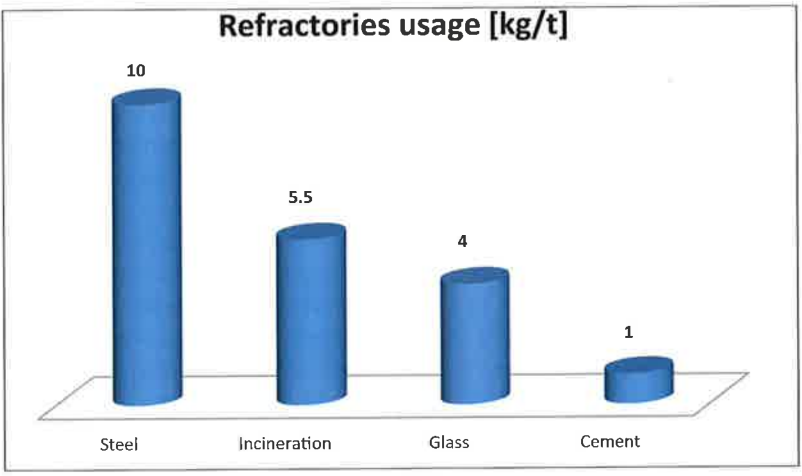

Fig. 1 Typical consumption of refractories in 2008 by user industries (Courtesy: PRE)

out refractories there would be no cars, no planes, no trains, no gas or electricity and we would be eating from wooden plates and living in mud-brick huts. Refractories therefore would seem to be not only important but perhaps absolutely essential and occasionally critical. There seems little to indicate that industries which rely on either containing or on transmitting energy in the form of heat will be any less reliant in principle on the use of refractories in future than they were in the past. There will of course be substantial and significant changes in the types of refractories produced and how they will be utilised by installers and by end users over time (Fig. 1).

Where did the modern refractories industry evolve from?

There are no completely accurate comprehensive global statistics for production and refractories use. This is because some potential sources are unable or unwilling to compile them or only release partial information or are late in recording and publishing information. It is possible to assemble much data however, from multiple international sources, and in many cases to extrapolate this information further to derive reasonable assumptions and predictions on trends based on the statistics currently available. These assumptions and predictions may very well vary of course depending on who is making them and for what purpose they are being produced.

Looking back over about 75 years of data in GB for instance, it would seem to indicate that the tonnage of refractories produced and used has fallen from in excess of 1 Mt/a to less than half of that today. Over the same period, there has been a tremendous rise in average prices, which very much more recently have stabilised or even fallen back slightly. An old advertisement from about a 100 years ago stated that the first American firebricks made from clay near Shenandoah Pennsylvania to compete with Scotch firebricks which then dominated the USA market were available at USD 20 per thousand. A current advertisement on the internet advises that high duty firebricks can be bought for USD 500 per thousand from stock in China. This current study indicates however that the price of refractory bricks in Europe has actually increased by much more than the rate of inflation mainly because of the changes in types of refractories used and the dramatic improvement in quality, giving much longer life in more severe conditions and better cost effectiveness. The more recent reductions in selling price have arisen due to global overcapacity and the increase in international trade.

Formerly, most refractories were in standard brick format while today more than half of the refractories used are monolithic products. The majority of refractories used previously were alumina-silicate bricks and blocks, with some semi-silica and silica qualities, while high grade basic products were also produced in relatively minor tonnages compared to the total market.

John G. Stein in GB was typical having 2 mines and 3 plants with a beehive kiln for high-duty silica, a multi-hearth furnace for calcined clay, 2 semi-continuous kilns and 5 tunnel kilns for firebricks, 2 tunnel kilns for high alumina, a shuttle kiln for ultra-high

Tab. 1 World consumption of refractories 2006 to 2016 [×1000 t] (Courtesy: Freedonia Group)

World Refractories Demand [×1000 t]					
				Annual Growth [%]	
Item	2006	2011	2016	2006–2011	2011–2016
World Refractories Demand	35250	39150	46300	2,1	3,4
North America	3465	2695	2855	–4,9	1,2
Western Europe	3785	2960	3035	–4,8	0,5
Asia/Pacific	21470	27150	32900	4,8	3,9
Central & South America	1650	1675	2070	0,3	4,3
Eastern Europe	3090	2660	3015	–3,0	2,5
Africa/Mideast	1790	2010	2425	2,3	3,8

