Introduction
For new developments of kilns for sanitaryware all plant components are to be submitted to thorough examinations in view of their design and construction as well as the required process and materials technology to find possible modifications which allow the plant to perfectly fulfill their function. The focal points in this connection are energy saving and the associated reduction of CO₂ emissions, including considering the appropriate heating methods and transport methods, design of heat insulating and heat absorbing components. The latest methods for determining stationary and transient heat transmission processes and for simulating flows for the optimisation of heat transmission and temperature uniformity, e.g. via computer calculations, are used for this purpose. The respective requirements are listed in a specification bringing out solutions such as the Energy Management System (EMS), Combined Heat Supply Network and the completely redesigned Riedhammer REKO shuttle kiln. The effectiveness of these newly developed products is documented by the respective operational data.

Tab. 1 Comparison of energy and emission data of tunnel kilns

<table>
<thead>
<tr>
<th></th>
<th>Riedhammer Tunnel Kiln</th>
<th>Tunnel Kilns Available on the Market</th>
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<tbody>
<tr>
<td>Energy consumption [kcal/kg net]</td>
<td>814</td>
<td>1260</td>
</tr>
<tr>
<td>Energy consumption [kcal/kg charge]</td>
<td>387</td>
<td>599</td>
</tr>
<tr>
<td>Total fuel costs [EUR/a]</td>
<td>519 767</td>
<td>802 326</td>
</tr>
<tr>
<td>Total CO₂ emission [kg/a]</td>
<td>3 465 116</td>
<td>5 348 837</td>
</tr>
<tr>
<td>Difference</td>
<td>+55 %</td>
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Initial situation
The production of ceramic products is always closely linked with thermal processes. As ceramic sanitaryware is fired at relatively high temperatures between 1180 °C and 1250 °C the theoretical energy requirement for obtaining such temperatures and without consideration of different heats of transition already amounts to 295–320 kcal/kg. The diverse products with their different weights require kiln furniture as refractory supports during firing which are used in a weight ratio of ware : kiln furniture = 1 : 1,1 to 1 : 1,3 [1]. This leads to a more than doubled mass of ceramic products to be fired and the theoretical energy requirement increases accordingly.

Whereas only a small quantity of energy consuming transport means are used in roller kilns as no kiln cars are necessary in this kiln type – (taking into account the slightly increased radiation losses of the transport rollers at the outer kiln wall) – the cars with their refractory superstructure have to be considered for the energy calculation in shuttle and tunnel kilns with car transport systems (Fig. 1). In these kiln types the heating is effected according to the laws of transient heat conduction. With modern computer simulation calculation methods [2] the most favourable change in enthalpy can be determined as a function of the firing cycle and of the temperature dependent on the refractory car insulation to be selected. On average the roller kilns have an approx. 25 % lower energy consumption in comparison with tunnel kilns with car conveyance.

Riedhammer has always focused on obtaining the lowest possible energy consumption for its kiln plants. According to Tab. 1 which draws a comparison between standard tunnel kilns with car transport and standard tunnel kilns available on the world market, up to 55 % of the energy costs and, due to the physical connection, also the corresponding amount of CO₂ emissions can be saved by using the available technology and experience. For this comparison a production capacity of 50 t/d and a natural gas price of EUR 0,3/m³n were taken as a basis. With up to 103 % the differences between Riedhammer roller kilns and conventional tunnel kilns are even more significant which is represented in Tab. 2. The same fuel prices as for Tab.1 were taken as a calculation basis, assuming, however, production capacities of 30 t/d. All kiln types for the sanitary ceramic industry are fossil fuel heated. The enormous capacities – more than 50 t/d are no rarity – require large plant cross sections [3] for which
electrical heating is not suitable for structural and thermo-technical reasons. Due to the inevitable waste gas losses the degree of efficiency in fossil fuel heated kiln plant is lower than in case of electrical heating, but the high prices for electric energy in most countries not only neutralise the efficiency advantage but also speak in favour of fossil fuel heating in view of the operating costs. It does not appear that electric energy generated by renewable energies will be obtainable at lower prices than fossil-fuel energy in the foreseeable future.

