

# Fire More for Less

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## A detailed report on fuel usage in ceramic factories

### Introduction

After four busy and successful years, **Dragon Kilns** is now well known as the firing design, specification and technical facility set up in close working association with **China's Tung-Chung Kiln Mechanical Co Ltd**. It works closely with key ceramic customers across the world and employs five technical and commercial staff, mainly operating out of the UK based hub. Around 40 large sized kilns are designed and specified by the team each year and these are fully or partly fabricated in a very modern, fully equipped, 30 000 m<sup>2</sup> manufacturing facility in Shenzhen/CN, thought to be one of the largest kiln building shops in the world. This purpose built unit, which is only a few years old, employs 250 full-time technical, commercial and manufacturing staff.

TC Kilns has a pedigree in the Chinese ceramic industry running back over many years and a track record which has seen it install hundreds of kilns across the country. When serious exporting began, then naturally other active parts of the Asian ceramic scene quickly became interested and Thailand was certainly no exception.

In just the last few years, Dragon & TC Kilns has worked with some of the most respected names in the Thai ceramic business, particularly those at the forefront in producing high quality export wares – be they domestic pottery, dinnerware, hotelware, sanitaryware, ceramic roof tile or quality giftware (textbox right). Careful attention is paid to all aspects of each project and the initial aim of the technical design and engineering team is establish what is the best type of kiln for the installation, especially bearing in mind load, mix and fuel consumption. This is all backed up fully at the Shenzhen end of operations where there is a proven track record in constructing shuttle, tunnel and roller kilns as well as dryers and pre-heaters, all as typically used by the larger ceramic product manufacturers. This early technical appraisal, conducted through close consultation with the prospective customer, is something that takes place as a matter of course and without any preconceptions or

prejudice. All the main types of units – shuttle kilns, tunnel kilns and roller kilns – are manufactured by the company and so they do not come to the table with any fixed ideas or skewed preferences.

### Kiln Types

#### Shuttle Kilns

Clearly with shuttle kilns there is a limit on size, although having said that, Dragon does have experience in manufacturing the very large types (e.g. a 140 m<sup>3</sup> unit delivered last year) which with rapid firing can hold their own against some continuous types. Nevertheless, a high

degree of flexibility is often what drives choice in the direction of shuttles. Typical fuel consumptions, taking a 60 m<sup>3</sup> sanitaryware kiln as an example, are around 2 000 kcal/kg. Amongst many installations in this sector, the client list includes manufacturers such as *Kütahya Porcelain*, *Fosco*, *Nahm Sanitaryware*, *DSF China*, *CUMI China*, and right at the moment *General Ceramics*, the Dubai based sanitaryware producer.

#### Tunnel Kilns

Tunnel kilns are not as flexible as intermittents and carry a higher capital cost but, if correctly loaded, can offer better consistency than shut-

## Major Dragon Installations in Thailand

### Royal Porcelain PLC, Kangkoi, Saraburi

Manufacturer of high quality porcelain and bone china tableware, producing around 30 million pieces per year (2 roller kilns)

### Raja Porcelain Co Ltd, Banpong, Rajaburi

An associate company of Chengteh Chinaware (Thailand) Co Ltd, Raja produces porcelain and fine china tabletop accessories and giftware for export. In all, Chengteh has annual group capacity in excess of 56 million pieces (12 roller kilns)

### Quality Ceramic Co Ltd, Hangchat, Lampang

Leading Thai manufacturer of high firing earthenware, domestic tableware and hotelware (1 tunnel kiln)

### Imperial Pottery Co Ltd, Hangchat, Lampang

Sister company to Quality Ceramic, established in 2001 to produce high firing earthenwares with bone china appearance (1 roller kiln)

### Indra Ceramic Co Ltd, Prabaht Muang, Lampang

Manufacturer of fine stoneware mugs and tableware with an annual capacity of around 6 million pieces. Almost all ware exported. (1 roller kiln)

### Eastern Chinaware Co Ltd, Sampanthawong, Bangkok

Major fine stoneware dinnerware and tableware producer, established in 1974. Exports around the world and ISO 14001 certified since December 2004. (1 roller kiln)