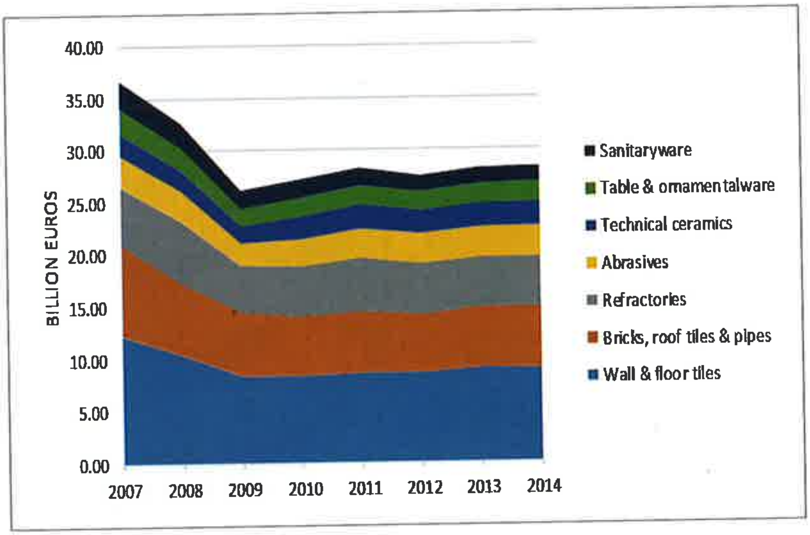

Fig. 2 Refractories and other ceramics production in 2014 (Courtesy: PRE)

alumina, a tar-impregnated dolomite plant and a basic tunnel kiln capable of firing bricks up to 1760 °C. The company also had a small monolithics plant which mainly produced mortar. The predominance of fireclay products previously made and sold can easily be seen from this information.

One of Stein's early successes was a large sale of firebricks to the North British Railway company who liked the size, shape and colour of the bricks so much, that they used them to build the Gleneagles Hotel and Golf Course Complex and then added a small railway station.

In the 60ies and 70ies, Stein firebricks were more normally being used to construct aluminium smelters such as the one for Alnor on Karmoy Island in Norway and then British Aluminium's Invergordon smelter in Scotland, Alcan's Lynemouth smelter in Ashington Northumberland England and Kaiser Aluminium's Holyhead smelter on Anglesey in Wales. The 3 GB-smelters have all subsequently closed when their energy supply contracts expired and could not be renewed on mutually acceptable terms removing large potential ongoing refractory sales from the market.

Ironically, the Stein plant which opened in 1928 was closed by Vesuvius in 2002 with some of the production moved elsewhere in Europe. In spite of efforts by the Scottish Government, the site still lies almost derelict, with the only structure that has not been completely demolished being the ancient Haining Castle which was originally built there by the Crawford family in 1417.

Equally dramatic perhaps, although different, but still quite sad, was a state-of-the-art greenfield firebricks plant opened only 20 miles to the west of Stein's Manuel plant in 1960. The new plant had its own new drift clay mine discharging high duty fireclay after weathering into European crushing grinding and mixing equipment. From there the clay was pressed into bricks at the rate of 4 every 10 s in an American brick press and the bricks fired in a new British tunnel kiln at up to 1350 °C. This plant is now also closed and has reverted to a brown field site with the investment being active for only about 50 years.

A third location situated between these two sites is set in some pleasant hilly woodland and every summer steam trains run excursions from a railway heritage site at Bo'ness to the ruins of the former refractories plant and mine at Birkhall, parts of which have been turned into an industrial museum and picnic area.

It is not unreasonable to suppose that Europe and other major markets have shown similar trends although the trends almost certainly initiate at different times and proceed at different rates. There are surely hundreds of similar interesting stories available to researchers and relating to companies all over the world.

How large is the modern refractories industry?

A major study in 2010 (Tab. 1), claimed that while there had been a contraction in the production of steel and some other basic commodities over the previous two years the world was again emerging from recession and that key indicators suggested that by 2015 the world production of refractories would reach 59 Mt valued at approximately USD 31 billion. In 2013, a second survey by a different organisation stated that by 2012 the world production of refractories would reach 42,5 Mt valued at USD 25 billion. The same report forecast that by 2017 the world production of refractories would be 46 Mt with an estimated value of USD 29 billion. The difference in total production forecast by the two organisations could be partly explained by the fact that one is predicting tonnage in 2016 and the other a slightly larger tonnage in 2017. There are however very significant difference in the sales values which were forecast and there is no obvious indication as to why this should be other than perhaps different assumptions on exchange rates and average values. The second report also suggests, that Chinese refractories production in 2012 amounted to 29,5 Mt valued at USD 14,3 billion, while Europe produced

4,1 Mt valued at USD 3,9 billion and North America manufactured 1,4 Mt valued at USD 1,4 billion, with 1 Mt from the rest of the world not identified in any detail.

