DFID Project R7413:
Mechanisms to Improve Energy Efficiency in Small Industries

Part Four: Improvements

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PART 4: IMPROVEMENTS

PREFACE

The main objectives of the DFID Project R7413 are to promote mechanisms to increase the adoption of energy efficient technologies and practices in the case of one small scale industry sector in India and Ghana. The sector chosen in India is the ceramic sector. The focus of the work has been in one large cluster of ceramic firms in Khurja, India. The process followed in the project has been to:

- map the operational practices in a sample of units and develop working relationships with relevant stakeholders;
- examine existing practices to determine possible improved practices that could be adopted including new technologies in the main energy using parts of the operations, and,
- analyse the extent to which energy efficiency gains can be achieved in a manner that is also financially attractive to the firms.

Finally, the intention of the project is to examine the barriers to the adoption of improved technologies and to suggest specific interventions to reduce the barriers. This is provided that the suggested improvements are found to have a sufficiently high rate of financial return, making them potentially sustainable without subsidies.

This section first offers some analysis of the previous studies undertaken in the Khurja pottery sector. Two different approaches to improve the overall efficiency and the quality of the pottery units in Khurja are discussed and the broad areas for improvement identified. The steps that need to be taken in order to prepare for change are outlined followed by a detailed description of all the recommendations to improve energy efficiency in the Khurja pottery sector.

The work done in India is detailed in the following sections:

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IMPROVEMENTS

The review of earlier studies supported our preliminary hypothesis that there were a number of improvements possible that would improve the efficiency of the firms in Khurja. These provide the potential of improved product quality, lower rejection rates, improved energy and production efficiency, all leading towards greater profitability, competitiveness, increased employment and wages. These have been later supported in the observations made from the field work and analysis of firms in Khurja. But it is important to note that in our work and in any future work that is undertaken in Khurja, or elsewhere, that these studies were insufficient to move forward to an action plan. The studies may well have been appropriate for the circumstances for which they were carried out. But to develop an action plan from out of them is difficult because first, there are many differences in views on specific improvements, their priority for action and the suggested direction. Most of the earlier studies focused on improved operations of the down draft coal fired kilns that had been the main stay of Khurja for the past 50 years. While as we believe that in Khurja these kilns have outlived their usefulness and any improvements that could be carried out will be insufficient to meet the degree of control required to improve product quality, nor can they be improved sufficiently to provide sufficient savings in energy consumption. The disappearance of the coal subsidy had rung the final nail on the coffin of these kilns and the firms were no longer interested in the small improvements possible. As shown in the table on kilns in Khurja, there is a rapid change over to oil-fired shuttle and diesel kilns.

Another major problem of the studies that we have reviewed is that there is an assumption inherent in them that there is one state of the art technology for the firms and all the advice tends to be generic. Any real strategy for change will have to build on the current conditions, knowledge and capacity of the industry, the managers and owners and the work force, and also the existing situation of support services available to the industry in Khurja. A final problem with all the studies, that we also faced, is the fact that for various reasons, largely to do with taxation and legal issues, the firms tend not to report the true details of their operation. This is one reason that the specific energy ratios reported in some of the earlier studies are highly unreliable. So, we started with a period of field work and an initial survey of a sample of firms in Khurja.

In this first survey of the units in Khurja, we focused on getting to know the units and to observe a small number of problem areas, say a dozen, carefully and intensively. These were chosen during the field work, so that this sample could offer the most immediate gains to productivity and efficiency for the firms. And, from that set, we tried to select a smaller subset of options, those which could be undertaken with low to negligible costs, yet offer a high benefit to cost ratio, and also provide a significant enough quantum of gains, (as the total quantity of gains in relation to the costs is also important to the firms to decide whether to pay attention to the recommendations) so as to draw the attention and interest of the firms. We also tried to focus on discrete improvements that can be easily implemented even after our interventions within the current DfID project are finished.

The first observation was that many of the owners, managers and workers are not formally trained in the technical issues relating to the ceramics or combustion processes, though many appeared to be very knowledgeable about existing operating principles and parameters from their experience. In fact among our sample of around 25 managers and owners, only one person has been trained formally in ceramics technology. We also found that the owners were very sceptical that there would be much advantage that can be gained from technological changes. This attitude stemmed from a belief that either they already did the best under the circumstances in which they worked, or sometimes, that while they had heard about, or seen improved machinery and procedures, these were not relevant to their own operations. They felt that any improved machinery and process would cost too much for them to implement in a cost effective manner. They also felt that any improved procedures will not be followed by the work force. And finally, given the poor market conditions, none of these were of much value anyway, as they could not get better price realisation from their efforts.

We did not make any attempt to prove to the firms at the beginning that there could be ways in which their operation could be improved. Hence, instead of engaging in a discussion of other reports and their findings above, we only spent time in observations and discussion in the first round.

This first round survey concluded that there are in fact a large number of improvements that can be made to the operations of the ceramic units. The units suffer from low quality products, high energy use per unit of output, relatively high rejection rates, and often low prices for their output. Unfortunately, some of our findings on improving kiln performance suggest that these are too complicated for the firms to undertake completely on their own and they will need considerable further support. But there are many others that can be carried out by the firms with the support and skills available locally. Some of the more complicated and longer term solutions will require a concerted effort with the help of agencies such as CG&CRI and PCRA.

Approaches

There are two broad approaches to improve the over all efficiency and the quality of the pottery units in Khurja.

One of them is to argue from economic theory that the principles of good kiln design, of material preparation, glazing, and firing are relatively well known. There are firms in India, and certainly in other parts of the world, which are using better kilns and better processes to achieve higher efficiency and quality. Setting up appropriate economic policies, of reduced subsidies, increased competition and the greater play of market forces, will ensure that the firms in Khurja buy the improved technologies or they go out of business. If the firms in Khurja can not compete, then new firms will take their place.