### Thai Ceramic Roof Tile Co Ltd, Nong Khae, Saraburi

Producer of the 100% ceramic EXCELLA lightweight roof tile and a member of the giant Siam Cement Group (1 roller kiln)

### Nahm Sanitaryware Co Ltd, Huaykwang, Bangkok

1 Shuttle Kiln (80m<sup>3</sup>)

Acquired by Villeroy & Boch last year and in the process of doubling capacity from 500,000 pieces to 1 million pieces per year (1 shuttle kiln, 80m<sup>3</sup>)

### Artway Co Ltd, Muang, Samutsakhorn

Established in 1993 as a manufacturer and exporter of stoneware and ceramic products, including bakeware, kitchenware, tabletop accessories and custom made tableware. Manufacturing plant covers over 10 000 m<sup>2</sup> with annual production capacity of 200 containers (40x40 foot). (1 roller kiln for tableware; 2 shuttle kilns for ceramic colours)



Fig. 1 Sanitaryware shuttle kiln (80m<sup>2</sup>, 8 cars)



Fig. 2 100-m sanitaryware tunnel kiln in China

ties. The modern fast firing models offered by Dragon are characterised by very consistent combustion conditions, tight multi-zonal control and high levels of automation. Crucially, if carrying a full load, tunnel kiln fuel consumption, taking the example of a 104-m sanitaryware kiln, is more in the region of 1 200 kcal/kg. The company has a rich history in tunnel kiln technology and numbers companies such as *CUMI, Kütahya Porcelain, Monno Ceramic Industries, Shinepukur, Artisan and Lobnya Sanitaryware* amongst a list of distinguished clients.

## Roller Kilns

Dragon specialises in the medium and large sized roller kilns and these are moderately flexible and usually of medium capital cost. Their major advantage is the combination of extremely consistent combustion conditions, faster firing cycles than alternatives and fuel consumptions which are substantially lower – say, 800 kcal/kg where a full payload is being carried. Specialised units are already playing an important role in the factories of majors such as *Royal Porcelain, Chengteh, and Eastern Chinaware* in Thailand and are soon featuring at *Wade Ceramics* in the UK.

## Dryers & Pre-Heaters

The expertise that Dragon & TC Kilns offers in this part of the production process also often sees the company called upon to design and manufacture other, ancillary pieces of equipment. These have included pre-heaters for the kiln and greenware dryers processing large volumes at low temperatures. Flexibility allied to reliability is the keyword when approaching any of these projects and the company has responded to the necessity to offer different types of systems and a variety of design elements, depending on a number of criteria presented by each customer. When considering pre-heat and drying systems, then clearly there is less clean, useful heated air extractable from shuttle kilns though this doesn't stop side-by-side installations being effective in some instances. However, for tunnel kilns a pre-heater for product and combustion air is highly beneficial; not a massive burden in terms of the overall capital cost and Dragon & TC Kilns has demonstrated impressively short payback periods.

## Different Combustion Systems

**Ratio Firing:** this is where the air and gas supplies are linked so that as one increases or decreases, the other increases or decreases as well. This link can be mechanical or it can use the pressure in the air line to adjust the gas feed to keep the ratio. This system is often used in tunnel kilns where the adjustments are only small.

**Fixed Air Modulating Gas:** this is where the air supply is fixed for sections of the programme and only the gas is regulated to adjust the temperature; in fact the air is set at different levels for different sections of the programme but in any one section it is fixed. This creates a controllable air movement and a fixed input of volume into the kiln keeping firings consistent and pressures easy to control. This has been shown to give the gentlest firing conditions for the products and it is especially effective in Sanitaryware shuttle kilns and tunnel kiln pre-heat zones.

**Pulse Firing:** this is where burners are set to operate in two conditions;

a high fire (where the settings are close to a stoichiometric gas air ratio) and a low fire. The idea is that the burner is switching between high and low for different amounts of time depending on the heat requirement. This can be effective for fuel savings but the additional mechanical movements and the random nature of the control system can make it complicated to operate. Also, some products do not react well to the rapid switching from high heat to low heat inputs.