In the ceramic sanitaryware industry light heating oil and fuel gases are used as fossil fuels; the use of heavy oil is very rare. For the transport through the pipes to the burner and for combustion purposes the heavy oil must be brought to a specific and constant viscosity which can only be realised with considerable effort and costs by means of piping with controlled heating. Components in the heavy oil, such as sulphur, react with the glaze and lead to higher reject rates. The use of coal dust as fuel would contaminate the sanitaryware products even more so that this type of fuel is to be regarded as inappropriate.

In Central Europe the natural gas prices are mostly bound to the price development of light and heavy heating oil due to long-term supply contracts of the natural gas importers with the suppliers of the supplying countries. Therefore the price index for natural gas follows that for heating oil with a small time delay. However, the upward trend of the import prices over the last decade (Fig. 2) [4] is to be regarded as an unpleasant common tendency. Due to the shortage of resources this trend is most likely to intensify in the future. The import prices for natural gas are indicated on the left coordinate in EUR t/a, the prices for crude oil in EUR t/a are shown on the right coordinate. The most significant price increases took place in the years 2000 to 2001 and 2004 to 2008, the prices in the year 2009 were only on the decline due to the worldwide economic crisis. The tendencies shown remain unchanged also in the case of an inflation-adjusted consideration. Every combustion process of carbon dioxide and hydrocarbons causes the formation of nitrous oxides and above all of carbon dioxide gases. The thermal NOx formed during combustion mainly consists of NO and 5 % of NO2. These nitrogen compounds act as acid formers in the presence of water and therefore cause the so-called “acid rain” in the atmosphere. The reduction of NOx during combustion is achieved by well-known primary and secondary measures, as described in the relevant literature [5].

The CO2 gas which is also referred to as “greenhouse gas” is a synonym for harmful impacts on the environment. It heats up the air at ground level by absorbing the infrared radiation of the earth’s crust and cools down the higher spheres by radiation. The CO2 emission is directly related to the fuel consumption. Low percent values in the waste gas are not an indication for a low CO2 emission.

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but evidence that the waste gas has been diluted with additional air. Fig. 3 illustrates this connection. The alternative to improve the heat transmission coefficient with high air excess is not applicable as the increase in the air quantity involves an increase in energy consumption which cannot be compensated by the improved heat transmission.

All the facts presented so far underline the urgent necessity of demanding a significant reduction of the energy consumption in the ceramic industry in the future.

With the European Community preparing legislation to require the furnace industry to reduce fuel consumption (the so-called Eco-furnace Study Group) as a part of the Eco-design directive Riedhammer is once again leading the way.

What are the requirements on modern kiln plants for firing sanitary ceramics?

For the above-mentioned reasons the following logical consequences are to be considered in the specifications for new development of kiln plants:

- Kilns are to be heated with fossil fuels for reasons of costs and operational safety.
- Despite intensive efforts in view of the composition of the materials the high firing temperature will not change considerably in the future.
- The mass ratio of the kiln furniture to product can be improved by using SiC materials.
- The lowest possible energy consumption can be achieved in roller kilns due to low ballast and/or kiln furniture quantities.
- Modern computer-assisted calculation methods permit the energetic optimisation of the transport car insulation.
- The CO₂ emissions are to be reduced.
- The energy consumption is to be minimised significantly.

The requirements indicated led to the following new developments by Riedhammer:

- Energy Management System (EMS) for all continuously operated firing kilns
- Combined Heat Supply Network between the firing units and the consumers in the factory
- REKO shuttle kiln.

These new developments are the result of Riedhammer’s experience from more than 88 years in the construction of kilns for the ceramic industry and the in-house synergy effects of the new technical kiln developments for sanitary and tableware ceramics, for advanced ceramics, refractories and carbon.