The only difficulty with this approach is that it does not concern itself with the livelihoods of a large number of workers in the small scale sector. Many of the existing technologies, such as imported kilns that are more efficient are also very expensive and beyond the capacity of the current manufacturers in Khurja. It will not be possible for the industry in Khurja to adapt on its own without support. We believe that while this view is based on classical economic theory, any belief that this will ultimately provide other benefits that economic development policy seeks to achieve, such as higher employment, equity, decentralised growth and reduced emissions, ultimately rests on theology that cannot be disproved. The other side of policy variables can be subsidies such as lower taxes, low capital costs, subsidised inputs etc. which can and have provided the basis for the industry in the past but are no longer viable.

The second approach is to combine the increased competition with support to upgrade the skill set and increase the application of knowledge and technologies to the current situation in Khurja so that over time the firms can become more efficient and competitive. The second approach requires that the solutions proposed be tailored to the current needs and the capacities of the existing units while applying the best technical knowledge that is relevant to the current situation.

This approach requires a careful baseline assessment of the existing technologies, and the problems. Then it requires a systems approach to developing a range of solutions and finally, it requires an operations research methodology, of making discrete changes in the operations of the units, recording the gains (and possible and unanticipated problems if any), stabilising the operations at the new and higher level, and then moving on with a new set of changes. All the while the changes must be calibrated to the skills, instruments, and equipment that are available and to their cost effectiveness or the rate of return from the investment.

The recommendations for action can be grouped into several main categories by the nature of actions recommended. The first category is the work required to systematise the information from each unit on key resultant parameters at the present time, and to maintain a record of changes made and the changes observed in the key parameters of output, efficiency and quality.

Areas for Improvement

The broad areas for improvements that are important include the following:

1. Improved specifications, preparations and testing of the clay compositions and possibly glazes.

2. Improved quality of moulds, drying and improving pre-firing inspection to improve quality of green-ware and reduce rejections.

3. Reduction in kiln furniture and the load of material heated in the kiln cars.

4. Improved operations of existing diesel kilns, including monitoring, controls, housekeeping and minimising heat loss.

5. Improving operations of tunnel kilns with installation of additional fans and developing an improved temperature and pressure profile.

6. Improved kiln design (for those who are planning to switch from coal to diesel or gas).

7. Reuse of waste heat.

8. Improved marketing and assistance to increase sales in export markets, if they do improve their quality. This would ensure that the technical improvements are reflected in increased gains and so provide the incentive and motivation.

In this project we have not done any work on item 1, and item 8, due to lack of time and resources. These need to be followed up in any subsequent work in Khurja. Already CG&CRI has a number of suggestions for item 1, and we recommend that they follow a careful and systematic procedure of working with the units who have expressed interest in undertaking improvements by moving in a step by step manner. Some work was done on item 2 but more remains to be done. The main focus of our work has been in areas 3-6, and we also recommend the reuse of waste heat, item 7.

Preparing for Change

Before any significant changes are carried out however, the firms first need to start with some minimum installation of instruments and a recording procedure to fully document the existing situation and to be able to observe the changes that take place with each modification. Without this instrumentation, which is currently lacking in all units, and without a minimum set of operating records, it is difficult to implement the required changes and it is difficult or impossible to be sure of the effects of the changes.

These measures should be seen in a similar light as taking recordings of a person's critical parameters such as heart rate, blood pressure, temperature and so on before starting treatment. These must then be checked along the way as treatment proceeds to see what improvements are being made and reversing or modifying the course when the results are negative.

The following steps were taken with the sample of 12 firms that we worked in the second part of our work in Khurja and will need to be carried out for all firms which wish to undertaken a series of systematic steps:

Getting Organised – Follow-Up Action for Instrumentation and Benchmarking

Establish an accurate method of measuring fuel use, in each firm – if necessary, fit fuel gauges/dipsticks, separate tanks
Measure mass of different pieces produced in each firm
Measure mass of refractory used, in each firm, and hence ware: refractory ratios.
Measure mass of kiln cars in each firm: This has been done for the current generation of kiln cars for tunnel kilns see Table 4.1

Table 4.1: Mass of kiln cars/trolleys

Tunnel kilns – standard for all kilns	
Dimension	5ftX2.5ft
Steel structure	115kg
Wheels	40kg
Fire bricks 3 layers (possible savings exist here – see below)	255kg
Total weight	410kg
Shuttle kilns – varies for all kilns	
Dimensions	6-9ftX4-5.5ft
Weight	750-1600kg

Other Required Measurements

Measure specific gravity (and hence calorific value) of fuel used (this could account for variations of 10%, but may not be important if fuel characteristic is known).
Design product quality, rejection rates and fuel use recording sheets
Train owners/operators in how to use sheets
Trial recording system for one week in each firm, then review and modify sheets/system/training as required
Gather minimum of one week of baseline data for each firm, and analyse data for average SEC and quality level for each firm
Install air and fuel flow meters
Implement changes, one by one, starting with items below. Then monitor impact after each change.

The following benefits are expected from the above metering, benchmarking and record keeping exercise:

- This will allow for better control of energy use, an increased awareness of energy costs, and a greater commitment towards improving the efficiency of energy use.
- Good energy cost information will enable improved manufacturing and commercial decisions. In many cases around the world, improved record keeping, leads to improved management practices which alone can reduce energy use in the range of 10% to 20% without significant capital expenditures.

- Finally, it will allow for rational implementation of cost-effective investments towards measures, which further improve the energy efficiency of the manufacturing processes.

BROAD AREAS FOR IMPROVEMENT

1. Improved specifications, preparations and testing of the clay compositions and possibly glazes

We were unable to undertake any work during the project in the areas below. The recommendations are those developed by CG&CRI. They aim to improve the quality of raw materials and include:

- Testing of each lot/batch of raw materials;
- Use of the same type of blended raw material in production;
- Testing the moisture content of china clay and ball clay;
- Testing particle size and particle size distribution of ground non-plastic materials and clays.