**Reduction Firing:** this is specifically required in kilns for porcelain where the CO reduction levels need to be tightly controlled to give products the required colours and effects. The systems employed by Dragon & TC Kilns operate automatically with different reduction levels in different zones by using the air flow to control the temperature requirement and then measuring the flow with a digital flow meter. The air flow is then sent to the control PLC which calculates the required volume of gas for that specific zone and the gas flow is adjusted accordingly. This system now allows accurate zone by zone control allowing cycles to be reduced and roller kilns to be used where previously only tunnel kilns were considered. For the shuttle kiln firing of sanitaryware, fixed air modulating gas systems tend to be used. This is the gentlest firing option and with the known, pre-set gas and air volumes it is easier to control pressure. This leads to the best possible temperature uniformity across the kiln and optimum yield levels.

It is possible to use pulse firing in shuttle kiln installations and where it is correctly employed then fuel savings usually result. However, care has to be taken before opting for pulse firing as the large changes in heat input can create thermal stresses and rapid pressure changes, causing problems particularly for sanitaryware items. For the tunnel kiln firing of sanitaryware, there is a combined approach to the combustion system. The tendency is to use fixed air modulating gas for the pre-heat and then ratio firing in the main kiln zones. This brings together the stability and consistency of ratio firing through the main cycle with the flexibility and pressure stability gained in the pre-heat zone. For tunnel fired

cordierite saggars	10-hour cycle, closed	4 052 kcal/kg
cordierite saggars	6-hour cycle, closed	3 867 kcal/kg
SiC kiln furniture	6-hour cycle, open	2 771 kcal/kg

Tab. 1 Special energy consumption of various kiln furniture

6-car	20-hour cycle	2 113 kcal/kg
6-car	Reduce to 16-hour cycle	2 058 kcal/kg
6-car	Reduce to 12-hour cycle	2 003 kcal/kg
Double kiln size to 12-car	12-hour cycle	1 604 kcal/kg
6-car	12-hour, 1 piece extra per m <sup>2</sup>	1 898 kcal/kg
6-car, Tile&Fibre	16-hour cycle	2 451 kcal/kg

**Tab. 2** Effect of shuttle kiln design on energy efficiency

100m long	20-hour cycle	1 361 kcal/kg
100m long	16-hour cycle	1 287 kcal/kg
100m long	12-hour cycle	1 213 kcal/kg
100m long	12-hour, 1 piece extra per m <sup>2</sup>	1 085 kcal/kg
Use Pre-heater	12-hour cycle	1 125 kcal/kg

**Tab. 2** Effect of tunnel kiln design on energy efficiency

products such as porcelain tableware, then it is common to use reduction firing on a fast fire cycle. Naturally, designing the combustion system and configuration is only part of the job – it is also crucial to achieve component performance and reliability. Dragon & TC Kilns uses burners from world leading

companies such as Kromschroder and Eclipse, always choosing the best possible burner set for each particular application TCK also manufacture their own burners which has offered additional flexibility and a more competitive option. A further consideration, which can have a significant impact on fuel



**Fig. 3**  
Open set porcelain  
tunnel kiln. (1400°C  
with reduction, cold  
to cold 6 hours)

consumption and efficiencies, is the kiln's pressure control system. In recent years, Dragon & TC Kilns has given special consideration to these pressure issues and how they affect both kiln performance and uniformity. The systems it now routinely puts in place are particular to the company and they are demonstrating benefits which can't currently be seen elsewhere.

## Tunnel Kiln – Sample Fuel Calculation Report

**105,4 m length, Sanitaryware First Fire, Natural Gas, 67 Cars**

Calculation safety factor	1,05
Kiln car capacity	26,25 pieces
Firing temp	1 250 °C
Ambient temp	20 °C
Furniture firing temp	1 250 °C
Entry temp of ware	20 °C
Number of kiln car	67
Mean entry temp. of car	20 °C
Mean entry temp. of chassis	20 °C
Mean temp. of car at peak	815 °C
Mean temp. of chassis at peak	118 °C
Mass of ware per car	480 kg
Mass of kiln furniture per car	354 kg
Mass of car tops	620 kg
Mass of car chassis	150 kg
Cycle time	12,0 h
(Heating time: 6,2h, soaking time: 1,0h; cooling time: 4,8h)	