Yet another third substantial report issued in 2013 claimed, that while there was an overall market growth averaging just over 4 % prior to the time of issue this would increase to an increase in growth of over 5 %/a and the world production of refractories in 2016 would be 46,3 Mt valued at USD 46,5 billion. It should be noted, that all of these were forecast and estimates which need a lot of further study and analysis to understand fully.

PRE statistics for 2014 (Fig. 2) seem to indicate that European producers actually manufactured refractories worth slightly less than EUR 5 billion, which is roughly in line with two of the three studies although tonnages were not stated in the published report available to the writer. Neither was it entirely clear what exchange rates were being used, so it is difficult to make exact comparisons. Since about 70–75 % of the refractories produced are used in the iron and steel industry, it would not be unreasonable to compare the trends in both industries.

It appears that global steel production in 2015 at 1488 Mt represents a current overcapacity and major producers are cutting back on the overall production by about 3 % this year, although there are big regional variations reported.

The PRE President in 2014, Jose Dominguez, indicated that the total refractories production in Europe overall had been more or less static, although countries such as Germany had posted a 4 % increase in tonnage, while countries such as Spain had experienced a drop of around 3 %. All had been subject to similar market pressures and had experienced falling prices and rising costs. These factors combined with a degree of overcapacity had generally impacted profit margins. Most observers forecast a small recovery in 2017, but this is dependent on several so far unresolved economic and political factors.

One conclusion therefore may be, that while tonnages of refractories manufactured have reduced significantly over the last 50 years higher value products are now growing slowly from their lower level at up to perhaps 5 %/a, although this is not strictly accurate for all product groups nor for all geographical markets within which there are still wide variations. Researchers need therefore investigate product and user trends in much more detail as these specifically apply to their businesses and aspirations.

Focussing on the production situation again, the manufacture of refractories has gone from very many small local companies to fewer larger integrated organisations operating in many cases globally and in virtually every case internationally. Many small companies, which were originally based close to their raw materials sources, have been closed as these sources became depleted or uneconomic. A GB historian claimed in 2015 to have a collection of 1850 different brands of Scottish firebricks, which may explain both how prolific the industry was and also why most of it has now gone. European environmental legislation and taxes have also made doing business more expensive and complicated. Some companies have merged, or been taken over many times over the intervening years, in the formation of big groups operating around the world. These organisations source their raw materials internationally with some being created synthetically and some being recycled and beneficiated products. As noted, this trend is at different stages in different continents and perhaps is not yet as fully developed in Asia as it will eventually be. A refractories industry directory based in China indicates that it has over 1000 member companies listed, while in Germany it shows less than 200, although it must be pointed out that not all of those are manufacturers. Neither of course is the situation that every company is listed, although it does tend to show differences between markets at different stages of development.

How many people are employed in the refractories industry?

50 years ago, in Europe some refractories companies with plants built on or adjacent to their quarries and mines were substantial employers of labour living in towns or villages near the plant. This is no longer the case for many reasons, the most important of which, is that most of these plants are no longer in operation. Many smaller, often family-owned companies have closed down, merged, been acquired, or new

Tab. 2 Typical properties of silicon-nitride bonded silicon-carbide refractories

	Bulk Density [g/cm³]	Apparent Porosity [%]	CCS Ambient [MPa]	MOR Ambient [MPa]	Thermal Conductivity [W/m·K]	Si_3N_4 [%]	SiC [%]
Value	2,65	15	145	35	16	>18	>72

business groupings have made new investments much closer to the end users rather than the raw materials sources.

PRE statistics for 2014 again indicate personnel numbers directly employed in member companies in the refractories industry in Europe have probably fallen by up to 30 % over the last 10 years. Anecdotal evidence and statistics from multiple other sources suggest that there has been a very large reduction in direct employment in the industry over the last 50 years and that while this continues, the rate of decrease has reduced to lower single figures.