The current situation is that around 25 traders / local suppliers are engaged in meeting the requirements of various raw-materials for the pottery industry at Khurja. These traders/suppliers meet over 80 percent of the aggregate requirements of the raw materials for the Khurja pottery industry. A few large units with relatively better financial resources, procure raw-materials directly from their sources at the of origin like Bikaner/Jaipur in Rajasthan and Ahmedabad and other places in Gujarat. Discussions held with a few local suppliers revealed that:

i. Among various raw-materials used by the pottery industry at Khurja, there is a wide variation in the unit prices of various grades of clay and quartz. For good quality products, the colour of clay should be white and quartz should be ground to a high fineness.

ii. Depending on level of whiteness, the price of clay varies from Rs. 1,200 to over Rs. 3,600 per tonne. It is in the range of Rs. 1,200 to Rs. 1,250 per tonne for Rajasthan clay, and Rs. 2,000 to Rs. 3,600 per tonne for clays from Ahmedabad and other places in Gujarat.

iii. The price of quartz varies from Rs. 1,150 per tonne to Rs. 1,500 per tonne depending upon its fineness (200 to 300 mesh size).

iv. Many of the local pottery units cater to the lower end of the market. Typical sale price for 6 dozen cups is Rs. 100, irrespective of quality. Units engaged in catering to this market often use lowest grade of clay and quartz of 200 mesh fineness

While as units that cater to the export market or to the high-end indigenous markets, use white clays from Gujarat and quartz of 300 mesh fineness.

So it is not an obviously valid suggestion that all units should use the best quality of materials. As in the case of kilns that we discuss later, the possible benefits and costs need to be weighed and the change here also needs to be a step by step change.

We recommend that CG&CRI should work with the KPMA and the firms which joined the second phase of our work in this project to develop testing schemes for the above with the firms. First CG&CRI should carry out these tests free of charge and observe the improvements. Once the value of these are established then CG&CRI can conduct training workshops for other firms charging a fee and should also provide these services to firms for a fee.

2. Improved quality of moulds, drying and improving pre-firing inspection to improve quality of greenware and reduce rejections

2.1 Mould quality

In many cases the moulds being used were cracked and defective. This naturally causes defective pieces to be produced and then either rejected or passed as poorer quality product.

2.2 Pre-firing inspection

It was observed that there was little systematic inspection of the ware before they were fired. Improved inspections will reduce the number of defective pieces that are fired and hence reduce the over all rejection rates.

2.3 Moisture content and water absorption

The greenware should ideally have a moisture content around 2%. A test was performed on a sample of green wares and it was found that the moisture content was highly variable and usually much higher than 2%, see below.

Table 4.2

Firm Reference	Moisture Content in Clay Bodies (%)
A	2.50
B	2.75
C	3.30
D	3.85

Almost all the units except one used ambient conditions to dry the greenware before firing. As this was variable, there is no possibility of obtaining ware with consistent moisture content. Given the large amount of waste heat that is, and will always be, available even after efficiency improvements, some waste heat could be recycled through a room where the ware can be dried to achieve consistent moisture levels. This will reduce the heat required during firing and reduce the rejections during the firing. The cost of this measure is not high however the benefits can not be easily estimated in advance. Once this is put in place, systematic testing of the ware will be able to determine that it is being dried correctly.

Furthermore, the water absorption in fired ware is supposed to be below 1%. The table below shows that some units produce very underfired ware, which is of poor quality, whilst others are over firing and wasting energy.

Table 4.3

Firm Reference	Water Absorption in Fired Ware (%)
A	0.47
B	2.49
C	5.52
D	0.00

There is no solution other than systematic testing of the ware before and after firing and setting the kiln temperature and time to have the products fired correctly. From time to time, the firms can have samples of the ware checked by CG&CRI for moisture content. Again these are all areas that the common services model, if developed by CG&CRI, should allow the firms to obtain the required services at low costs.

3. Reduction in kiln furniture and the load of unproductive material heated in the kiln cars

3.1 Kiln cars

At present the kiln cars used for tunnel kilns are made of a steel frame with three layers of fire bricks. A suggested change would be to modify the design to replace at least two thirds of the refractory bricks with ceramic fibre. A few manufacturers outside Khurja have adopted a similar design.

A local kiln consultant, Mr. Viswanathan, is confident that he could assist Khurja units in the manufacture of a modified trolley using ceramic fibre filling. He needs the bare trolley, refractory bricks, some white heat castable materials and ceramic fibre. He has indicated that his charges for developing a model trolley would be around Rs. 8,000. All materials need to be supplied by the respective pottery manufacturers. According to Mr. Viswanathan, the weight of refractory material and ceramic fibre will work out to about 40 percent of the total weight of material currently being used on the trolley.

Table 4.4: Cars for Tunnel Kilns

	Existing	**Modified**
Steel structure plus wheels	155kg	155kg
Fire bricks, 3 layers	255kg	100kg
Total weight	**410kg (100)**	**255kg (64%)**
Savings in weight		**155 kg (36%)**
Estimated fuel savings		~ 10-15%

3.2 Reduction in the weight of kiln furniture

Following types of kiln furniture are currently being used by Khurja potteries:

- Plates with pillars / posts: made from silicon carbide or corderite mullite

- Saggers: made from fire clay and grog mix

Of the 12 units studied by us in the field survey, 5 units operate shuttle kilns. All these units are currently using plates with pillars or posts as kiln furniture. They use either silicon carbide or corderite mullite plates from well-established manufacturers like Grindwell Norton or Universal Carborundum. The average useful life of a silicon carbide plate is about 400 cycles as compared to about 200 cycles for corderite mullite plates. Price-wise, silicon carbide plates are almost twice as expensive as compared to corderite mullite plates for a given size.

Two units use corderite mullite plates, while the other three units use a combination of silicon carbide and corderite mullite plates. According to Mr. A.K. Gupta of CG&CRI, the heat absorption capacity of silicon carbide plates is almost 20 percent lower than that of corderite mullite plates. Units 24 and 25 use heavier plates 660x690x30 mm in size, whilst all other units use plates 500x400x25-30 mm in sizes.