### Fuel Consumption

129,04 Therms/h	12903774,59 BTU/h	3 251 959,32 kcal/h
0,88 Therms/pc	88042,81 BTU/pc	22 188,21 kcal/pc
48,15 Therms/ton	2149,48 BTU/lb	1 213,42 kcal/kg

### Thermal Balance

Heat to ware	36,1850 Therms/h
Heat to kiln furniture	24,2604 Therms/h
Heat to car top	27,4630 Therms/h
Heat to car chassis	0,8190 Therms/h
Heat radiated during preheating	11,2416 Therms/h
Heat radiated during cooling	8,7032 Therms/h
Heat radiated during soak	3,6263 Therms/h
Heat recovered from ware, cars & furniture	59,6471 Therms/h
Heat down tunnel	17,8941 Therms/h
Heat recuperated	41,7530 Therms/h
Heat to exhaust	37,9327 Therms/h
Heat to burner air	0,7409 Therms/h

## Kiln Lining

The four main options here, all of which can be supplied, are refractory brick, ceramic fibre, brick with fibre veneer or cordierite tile hot face backed with fibre. In shuttle kilns, an all-fibre lining is commonly used for firings below 1300°C, chiefly because an all-brick lining would waste immense amounts of energy in all the heating/cooling phases and would also be degraded as a result. Above this temperature the construction consists of refractory brick faced with a ceramic fibre for high working temperatures (up to 1 600°C). This fibre costs 10 times the 1 300°C material and so it would clearly not be economical to design all-fibre linings in most cases. The cordierite tile and fibre combination can in certain circumstances prove useful, but one has to take into account the disadvantages associated with this configuration. It results in a hotter roof, one can't see or deal with fibre shrinkage because of the sealed hot face and there may be contamination problems from organics attacking the fibre if left untreated. For these reasons, although it occasionally has its place, tile and fibre lining is not generally the best option.

## Shuttle Kiln – Sample Fuel Calculation Report

65 m<sup>3</sup> sanitaryware kiln (first fire, natural gas, 6 cars x 2 decks)

Calculation safety factor	1,1
Ware factor (1=Fired, 1=Green)	1,1
Number of kiln cars	6
Kiln car capacity (pieces)	81
Mass of ware per car	1 215kg
Mass of kiln furniture per car	1 062kg
Mass of car tops	1 260kg
Mass of car chassis	200kg
Mass of walls	2 880kg
Mass of roof	3 280kg
Mass of frame	2 650kg
Area of each car top	4,7 m <sup>2</sup>
Area of walls	76 m <sup>2</sup>
Area of roof	80 m <sup>2</sup>
Ambient temp.	30 °C
Ware firing temp.	1 220 °C
Furniture firing temp.	1 220 °C
Mean car top temp., peak	796 °C
Mean car chassis temp., peak	116 °C
Mean wall temp. peak	799 °C
Mean roof temp. peak	799 °C
Mean frame temp. peak	78 °C

Firing cycle time			11,75 h
Stage	Duration (h)	Start Temp (°C)	End Temp (°C)
1	2,25	30	530
2	1,00	530	650
3	0,01	650	650
4	1,25	650	1 050
5	1,25	1050	1 220
6	1,00	1220	1 220
7	0,01	1220	1 220
8	1,00	1220	650
9	1,50	650	520
10	1,00	520	350
11	1,48	350	150

### Capacities

Capacity per kiln car	1 215 kg
Kiln capacity	= 81 pieces @ 15 kg/piece 486 pieces/fire = 7 290 kg/fire

### Fuel Consumption

2 003,71 kcal per kg ware
1 069,18 kcal per kg (ware + kiln furniture)