It remains the company’s central task to continue with the design and construction of kilns with the minimum possible energy consumption and CO₂ emission, a major concern which has been given top priority.

The Energy Management System (EMS) for all continuously operated kiln plants

In a functioning system – such as kiln plant – many single components have to be correctly linked with each other. New components have to be fitted into an existing and well proven overall concept to be equipped and controlled with state-of-the-art measuring and control technology in the most advantageous way according to the latest developments and know-how.

As a first basic measure for reducing the energy consumption of kiln plant, the heat transmission should be optimised according to the following points:

- Optimal and complete use of the clear cross section
- Installation of performance-adapted burners
- Correct and well-conceived burner arrangement
- Efficient cross circulation of the hot fluids by means of sufficient injection points

Furthermore the energy management system EMS comprises of an optimal combustion adjustment of the burners, i.e.:

- Combustion air preheating
- Measurement of the combustion air temperature
- Measurement of the gas and air flows
- Exact compliance with the preset gas/air flow ratio and simultaneous consideration of the current combustion air temperature.

Tab. 2 Comparison of energy and emission data between roller and tunnel kilns

<table>
<thead>
<tr>
<th></th>
<th>Riedhammer Roller Kiln</th>
<th>Tunnel Kilns Available on the Market</th>
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<tbody>
<tr>
<td>Energy consumption</td>
<td>620</td>
<td>1260</td>
</tr>
<tr>
<td>[kcal/kg net]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Energy consumption</td>
<td>497</td>
<td>599</td>
</tr>
<tr>
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<td></td>
<td></td>
</tr>
<tr>
<td>Total fuel costs [EUR/a]</td>
<td>237 209</td>
<td>481 395</td>
</tr>
<tr>
<td>Total CO₂ emission [kg/a]</td>
<td>1 581 395</td>
<td>3 209 302</td>
</tr>
<tr>
<td>Difference</td>
<td>+103 %</td>
<td></td>
</tr>
</tbody>
</table>
Solely by combustion air preheating an energy saving potential of more than 12% can be achieved. The EMS equipment and process technology mainly consists of:

- maximum use of kiln waste heat
- recuperators installed in the kiln firing chamber for combustion air preheating
- regulation and control equipment for a fast switchover, for example weekend operation
- a large number of burner groups
- the supply of sufficient warm air volumes for up or downstream use in the factory.

The basic function of the EMS consists in the transfer of the kiln’s waste heat produced during the firing process to fresh air which can be used as combustion air via a ceramic recuperator system installed in the kiln body. This system contributes significantly to energy savings and to an improved glaze quality.

The controlled recuperator system not only helps to realise energy saving potentials, but also allows an exact temperature control in the cooling zone, particularly in the range of the quartz inversion point so that full-scale production can be resumed immediately e.g. after a stop during the weekend.

Another contribution to energy saving is the well-conceived division of the high quantity of burners into a large number of regulation groups with the intention to conduct only the minimum necessary energy to where it is required. This procedure also includes flexible temperature control of the plant for automatic heating up and cooling down during non-production days.

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corresponding fittings attached to each burner.

The effects of the described measures on the energy consumption and CO₂ emission are illustrated in Tab. 3 for tunnel kilns with car transport in comparison with tunnel kilns that are available on the remaining market. Here the saving of energy costs by using the EMS system as well as the CO₂ emission reduction amounts to up to 84 %, without considering the cost reduction resulting from lower CO₂ certification costs. The calculation is based on a production capacity of 50 t/day and a natural gas price of 0,3 EUR/m³n.

Tab. 4 shows a similar comparison of costs and emissions between roller kilns with EMS and standard industrial tunnel kilns, based on a production capacity of 30 t/d and the same natural gas price. As expected, significant differences in the cost and CO₂ savings can be found here, they amount to up to 125 %.