Data on furniture weight to product weight for the five units covered during the field survey are as follows:

Table 4.5

Unit Reference	Average Furniture Weight/Cycle (kg)	Average Product Weight/Cycle (kg)	Ratio Furniture to Product	Weight of One Plate (kg)	Average Product Load/Plate (kg)
Plates – 500x400x25-30mm					
Unit 23	1,000	1,600	1.60	12.5	7.5
Unit 12	2,100	1,500	1.40	12.0	10.0
Unit 2	2,100	1,500	1.40	14.0	10.0
Plates – 660x690x30mm					
Unit 25	5,400	4,500	1.20	35.5	35.0
Unit 24	5,700	5,000	1.14	35.5	35.0

Our field survey included 8 units equipped with tunnel kilns. Of these kilns only three units (Units 1, 5 and 19) are currently using plates with pillars/posts as kiln furniture; these are all made from corderite mullite. The other five units (units 10, 14, 20, 21 and 22) use saggers which are manufactured captively by each unit from fire clay and grog mix. Data on the furniture weight to product weight for these eight units is as follows:

Table 4.6

Unit Reference	Average Furniture Weight/Trolley (kg)	Average Product Weight/Trolley (kg)	Ratio Furniture to Product	Weight of One Plate or Sagger (kg)	Average Product Load per Plate or Sagger (kg)
Saggars					
Unit 10	252	100	2.5	3.0	1.2
Unit 20	252	100	2.0	3.0	1.2
Unit 21	252	125	2.0	3.0	1.2

Unit 22	288	160	1.8	2.4	1.3
Unit 14	360	360	1.0	9.0	9.0
Plates (corderite mullite)					
Unit 5	216	130	1.70	9.0	6.0
Unit 1	350	105	3.3	7.2	2.6
Unit 19	350	130	2.7	7.2	3.1

The heavier plates can be a distinct requirement in the case of Unit 24 and Unit 25. Ceramics as their loading per plate is quite high (35 kg). In all other cases, it may be possible to decrease the thickness of these plates to 25 mm or even 20 mm, since the product load per plate is quite low. This would correspondingly reduce the weight of kiln furniture and increase the product to furniture ratio. We have advised these units to go in for plates of lower thickness on a trial basis.

The cost of furniture in the case of shuttle kilns is much less as compared to a tunnel kiln on a per kiln basis. In the case of a shuttle kiln, the number of trolleys are 2-4, while in the case of a tunnel kiln, the number of trolleys may be as high as 30-35 per kiln. For that reason, of the 8 units equipped with tunnel kilns in our survey, only 3 units (units 1, 5 and 19) use corderite mullite plates/pillars as kiln furniture. (Note: the per tonne cost of the more expensive kiln furniture is likely to be the same in tunnel and shuttle kilns but as all tunnel kilns in Khurja have a higher capacity than all shuttle kilns the total cost of replacement, or the capital cost, for the tunnel kilns will be higher).

The remaining 5 units use saggers. There does not appear to be much benefit in using the corderite mullite plates in so far as furniture product ratio is concerned. However, use of corderite mullite plates results in the following benefits:

i. Lower heat absorption capacity as compared to saggers;

ii. Better room for circulation of hot gases.

Corderite mullite plates have an average useful life of 200 cycles as against 15-20 cycles in the case of saggers. However, there is vast difference in the cost of these plates as compared to saggers. Corderite mullite plates of 500x400x30 mm thickness cost around Rs. 800 per piece, as against Rs. 15-20 per piece in the case of saggers. However in the ultimate analysis, use of plates would result in significant savings in fuel consumption and improvement in the quality of products.

One unit which shall be referred to as Unit BB has borrowed a few sillimenite plates (more or less similar in characteristics to corderite mullite plates) from CG&CRI. While they normally use saggers as kiln furniture, they have equipped one trolley with these plates on experimental basis. According to their observation, as and when this particular trolley enters the firing zone, the temperature in the firing zone goes up substantially. As a result, they have to adjust the burners suitably, indicating relatively lower fuel consumption. The only explanation for this phenomena is better circulation of hot gases achieved in the case of plates. Use of plates is therefore desirable in place of saggers. However, the cost of plates/trolleys work out to almost Rs. 20,000, i.e., upward of Rs. 6

lakhs for the entire set of trolleys for one tunnel kiln. This cost will have to be evaluated while recommending suitable solutions.

4. Improved operations of existing diesel kilns, including monitoring, controls, housekeeping and minimising heat loss

4.1 Smaller Burners

The fitting of additional, smaller burners and/or replacing some of the present burners in kilns in Khurja with smaller burners will create more even firing temperatures and lower flame levels. This in turn will improve product quality and reduce rejections. (There is no other direct energy efficiency gain).

The rate at which fuel is used is within the range of 5-13 litres/hour. Given the fuel calorific value of 10,000 kcal/kg, the current burner capacity is therefore between 50,000 kcal/hour to 130,000 kcal/ hour. Figures from the burner manufacturer indicate a rate of 4-24 litres of fuel being burnt per hour at 35'' wg for Model 2A; Wesmann, another burner manufacturer has similar figures for its Series 5422.

Typically 2-4 burners per tunnel kiln are used in Khurja and they have a range of 2 to 5.2 therms through put. A similar sized tunnel kiln in the UK would have around 20 smaller burners with 1-1.5 therms throughput; not all of these burners run at full power – only those in the peak firing zone. Thus in theory firms in Khurja could hence replace their current burners with smaller ones or supplement their burners with the smaller burners.

The cost estimate for increasing burners:

Low Cost Estimate	Rs. 48,000 (Rs. 3,000X16)
High Cost Estimate	Rs. 112,000 (Rs. 7,000X16)

However, since the price of burners varies little with size, using an increased number of smaller burners instead of larger burners becomes more expensive.

It is not be possible to do this in retrofit to the kilns in Khurja. This is because there would be no space to fit the burners, which are normally mounted underneath, and fire between the cars.