The Canadian Government organisation responsible for collating refractories industry statistics has stated, that aside from cyclical economic fluctuations several factors may contribute to changes in the composition of an industry segment's workforce. In an increasingly knowledge-based economy, the administrative component of the workforce (including business administrators, managers and professionals such as engineers and computer and research scientists) may be growing in significance. Technological advances may result in lower demand for production workers, which can in turn have a proportional impact on requirements for managers and support staff. At the same time, automation and the trend to outsource work to subcontract rather than performing it in-house can have an impact on employment levels for all production technical and administrative staff.

What changes have taken place in raw materials?

In the area of raw materials there have been major changes from locally sourced products, which would be quarried or mined near to the plant, to much higher quality imported raw materials, synthetic products or even beneficiated recycled aggregates in many cases. There still are local sources of low iron kaolinitic fireclays in South Africa, the USA and other places but the proportion of firebricks produced has fallen substantially as refractories requirements have had to meet demands to operate at higher temperatures for longer times in more aggressive conditions. Most specifications now call for alumina contents in excess of 55 % which are satisfied by raw materials based on andalusite, sillimanite and bauxite, although there is growing requirement for the use of mullite, tabular alumina and even spinel based compositions. Silica-based refractories, other than for induction furnaces applications, have been developed with fused silica aggregates rather than even the purest grades of quartzite. This has been both for technical reasons and for health and safety considerations. Quartz exhibits the well documented inversions and transformations (Fig. 3). Refractories with a high quartz content have a relatively high thermal expansion especially at temperatures around 573 °C and this can result in severe disruption. The transformed products trydimite and cristobalite also exhibit high expansion over narrow ranges at low temperatures. Although, high-purity super-duty silica bricks are still the main specification for glass tank roofs due to their ability to exhibit very high compressive strength very close to their melting point several other applications such as coke ovens, many in new designs, no longer rely on silica refractories to the extent that they once did. Vitreous silica or fused silica aggregates have however found favour in applications such as aluminium furnace launders and filter systems where they are very cost effective.

Residual quartz in refractories, especially during demolition, has been proved to be carcogenic and legislation limits the allowed levels in most countries. Even ceramic fibres have been largely replaced by so called biosoluble grades which are claimed not to persist in the lungs. The additives used to stabilise the fibres have led to some down grading of the temperatures of use, although the thermal conductivities are still the same at similar temperatures.

50 years ago, basic bricks were manufactured in various grades from local deposits of magnesite, chromite or dolomite, until a number of sea water magnesia plants were commissioned to give higher purity magnesia aggregates. These local magnesites were often used in conjunction with chrome ores to make magnesite-chrome bricks or occasionally chrome-magnesite bricks but this has largely been superceded partly on health and safety concerns as well as on quality and economic issues. The direct bonding of magnesia grains at very high temperature and the rapid development of spinels within refractories before and during service, has led to further great benefits in performance and cost effectiveness. The development of high-purity synthetic silicon-carbide grains and the technique of creating strong silicon-nitride bonds between the grains (Tab. 2) have also led to advances in some sophisticated applications with aggressive environments.

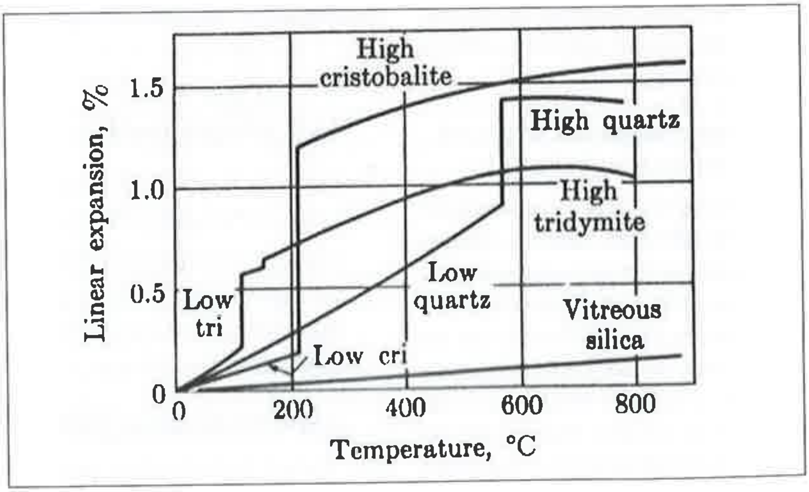

Fig. 3 Quartz phase transformations and inversions

How has the usage of refractories evolved?