With this saving potential and in times of constantly rising costs for energy and CO₂ certificates economically interesting amortisation times can be expected.

**Combined Heat Supply Network between the firing units and other consumers in the factory**

In general, it is useful to conduct the heat that is produced and released from the fired product and the transport material during the cooling process back to the kiln plant, thereby using the shortest possible route. In this process it is not so much the energy level but rather the temperature level which is decisive for further use. In the last cooling phase after the quartz inversion point the ware is cooled down to temperatures of <80 °C over a relatively short distance. The heat transmission must be effected with high convective heat transfer coefficients which requires considerable cooling air velocities and thus huge volume flows with high enthalpy, but low temperatures. The cooling air volumes are too large to be used completely as combustion air, but in view of their quantity and temperature level they are suitable for re-usage in dryers, spray towers, heaters etc. As the respective energy requirement and the CO₂ emissions are not insignificant for the individual units, a Combined Heat Supply Network between these units and the kiln with the Energy Management System (EMS) is ideal. Such a network reduces the total energy requirement by the amount of energy which can be supplied by the kiln via energy recovery. The same applies to the reduced CO₂ quantity.

There are a large variety of possibilities for operating and controlling the different units in a Combined Heat Supply Network. It is a matter of course that the respective application is to be discussed in detail between the plant constructor and the plant operator before being optimised.

**The Riedhammer REKO shuttle kiln**

Among the intermittently operated kiln plants the shuttle kiln is definitely the most frequently used kiln type in the ceramic sanitary ware industry.
Energy consumption and CO₂ emission are somewhat higher than those of continuous kilns. This is on the one hand due to the higher ballast weight of kiln insulation and kiln car which has to be heated up again in every cycle from initial to final temperature, but on the other hand also to the waste gas losses which naturally reach their highest level at the maximum temperature. In modern plants the kiln wall and kiln car insulation is calculated and optimised with the latest computer technology according to the principles of the transient heat transmission. The flow conditions in the kiln firing chamber are determined by special computer programs so that the most favourable burner positions and operating methods can be fixed and the temperature uniformity in the kiln firing chamber is further improved.

In Tab. 5 the energy-related data of a shuttle kiln designed according to the above-mentioned methods is compared with those of a standard industrial shuttle kiln. The measures described are already sufficient to realise energy savings and CO₂ emission reductions of up to 82 % in comparison with standard industrial kiln plants that are available on the market. This calculation is also based on a fuel gas price of 0,3 EUR/m³.

REKO shuttle kilns use additionally to the above mentioned calculation methods innovative patented burners. For each burner the gas and air volumes are measured on the cold side of the fluid supply which makes temperature correction unnecessary. The electronic components of the gas/air quantity regulation system guarantee the required optimal combustion for the entire firing process. Instead of a recuperator in a common waste gas pipe, which has been up until now common practice, a heat exchanger is installed for each individual burner in the kiln wall for preheating the combustion air and gas. As the energy transfer takes place directly in the kiln body no
conduction losses, which are usually high in conventional processes, are to be expected. This measure permits a considerably increased energy efficiency as can be seen from Tab. 6. The comparison is drawn again between a Riedhammer REKO shuttle kiln and a standard industrial shuttle kiln available on the market using the same price for the standard cubic meter of fuel gas of EUR 0.3. A saving of energy costs and CO₂ emissions by up to 138 % is achieved with the Riedhammer REKO shuttle kiln. With this enormous reduction of the production costs the plant operator will surely benefit from advantages in global competition.

Summary
The main goal of the developments presented is to save energy and to minimise CO₂ emissions. As an optimal combustion of fuels according to physical laws causes the highest CO₂ reaction it is not possible to reduce the concentration of the CO₂ emissions in the waste gas but only their quantity which can be realised with a lower energy input. This has been excellently achieved with these new developments as shown by the results in the tables. Further development continues.

References