A combination of smaller and larger burners also makes it more difficult to manage the system without automatic controls; thus additional investments in control equipment would be required.

The fitting of more, smaller burners therefore, is not one of the key measures, as it is actually quite a sophisticated thing to do. This could be explored much later if totally new kiln designs are to be developed in India.

4.2 Replacing existing burners

The industry in Khurja uses locally made burners and copies of US Weisman burners. It was proposed by several people including burner manufacturers that the efficiency could be improved by replacing the existing burners with higher quality burners. However we did not find any evidence that the existing burners were inefficient or that higher priced burners will improve the combustion efficiency significantly.

4.3 Burner Controls

Ideally, oppositely placed burners should have the same amount of excess air; this is required for the desired combination of quality of surface finish and energy efficiency. They should also have the same thermal output, to give even heating of the ware. The thermal output of the burners is adjusted to give the desired peak temperature. This is done by adjusting both the air and fuel supply to maintain the optimum air:fuel mix.

At present, in Khurja the adjustment of the air/fuel mix is done by eye, similar to the way it is done with an oxy-acetylene welding flame – the relative mix of air and fuel can be varied by controlling either the fuel throttle valve, or the air throttle valve, or both. From experience of CERAM in the UK, "Burners set by eye can vary by a considerable margin", that is, burners can vary between each other in terms of both thermal output and excess air. This is shown by the PCRA data which shows that both the flue gas temperatures (indicating flame temperature, which is linked to the air:fuel mix), and the oxygen level (indicating excess air) differ between burners in the same tunnel kiln (see table in the Annex on temperatures in the kilns).

The installation of flow meters – to both the air and fuel supply lines for each burner – would enable feedback to be given on the total amount of fuel going in (which will relate to thermal output), and the relative quantities of fuel and air. The cost of air flow meters is Rs. 2,500 each and fuel flow meters Rs. 4,000, giving a total cost per burner of Rs. 6,500. The setting up will continue to be done manually; automatic controls are not recommended due to their high cost.

If burner graphs are available however for the burners being used, it may not be necessary to fit air flow meters. In this case all that will be required is to take a reading of the pressure drop across the air supply to the burner, with a differential manometer. The airflow can be read off the burner graph for the measured pressure drop.

It was suggested however that the installation of air and fuel flow metres be avoided in favour of having pyrometers at each side of the furnace/kiln chamber to ensure that the temperature on both sides are the same. But we believe that an optical pyrometer can only be used as a guide for balancing opposite burners and is not a reliable way of calibrating the burners to run at stochiometric; flow meters and/or burner graphs are still required to do this accurately.

An alternative to using a pyrometer is to use a thermocouple, which would measure flame temperature. But, as per the pyrometer, this is also unreliable for calibrating the air:fuel mix. This unreliability is due to the fact that the flame moves about due to the air flow in the kiln, so it cannot guarantee that the probe is measuring the hottest part of the flame.

It is recommended that air and fuel flow meters should be fitted, or if burner graphs are available, then these can be used in conjunction with fuel flow meters. These meters, on their own, will be sufficient for accurate setting up of the burners, and for monitoring fuel consumption.

4.4 Savings from reducing excess air

Many past studies have recommended that the amount of excess air over that required for complete combustion was high in the kilns in Khurja. Reduction in this could reduce the heat losses from the excess air supplied for combustion.

There is a problem with the calculated savings due to reducing excess air made by other studies, as this cannot be done theoretically. Several critical parameters affect the calculations of the value of savings that will be effected. First, the calculated saving is affected by the temperature you use for the inlet excess air. PCRA used the ambient temperature of 35°C. However, this is only true for the burner air. The air curtain air will be considerably pre-heated inside the kiln before it reaches the firing zone, and this would make a big difference to the potential savings.

It is difficult to put a precise number on these, for two reasons:

a) it is unclear as to what temperature we should use for the "inlet" temperature for the excess air;

b) the amount of excess air in the kiln will affect product quality, and this to a certain extent varies from kiln to kiln. A common figure for excess air in UK kilns is 30%. In order for all the carbon in the clay to be burnt off there is a minimum amount of excess air that is required for the process and that is at least 10-15% over the 4-5% normally recommended for complete combustion.

But once the kilns are properly set up with the measurement devices, it should be possible to adjust for the excess air, by slowly reducing it until the optimum results are obtained. Our estimates are that different units will show different gains from this measure as there are currently different amounts of excess air.

The highest gains from this could be as much as 14% for some units. But we expect that the actual savings will range from 2% to 10%. (The spreadsheet in Annex 1 shows the range of the possible fuel savings for different temperatures of the excess air – this confirms that the resultant savings are highly sensitive to the value of this variable.)

4.5 Automatic temperature and air fuel controls

In more expensive and imported kilns there are automatic temperature and air fuel controls. These systems automatically adjust the air:fuel mix, and vary thermal input to achieve the desired temperature profile. Such controls are considered to be too expensive for the firms in Khurja.

4.6 Improved House Keeping (of Kilns)

4.6.1 Maintenance of refractory bricks on kiln cars

The maintenance of refractory material on kiln cars is quite poor. The bricks provided along the periphery of the trolley usually tend to chip off as a result of impact between two trolleys during pushing, both inside as well as outside the kiln. The places where the refractory material is chipped provide ready escape routes for hot gases in the kiln. We checked the surface temperature in the under carriage of the trolleys in a few kilns at various locations with the help of instruments available at PCRA. In almost all cases, the under carriage temperature averaged over 200 degrees Celsius, which is quite high. Leakage of hot gases from these spaces created as a result of breakage of refractory bricks appears to be the main reason for high surface temperature at the bottom of the trolleys. This requires proper maintenance and sealing of refractory bricks on the trolleys before these are pushed into the kiln. The possible gain from this measure varies with each unit but is likely to average around 5%. This cost of this measure is negligible since it simply requires better work practices.

