Modern Trends in the Heat Treatment of Advanced Materials

A. Hajduk

Introduction
Of all materials and products that have to undergo heat treatment in a production process, the development potential for technical ceramics and advanced materials is enormous. This can be attributed to the need to bring more and more novel and optimized products to market. One driving force in product development is a complex matrix of technical and economic aspects as well as environmental influences and emission regulations. The manufacturers in global competition are forced to constantly improve their products, develop new and innovative products and increase the efficiency of their production processes in every respect.

These market requirements have a direct effect on the demand for continuous optimization of heat treatment equipment. If we look at the latest development trends from the perspective of the 90-year company history of RIEDHAMMER GmbH, a shifting of focuses can be clearly seen.

Key development trends
Over the course of many decades, a large number of milestones have been set in the development of heat treatment equipment. Initially intermittently operated kilns were followed by kilns that could be used in quasi-continuous operation. To handle high production capacities, the tunnel kiln with continuous car transport was developed. The introduction of PLC-based control systems as well as the rapid spread of sensors for a wide range of measurement, control and regulation applications has revolutionized all areas of modern plant engineering, from which kiln engineering also profited strongly. As a result, increasingly precise real-time measurements of control variables could be made, and accordingly more precise control circuits set up.

With the existing technical means, wide diversification of the types of heat treatment equipment became possible. The intermittent kilns could be operated according to the chamber, top-hat or shuttle kiln principles, and for shuttle kilns different layouts emerged, above all with ever larger useful volumes. Today RIEDHAMMER GmbH covers a useful volume range between 1 and 1000 m³.

At the same time, electrically heated kilns became substantially more important for certain products. As key representatives of this development, top-hat and elevator kilns can be mentioned, which first made possible the production of a large number of very sensitive electronic components. This group of kilns usually has numerous electric heating elements which can be collected in an appropriate number of control groups depending on requirements. Such kiln types are very suitable for gas-tight design and can be operated both with pure oxygen and various inert gases. Fast atmosphere changes are possible. The oxygen content can be reduced to around 30 ppm in a short time.

Further development in continuously operating kilns led to another diversification, which has thrown up several modern representatives of this operating type. For the mass production of sensitive electronic ceramics, the elevator kiln has reached the limits of its capacity. Here the so-called pusher-type kiln has found wide application. This is a type of tunnel kiln in which the product to be heat-treated is placed on ceramic batts and is pushed steadily by means of a hydraulic or electromechanical pusher system on a ceramic slide-track through the kiln channel. In these kilns, one, two or three rows of pusher plates are used, which are transported at the same time through the tunnel, the two-channel pusher-type kilns being the most common. In many applications, a debinding unit is installed upstream of the sintering plant. With electric heating, individual recirculation zones are usually connected together to improve heat transfer as a result of high flow rates. In gas-heated debinding units (Fig. 1, [1]) there is indirect heating with an integrated thermal post-combustion system. On account of their special operating principle, pusher-type kilns are limited to lengths of around 40 m and designed today for different atmospheres, e.g. N₂, Ar, H₂, the maximum operating temperature being up to 1650 °C.

Selected development trends in recent years
Another important representative of the tunnel kiln is the roller kiln, a very versatile plant that can be heated both with gas...
and electricity. The key advantage compared to the tunnel kiln with car transport is the much lower specific energy consumption as no kiln cars have to be heated up or cooled down in each cycle. Unlike with the pusher-type kilns, limits to the kiln width are reduced. In respect of their useful dimensions, modern tunnel kilns are built wide and not so long, which was only made possible with novel lining and roller materials as well as heating systems.

With this design, investment costs are reduced, because the kiln length is known to be more expensive than the kiln width. With an increase in the useful width, the useful height can be reduced, which in turn results in a much better temperature distribution in the kiln cross-section. So in the case of the roller kiln, depending on the application, a multiple (two- to six-fold) of the width of a pushed batt kiln is possible, which naturally leads to an enormous increase in capacity (Fig. 2).

The belt kiln is another representative of the tunnel kilns and it is enjoying growing popularity in a large number of industrial heat treatment processes. One possible design of a belt kiln is shown, for example, in Fig. 3. This type of kiln uses a metallic belt (usually in the form of a link conveyor belt), to transport the product through the kiln. Depending on the application temperature and the nature of the product, belts with suitable geometry in different heat-resistant steel grades are available. With a relatively simple solution for the transport system, the belt systems are less cost intensive, which naturally favours their widespread distribution. The limitations to their application are set by the maximum application temperature to around 1100 °C, as the metallic belt does not permit any higher temperatures.

Today, RIEDHAMMER GmbH realizes belt widths up to 2,2 m, although even much wider kilns are possible. At the same time it must be taken into account that, for example, a 25-m-long kiln requires a belt with a length of around 60 m. The kilns are usually used for fast throughput times, typically around 30–180 min. Only when this is taken into consideration do the mechanical and thermal stresses on the belt become clear. For this reason, for this type of kiln, the development trends are focussed on gentle treatment of the belt so that components for belt guidance, belt support, belt control and determination of the belt position are constantly being improved and further developed. A special design of this type of kiln is the belt kiln with recirculation system in which very high flow rates, usually geared to the product geometry, can be realized. The type of operation is enormously important for certain calcining processes as the product quality is directly dependent on the homogeneous temperature distribution in the kiln cross-section and on the high and optimum flow rates.