### Kiln Furniture

For the firing of sanitaryware, SiC beams with cordierite batts and props are standard throughout the world as far as modern installations are concerned. For other products, porcelain tableware for example, there remains the choice between ware carried in cordierite saggars or open set on SiC kiln furniture. Some choices will be guided by the specific

types of ware but where cordierite or SiC could equally be used, various factors come into play. With SiC systems, there is a much higher front-end cost. However, set against that, an open set SiC porcelain system can deliver top quality ware with good consistency and optimum fuel efficiencies. As the differences in fuel consumption are dramatic, it is useful to look at a quick example, taking

a typical reduction fired porcelain tableware product: These figures are only indicative, particularly the second one as a six-hour cycle with saggars is not realistic, but they nevertheless demonstrate that on a time-for-time basis SiC open setting uses 28 % less fuel and in an actual operational comparison uses around 32 % less fuel. Crucially, Dragon & TC Kilns possesses the technical expertise and in-plant experience to ensure that this SiC option retains full viability – with the company able to supply very fast firing kilns which effectively is how the greater initial investment is repaid. Once this has been achieved, then the benefits multiply incrementally over the years that follow.

### Fuel Consumption versus Yield

At the heart of correct decision making is a balanced assessment of expected fuel consumption and product yield. In many areas and for many people, fuel consumption is easier to calculate, to control and to monitor. It is also a parameter for which it is simpler to demonstrate improvements.

While clearly fuel consumption is an important factor, it is arguable that product yield is more significant and that an improvement in the kiln yield has a much bigger impact on overall plant performance than does simple fuel consumption. Typically, a 1 % yield improvement is often better than a 5 % fuel saving when assessing a company's total production costs. Taken in isolation, fuel consumption figures won't tell the whole story. Using every available aspect of modern firing technology to achieve temperature uniformity is closer to the mark and will always be part of Dragon & TC Kilns' approach in the feasibility stage and beyond. It is key to delivering optimum product yield, while at the same time of course maximising energy usage in any case. The company's technical team spend a great deal of time assessing customers' current operations, looking at staged goals and methodically working through the options – as a partnership – to finally settle on the correct solution for them. The experience being brought to bear here is vast and the range of options quite complex, certainly too complex to demonstrate easily in a paper such as this. However, the flexibility of approach is evident – one only has to look at

the full set of references around the world across many products – and some simple considerations can help make the point. What effect, for instance, might we expect to see if we make alterations to cycle, to setting or lining?

## Sanitaryware Shuttle Kiln (Fibre Lined)

Here we can see that reducing from 20h down to 16h results in a fuel consumption decrease of 2,6 % but a further cycle reduction to 12h doubles the effect – decreasing fuel consumption by 5,2 %. The 12h cycle is what Dragon & TC Kilns is already achieving and so the benefits are readily quantifiable. Further, we can see that by further optimising the setting and adding one extra piece per square metre the fuel consumption drops even further, by another 5%, while doubling the size of the kiln results in the per kg consumption dropping another 20 %.

Drawbacks associated with cordierite tile and fibre linings, causes fuel consumption to rise signifi-

cantly – by 16% on a like-for-like cycle basis.

## Sanitaryware Tunnel (KilnBrick Lined)

By reducing down from 20h to 16h alone reduces fuel consumption by 5,4 % and by reducing to just 12h reduces it by around 11 % (and achieving in the process something which betters a shuttle kiln by 40 %). With a change to the setting, improving it by one extra piece per square metre, the effect is even more dramatic than in the shuttle kiln, a decrease in fuel consumption of 10,6 %.

Another option we have considered – and it is not unusual for it to be adopted for this reason – is the use of a pre-heated combustion air system. We see in this example how it further reduces fuel consumption by up to 7 %.

To complete the picture in such an exercise we could post theoretical figures for a roller kiln operation, although in practice if we were using sanitaryware it would not for most

pieces be an option. Fuel consumption would be around 917 kcal/kg – and importantly the differential between this and shuttle and tunnel kiln alternatives holds good for other ware for which roller kilns are more the automatic choice. This is an important point because we can see that this represents a 24 % improvement over tunnel kilns and a 54 % improvement over shuttle kilns – taking both of those at their most efficient 12h cycles where roller kilns are usually operated even faster. These and other detailed analyses (Textbox 2 and 3) are merely the start point for the wide attention to detail and close discussions which characterise the company's approach to the complex issue of kiln selection and attendant issues such as combustion systems, construction, linings, kiln furniture materials, pressure control, automaticity, handling and maintenance. Dragon & TC Kilns welcomes the opportunity to make an in-depth assessment – whatever the product, whichever is the best kiln option, wherever it may be.

Dragon