4.6.2 Sand seal

Some of the kilns were found to have faulty designs of sand seals (see CERAM report) or in fact no sand seal at all. These are both due to the kiln builder thinking that the reason for the sand seal was solely to protect the undercar from excess heat, without realising that the kiln can operate under negative pressure, causing cold air to be drawn in. Those kilns having faulty sands seals or no sand seal at all need to rectify the problem (details are provided in the CERAM report and were discussed at the workshop held with the manufacturers).

Furthermore, currently most of the units are using grog mixture as sand seal. It is suggested that the use of river sand in preference of grog for this purpose will improve insulation. In a number of kilns the seal was not maintained and this should also be checked periodically.

4.6.3 Wall insulation of kilns

The readings of the outside kiln surface temperature shows that for some units these temperatures are very high. When the kilns are shut down for periodic maintenance, the existing insulation levels and their conditions should be checked. Where the insulation has pulled away leaving gaps this needs to be repaired. (We discuss the insulation levels again in the kiln design, however, in general for all kilns the amount of insulation can be increased and energy losses reduced)

4.6.4 Oil and air filters

The impurities in the fuel and the dust particles in the air tend to leave unburnt deposits on the fired products reducing their quality. This can be solved by the use of filters in the fuel and burner air lines. The cost is approximately Rs. 500 per filter.

4.7 Shuttle Kiln Pressure
In shuttle kilns, many were found to have excessive positive pressure inside the kiln. This can reduce the life of the insulating fibre. In all cases, the required pressure needs to be positive but only by a small amount, i.e. 2-3mm, to eliminate cold air filtration.

4.8 Other
Two suggested steps to improve quality (and also improve energy efficiency by small amounts) would be firstly, in shuttle kilns, on start up, to light the burners on low oil, high air settings and thereby reduce the thermal shock. Secondly, the kilns, both shuttle and tunnel, use a soaking temperature of 1225-1260^{o}C. This could be reduced in small incremental steps, of say 3^{o}C, and the quality of the output monitored. As long as the quality does not deteriorate, the temperature could be reduced until it reaches 1200^{o}C (or when quality is seen to be poorer).

5. & 6. Improved operations of tunnel kilns with installation of additional fans and developing an improved temperature and pressure profile, and Improved kiln design *(for those who are planning to switch from coal to diesel or gas)*

The tunnel kilns are all built to the same basic design. The kilns vary in size and proportion slightly and there are some differences to the exhaust stack, one kiln under construction also has a cooling stack not seen on the others. The differences in design appear to be linked to the builder, there are three kiln builders and there are differences between them. The background to the design is not clear, one of the kiln builders was available at the time of the visit and he was not clear about design as someone else had passed it on.

The kiln builder is just that, a builder, he does not have technical knowledge of the design or theory of operation. Although the basic layout is similar to designs found in Europe or USA there are some fundamental differences. The main difference is around the airflow inside the kiln. In a conventional tunnel kiln the air movement is from exit to entrance, a fan in the exhaust stack is used to pull the gases down the kiln. With ware moving against the airflow the kiln is effectively operating as a counter flow heat exchanger. This means that the exhaust gases from the firing zone are used to preheat the ware before they exit through the exhaust stack.

The waste heat from the cooling stack can be reused as it is clean air, typical uses could be preheat air for the burners or preheat air curtain (instead of blowing in cold air). Note the preheat air curtain is not really an air curtain, in Europe or USA it would be referred to under a variety of names but not curtain. It is used to cause some turbulence to reduce crown drift and help to push hot air down into the load.

The most immediate difference on the kilns in Khurja is the lack of an exhaust fan. The lack of an exhaust fan stems from a misunderstanding of tunnel kiln operation, here it generally believed that the hot gases need to be kept in the main heating zone, instead of being drawn through to the preheat.

The kilns have been built and set up with the belief that the majority of the gases from combustion should be kept in the firing zone, the preheat air curtain is used to restrict the flow of hot gases to the front of the kiln. The cooling curtain is used to provide some cooling, it would appear that a quantity of cooling air is going into the firing zone. There is some flow of gases through the preheat but this is due to pressure from the cooling curtains and velocity from the burners.

The lack of exhaust fan means that exhaust gases are not drawn down through the load and there will be a less efficient use of exhaust gases. An observation that drew attention to the lack of hot gases being pulled through the preheat is the exhaust gas temperature, most of the kilns had exhaust flue around ambient temperature, some were around 50-60^{o}C in a more conventional kiln it would be usual to see this temperature well in excess of 100^{o}C.

The present set up can lead to a less than desirable temperature profile, the preheat section of the kiln may stay at quite low temperature ~300-350^{o}C where it may be more desirable to have a temperature of ~500-600^{o}C. This would allow more heat work to be done through the preheat section giving better temperature distribution and possibility of reducing peak temperature slightly. After the exhaust blower is installed there could also be an additional contravec (air curtain) at the entrance to the kiln, to prevent the hot air escaping from kiln entrance.

5.1 Fit exhaust blower

This will give more control over the pressure profile of the kiln, i.e. negative pressure upstream of main firing zone, which will allow hot gases to be drawn upstream to preheat load – so the kiln acts more like a contra-flow heat exchanger (the most efficient form of heat exchange). For a 5-7.5 horsepower motor the cost would be Rs. 15,000-20,000. It must be noted however, that an exhaust blower increases energy consumption which must therefore be recovered from improved energy efficiency and product quality. These costs will need to be checked against the potential gain.

5 hp motor = 5 X 0.746KW = 3.75 KW increase in demand

Additional energy cost for the fan:

3.75 X 24 hours X 300 days = 27,000 KW hr

At an average rate of Rs. 3 per unit = Rs. 81,000 per year.

But, in many firms, by having separate blowers for burners (addressed below), and air curtains, the existing fan to supply burner air can be reduced and this can reduce electricity consumption, which will offset extra demand of the new fans.

Note that standby generators must be checked to ensure that they can handle the increased load.