The change from the use of 100 % bricks and blocks to over 50 % monolithic products today has been a major trend which started about 75 years ago has since accelerated rapidly and still appears to be continuing, although the overall rate has slowed considerably.

In earlier years, there were sometimes localised or temporary shortages of firebricks. One solution was to crush and screen some reclaimed bricks and mix them manually with added binder such as Ciment Fondu and usually too much water using a shovel on a steel plate on the floor. The material could then be shoveled into a wooden mould to make a special shape or even put into an existing refractory lining with suitable shuttering. In the case of the blocks made in moulds, these could be cured overnight, although the curing of material incorporated into the lining itself was much more problematical and could result in lining failure when initially heated as there was seldom much control. Stiff clay mixes prepared for making special brick shapes could also be transported to nearby linings and hammered into damaged areas as a convenient small repair.

The invention and patenting of Ciment Fondu by Jules Bied of Lafarge in 1908 and its subsequent commercialization along with William A. L. Schaeffers formation of the Pliable Firebrick Company (Plibrico) on a clay deposit on Goose Island Chicago 5 years later, started and accelerated this trend to monolithics, which is now global.

Plibrico expanded from the original site to become one of the top 3 monolithic producers in North America and elsewhere in the world, although today Goose Island is renowned more for its beer rather than its refractories. From these early beginnings, at the start of the 20th century came free-flow castables, low-cement castables, ultra-low cement castables, no-cement castables, gun mixes, shotcretes, ram mixes and even plastic gun mixes with all their many derivatives.

What developments have there been in the installation of refractories?

When the supply of refractories was mainly in brick format, the installations were carried out by skilled masons assisted by helpers and usually also by apprentices who served for 5 years before being qualified tradesmen themselves and carrying on the traditions and skills. Because the tonnage of bricks used was very large and the lives of the furnaces fairly short, most end users had their own tradespeople who were permanently employed on construction and maintenance.

A very large glass tank furnace might require 1000 t of refractories and a large open hearth furnace 1800 t, since both had extensive melting chambers, regenerators, chequer systems flues and stacks. A large blast furnace with several hot blast stoves with associated ducting and launders systems could easily require double even that weight of refractories.

Since a good refractories mason supported and supplied by helpers could lay up to about 40 standard bricks per hour on average over an 8 h-shift, it can be seen that with these tonnages and the number of bricks involved the labour requirements were substantial, even if activities such as demolition are discounted. In other areas involving for example hot metal transfer, permanent crews were involved in the constant wrecking, reline and preheating of large fleets of ladles. Bricklaying therefore allows quality installation rates of up to about 200 kg/h per team.

A recent study in GB indicated that there is a both finite and reducing availability of skilled men and that their average age is over now 55 and increasing. For many years, British bricklayers have always worked and supervised refractory constructions not only in Britain but around the world.

Currently in GB, there is a big net inflow of bricklayers especially from Europe when manpower requirements peak. Even here, however, there is much increased mechanization with equipment like pneumatic bricklaying rigs in rotary cement kilns to boost productivity. There has also been a net inflow of non-European construction workers in major projects, for example in the Middle East and Africa. Part of this is due to major Chinese corporations not only selling a turnkey installation to supply and install refractories, but also taking equity in the project making it essentially a joint venture.

Installation of refractory castable might be accomplished at installation rates of up to about 600 kg/h per team with the appropriate equipment like a 100 kg-capacity high-intensity paddle mixer as required to prop-

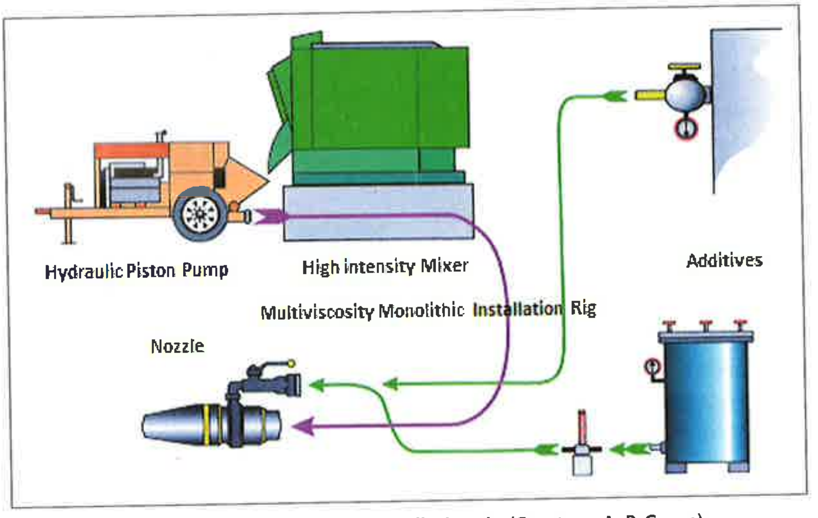

Fig. 4 Modern multiviscosity monolithic installation rig (Courtesy: A. P. Green)