In a review of continuously operating kilns, naturally the rotary tube kiln with its wide-ranging application options in all technical variations should not be left out. However, to keep within the framework of this publication, a detailed description has been omitted. Instead reference is made to other literature devoted to this topic. In this connection, [2] should be mentioned for example.

The introduction of 3D-based design systems can be described as a further milestone in the development of heat processing installations, as today this enables a kiln to be shown as an integrated model and collisions to be reliably avoided at the installation site. The interfaces to the up- and downstream processes are also designed precisely and faultlessly. The main advantage is that the kiln can be described with every interesting detail, can be viewed from all perspectives and in all necessary steps. Such an approach, complemented with the available calculation and simulation techniques, enables the designer to perfect detailed solutions.

The connection of 3D design programs and steadily increasing power of modern computer systems has made simulations of the thermal processes attractive for kiln engineering. Although a complete simulation of the transient heat and flow processes in a continuous kiln cannot yet be realized at a reasonable cost, partial simulations of certain specialized solutions are certainly common.

In this connection, a further development of the existing pusher-type kiln concept serves as an appropriate example.

In this project, several measures were applied aimed at drastically increasing kiln efficiency. First the focus was on a substantial increase in the production capacity compared with similar firing plants. As the pusher-type kiln is limited in length, the desired solution would automatically lead to an increase in the useful height and width. From this extension in the dimensions in connection with the high treatment temperature, the necessity resulted to fundamentally change the heating and flow system to achieve an equivalent or improved uniformity of temperature and flow in the kiln cross-section.

Such bold technical measures can quickly reach the load limitations of the materials used. To technically assess the novel concept, the critical processes were safe-
guarded by means of simulation processes. As a result of this development, ultimately a useful width of 720 mm and a useful height of 550 mm could be successfully realized in several kilns. Accordingly a load of around 90 kg per pushed batt could be realized, which at the same time led to a substantial reduction in the specific energy consumption. Fig. 4 and 5 show excerpts from the computer simulations, in which the data and findings derived from this have been confirmed in practical applications. In a review of modern development trends for heat treatment plants from the perspective of the RIEDHAMMER GmbH portfolio, the Low O₂ kiln should not be omitted either [4]. In the year 2007 the first reference was successfully launched onto the market. From this, a strategically very important product series has been developed. Basically this is either an intermittent kiln (Fig. 6) for relatively low to medium production capacities or a tunnel kiln with car transport for mass production. A special temperature and atmosphere control is taken as a basis. The Low O₂ System is very good for difficult de-binding and sintering processes and is widely used especially for highly complex structural ceramics, such as catalyst carriers and diesel particle filters with high binder content. The challenge in firing such materials is to optimally control the kiln during the heat treatment process to meet the high product requirements. If you look at a typical temperature curve, it is necessary to heat up to debinding temperature as fast as possible. Local overheating, however, would be fatal as exothermal reactions could be triggered in parts of the product, which could ultimately lead to its destruction. The RIEDHAMMER Low O₂ System works indirectly in this range. This method of operation eliminates hot spots, and very good and homogeneous heat transfer to the product is enabled. The speed of the exothermal binder combustion is selectively controlled by the RIEDHAMMER Low O₂ System, so as to prevent local hot spots and achieve a fast but at the same time gentle debinding process with optimum temperature distribution. At around 600 °C debinding is complete in most cases. Now the standard kiln operation follows with a steep preheating gradient and the soaking phase. The kiln burners are usually operated in pulse mode, which substantially improves the temperature homogeneity. In the meantime, RIEDHAMMER GmbH has an impressive reference list for Low O₂ kilns. This development, however, is being further pursued intensively, which is described in the following with reference to several examples. First, a very high value is attached to the perfect sealing of the kiln to avoid possible process gas leaks to the outside as well as binder and tar condensation at cold points. The challenge for detail design solutions becomes more complex because, as a result of escaping product components, chemically very aggressive, mainly acidic condensates are formed. In real production plants, pH values up to 2 have been measured. Also in firing technology, further developments have been realized. This includes the possibility to operate the kiln burners either with ratio control or in pulse mode. Also the perfect burner arrangement in relation to the kiln setting as well as the option to individually control burners enable a considerable improvement of process parameter control. As debinding leads to a concentration of the process gases with high-calorie components, plant reliability must be thoroughly analyzed, especially in the event of a fault, and safeguarded with appropriate measures. Here there is enormous development potential because for the reliable operation of a plant, basically no compromise is possible. On the other hand, a trouble-free operating analysis system must be ensured. In most cases, this consists of instruments to record oxygen, carbon monoxide, carbon dioxide as well as hydrocarbons. So-called LEL (Lower Explosion Limit) devices can be used depending on the application. The above-mentioned analysis systems are naturally very cost intensive, the main challenge for development being to find the best cost-performance ratio for an absolutely reliable technical solution. Novel insulation materials enable the building of much more effective kilns, not only in the low O₂ range. They lower the energy consumption by minimizing the radiation losses and allow a shortening of installation and repair times. As a result, cost-driving factors in the production of ceramic products are reduced. As the final example of development trends in modern kiln engineering, the interface extension should be mentioned. In the past, heat treatment equipment was often only equipped with an automatic circula-
solution can be described in the associated offers. The only way to correctly assess the plant concepts the user is considering is on the basis of intensive consultation and joint development. The latter-mentioned aspect plays a key role as plant and product know-how are exchanged with the goal of finding an optimum solution in every respect.

References

[1] Patent Nr. 4420295, 26.10.1995 Deutschland; Nr. 6,116,894; 12.09.2000, USA; Nr. 3047192, 24.03.2000, Japan