5.2 Separate the air supply to the burners, from that to the air curtains

Separating the air supply to the burners from that to the air curtains necessitates having a separate blower for the burners. An independent air supply to the air curtains will give more stability to the pressure profile in the kiln – at present, any alteration to the air supply to burners affects the supply to air curtains.

From our calculations (and from the TERI report, p.83) burner air only makes up about 20-30% of the total air currently going into the kilns (to supply air curtains and burners), as measured by PCRA. As TERI points out, at present all of this air is having to be raised to a pressure high enough to meet the requirements of the burners (which, according to Viswanathan is at least 20" w.g.), whereas, according to TERI, air curtains require only about 8" w.g.

The current range of motor sizes used for the blowers is from 5 (for 5 firms) 7.5 for one, and 10 h.p. for one. Therefore, the size of motor needed to supply air to burner will only need to be 20-30% of this (less, in fact, as duct losses will be reduced as well), therefore from 1 to 3 h.p.

From looking at ENCON catalogue, their smallest medium pressure is 3h.p which will supply 300 cfm, at a pressure of 28" w.g. – this would be ample for the tunnel kilns at Khurja. The amount of burner air is in the range of 150-200 cfm. So, if a smaller unit were available, say 2 h.p. then this would suffice.

Therefore we would agree with TERI that electricity consumption here can be reduced by having two separate, smaller blowers, rather than the current arrangement of a single blower which is supplying both the air curtains and burners. The smaller size of the blowers (reduced from about 5h.p. to between 1-3h.p.) would offset the increased electricity consumption of having a motor for the exhaust fan.

5.3 Re-shaping of the roof in main firing zone

Re-shaping of the roof in the main firing zone will ensure there is a smooth transition from the firing zone to the pre-heat zone to prevent turbulence – this will allow hot gases to move upstream more easily. This has been done at one pottery and reported in case AA, in the previous section. The cost was negligible and the benefits are not of an amount that can be quantified.

5.4 Sand seal

As mentioned above kilns which have faulty sand seal designs or no sand seal at all should rectify this problem. Also all firms using grog mixutre as the sand seal should switch to river sand as this will improve insulation.

5.5 Waste heat offtake

Another important change that would increase energy efficiency would be to add a waste heat offtake downstream of the main firing zone, so that this waste heat can be reycled to preheat curtains and/or supply preheated air for the burners (or supply to a drying chamber). This is not very expensive and the costs could be recovered in energy savings in 15-20 months.

7 Reuse of waste heat

The various ways of reusing waste heat have all been mentioned at several places and thus will only be listed here:

- use of waste heat from the cooling stack, which is clean air, to preheat air for burners or preheat the air curtain;
- addition of a waste heat offtake system;
- recycling of waste heat to dry the greenware.

Safety systems

The more expensive and imported kilns have a safety system that is not used in Khurja. This is an automatic system that turns the fuel supply off if there is no flame. Safety systems are arguably more important for shuttle kilns, as they are continually being started up.

The key risk is if the fuel is left on but someone forgets to light it, there could be an explosion. To prevent this, just as with domestic ovens, there is a flame failure monitor usually fitted. This is a thermocouple device, linked to an electrical actuator that controls the fuel supply valve – if no lighting flame (or pilot light) is detected, then fuel supply shuts off. This is fail-safe, in that the fuel supply valve will always fall shut if the power supply fails. As long as there is a good procedure for lighting up kilns and monitoring them in Khurja, then this safety system is probably not required.

We wondered whether there were many close escapes, or even accidents, in Khurja. In enquiries with the manufacturers, related institutions, and from medical practitioners, the unanimous response has been that there has been no such accident. Thus the current experience suggests that this is not a high priority change for the moment. But if and when the units do change to gas, this will be important. And, even as more units change over to oil from coal, the likelihood of an accident taking place increases. This is simply a function of the increase in number of units, the number of people involved, and over time a greater sense of complacency develops. This needs to be reviewed by the firms over time.

Reduction of Rejects

Ceramic ware is a high value added product and thus keeping rejects to a minimum is important. Rejects after firing cannot be recovered and result in the total loss of the entirety of the valuable energy expended on the product during the various stages of the production process. Tunnel and shuttle kilns have lower rejection rates at around 10% in Khurja, much lower than downdraft kilns, where rejection rates up to 25% were found as mentioned above. In Khurja though there has been apparent gain in the reduction of total rejections with the change from down draft coal fired kilns, the existing rejection rates are at around 10%, and the production of third and second grade qualities are all unacceptably high.

Controlling the quality of final product is ultimately dependent on the control of the entire production process. This begins with the raw material composition, preparation, moulding and ware handling systems, moisture levels and also the kiln performance, or all the items 1-7. So while our recommendations focus on the kilns we wish to emphasise that this is a process and all aspects of it need to be taken into account. When the processes are improved the rejection rates should drop by at least half from the current figures of around 10%.

SUMMARY OF RECOMMENDATIONS

Below are some of the key points of the current findings. From the recent analysis of kiln operations we have the following universe for which we have information:

Table 4.7

Studied 12 existing firms and kilns in total	
7	Tunnel kilns
5	Shuttle kilns
And, advised on	
1	New tunnel kiln under construction

The summary of the observations, data and readings for individual units, specific results and findings are in the reports of CERAM and PCRA. These have been given to KPMA for the units to make changes and improvements that are suggested.

Below we place a summary of some overall figures for the 12 firms.

Table 4.8

	Tunnel Kilns (7)	Shuttle Kilns (5)
Total through put	2.5 to 4.0t/day	1.5 mainly; 4.5 and 5 t/day
Burners	2-4	4-6
Fuel	115-288 l/t Representative range is 170-200 l/t of ware	224-500l/t
Annual Fuel	200KL (approx.)	125 KL
Fuel Price	11-18 Rs./litre	11-18 Rs./litre
Fuel Cost per year	Rs.30 lakhs (3,000,000)	Rs.15 lakhs (1,500,000)
Value of upper bound on fuel savings at 50%	Rs.15 lakhs/year	Rs.8 lakhs/year
Investment range with one year pay back	Rs.15 lakhs	Rs.8 lakhs
Do, with 2 year pay back	Rs.30 lakhs	Rs.15 lakhs

We have a number of recommendations to improve the energy efficiency of the kilns, by improving combustion efficiency, air circulation, and reduced losses of various types. Of these, some can be immediate, then some medium term and others longer term. We also have others, which improve the efficiency, by increasing the ratio of useful products to non-useful weight, such as cars, saggars, and so on.