erly mix the materia, as well as transport to the shutters and equipment to vibrate it into place. A basic team would have three men and of course installation rates can be significantly increased by using bigger or multiple mixers with more labour or a pump for transportation.

Guniting a lining could give installation rates of between 2,5–5 t/h per crew with a big metric ton bag feeding into and perhaps suspended from a forklift boom above the gunite machine. The gun equipment now would comprise of a multi-chamber gun with a high efficiency throughput, a large powerful compressor and a water pump.

The rate can be increased, if the distance the material has to travel, especially in a vertical direction, can be reduced and especially if the rebound losses can be curtailed. Shotcreting which involves mixing castables or no-cement castables in a mixer to make them fluid, transporting them through hoses using a large double piston pump and adding fast setting additives at the nozzles can be a system to install even more material even more quickly (Fig. 4).

The limiting factors are not always skilled labour but more the necessity to set up, use and clean down high tech equipment which can cost in excess of EUR 100 000 and to closely control the additives so that the material flows then sets very quickly.

There is seldom very much justification of using such techniques with an installation rate of up to 10 t/h, if the total repair only involves 10 t of material. For major jobs, an increased rate of installation is possible and is achieved by using more sophisticated and expensive equipment, but this is not always the cheapest solution nor does it necessarily always represent the highest quality lining. When all of the factors including shuttering, installing, curing, and applying a controlled dry out and heat up schedule are taken into account, the economics of the fastest installation can often look very different.

The absolutely high uniform quality of precast-prefired blocks, speed of installation and the reduced need for controlled heat up can in some cases therefore be an extremely attractive alternative and can reduce the downtime in the furnace and the labour costs on site by almost 50 %.

What impacts has end user technology imposed on the refractories industry?

In most user industries, nearly all furnaces have become bigger and operate at higher temperatures. Glass furnaces can produce up to about 1000 t/d at close to 1600 °C roof temperature with oxygen enrichment of the fuels which also make the ports and regenerators operate at higher temperatures.

Cement kilns have gone from long wet process furnaces to short dry kilns with preheaters and sometimes precalciners. There has also been a huge increase in the use of secondary fuels which can give rise to the buildup of alkalis in the system and more aggressive refractory attack.

Aluminium reduction cells are very big and pushed harder, while carbon bake furnaces are also much larger and work at higher rates of heat transfer between flues and walls. Aluminium melting furnaces may be charged with recycled can shreds or other light scrap to increase melting rates.

In the iron and steel industry fewer bigger blast furnaces are producing pig iron which is transported at high temperature in large torpedo ladles to be charged to basic oxygen furnaces. For economic and technical reasons there is a substantial move to processing less ore and more scrap and this has led to increased size and major improvements to electric arc furnaces while today more and more processing takes place in the steel ladles before final casting.

A recent conference in Germany gained recognition even from companies with large fixed investments who have traditionally relied on blast furnaces that there was compelling case to re-evaluate the entire steel making process.

Ceramic furnaces today often rely on low thermal mass linings to fire the ware faster and more cheaply while in incineration and in some other fields plasma arc energy can increase process capacity although as has been proved can be very difficult to control.

In many applications, but especially in precast shapes simple or in some cases complex drawings were replaced by CAD, which could allow the shape to be represented 3D and rotated through 360° in every plane. There has even been models produced using 3D-printing so that every aspect of the construction can be evaluated.

As has been noted there are fewer people in the industry with more input from external technical and research establishments along with engineering and installation support and the majority of these personnel are better educated and much more experienced than in the past.

The refractories industry has reduced in size but increased in value while embracing many new purer raw materials and sophisticated user technologies. Perhaps in the current situation it is a period of reassessment when the industry and its leaders are carefully considering which markets, materials, technologies, industries and applications to focus future investment in.

If this is indeed the case then there is future for all of us who have already invested time money and effort personally and are prepared to embrace change and focus on opportunities.