We also have recommendations for improving the ratio of good quality products and reducing post firing rejections and lower grade products. The rejection rates are on the average around 10%.

All the 20 recommendations regarding energy used in firing are summarised below in two tables. These follow after the implementations listed in the benchmarking section. Below in Table 4.9 we list some of the simpler changes that will not require the presence of a kiln expert to implement. Then in Table 4.11 we list those improvements which are a little more complicated and will require the availability of a kiln expert to provide adequate support. Ideally, beginning an implementation program will require careful design and continued support at the local level in Khurja at the level at which it was provided during the diagnostic phase of this work.

Table 4.9

No.	*Description*	*Item*	*Rough estimate of possible contribution*
1.	Burner efficiency	Check high efficiency burner	0 to 2%
2.	Fit air and oil filters		Improve product quality
3.	Minimise excess air level	Fit air and fuel flow meters for each burner. Minimum oxygen level needed for finish and to ensure carbon burn off	7.5%
4.	Equalise burner energy output		Improved product
6.	Lower temperature in steps to 1200 and increase time		5%
7.	Increase drying and reduce moisture below 2%	Test moisture content	Reduce cracks, rejects, some fuel saving
8.	Under car seals	Check and fix	0-5%
9.	Sand seals	Correct and use river sand instead of grog	

10.	Explore with one or few redesigned kiln car	Design specified	10%
11.	Explore with lower weight kiln furniture, purchase from market	Needs preliminary costing	10%
12.	Light burners on low oil, high air settings (shuttle kilns only)	Reduce thermal shock	Reduction in rejects
13.	Reduce kiln pressure (shuttle kiln) need 2-3 mm positive pressure, to eliminate cold air infiltration.		Increase life of fibre lining.

If the above estimates are correct we get up to a 25 to 45% reduction in energy consumption.

Then we should start with the changes to the tunnel kilns to get them to operate more closely to the principles of tunnel kilns in terms of pressure, temperature profile and preheating. And, examine the best means of using the waste heat in both tunnel and shuttle kilns.

Table 4.10

No.	*Description*	*Item*	*Rough estimate of possible contribution*
14.	Fit pitot tubes (tunnel kilns)	Get pressure profile	
15.	Exhaust Fan/blower (tunnel kilns)		Maintain better temperature and pressure profile; 5 to 10% gains
16.	Fan for air curtains (tunnel kilns)		
17.	Reshape combustion chamber (tunnel kilns)		At time of renovations
18.	Calculate optimal insulation		At renovation and for new tunnels
19.	Cooling air fan (tunnel kilns)	Size and cost	
20.	Recirculate cooling air to burner air supply and/or air curtains (tunnel and shuttle kilns)	Size and cost	10%

Hopefully this will bring the consumption down by another 10-20%.

Annex 1

ANNEX 2:

Measurements Needed and Design Tips to Implement Phase 2 Modifications

The bare minimum of measurements needed for setting up and optimising performance of kiln for are as follows:

i) Fit oil and air flow meters (or use burner graph for air flow) – this will allow burners to be accurately adjusted to stochiometric ratio.

This ratio is 11.9 m^3 of air for 1 kg of fuel oil (at specific gravity of 0.84). So, from readings on flow gauge, for each burner, if oil line says 10 LPH (litres per hour), air guage should say 100m^3/hr of air. (note – this may not necessarily lead to any fuel savings, as the excess air may not be coming in via the burners).

ii) Measure pressure profile – this will be needed to adjust the damping of the exhaust fan, once it has been installed. Need to measure profile before and after.

The sizing of the exhaust fan can be estimated from adding 50% to size of existing blower – however, it would be more accurate to carry out an air flow balance (see below). The pressure profile will also be very useful when a separate air supply to air curtains is installed, as this will also affect pressure profile. More information on how to measure the pressure profile is given below.

Measure temperature profile, including measurement of peak temperature – this has already been done, and the tunnel kilns already have the necessary thermocouples in place. (See table of temperature profiles in Annex)

iii) Once burners have been set up properly, and the air supply to the curtains has been separated from the burners, then it would be useful to measure the excess O2 level in the burner flue gas. As the burners are set to stochio, then all of the excess air must be coming from either the air curtains, or the exit and inlet to kiln. It will be possible to reduce this excess air level, by either increasing the damping on the exhaust fan, and/or increasing damping on air curtain supply. But there will be a minimum amount of excess air required for the desired quality of finish on the product – this will need to be arrived at by trial and error.

Measuring the O2 level will require the use of a flue gas analyser. His wil need to be a common property as it is not required all the time and could be organised by CG&CRI or KPMA.

iv) Air flow balance – this should be carried out when making any major change to the kiln. It is basically a measure of all of the air coming into the kiln, and exiting the kiln. How to do this is described in more detail below.

The measurements of pressure profile and air flow balance are measurements that should be made any time that major changes are made to the kiln (e.g. introducing exhaust fan, separating supply to air curtains and burners).

When only minor changes are made to the kiln, such as changing burner settings to fire a different product, then it is enough just to measure pressure profile, to check it is still correct. However – it is one thing to take these readings, it is another to have someone who can interpret them correctly. Experienced technical people are required to make use of these readings.

The following measurements are optional, and serve as double-checks for some of the above:

v) Measure temperature in stack – this is a further indication of whether the air flow pattern within the kiln is close to optimum or not. The temperature in the stack indicates how heat is being pulled back through the kiln to pre-heat the unfired ware. Thermocouples would need to be fitted in the stacks to do this.

vi) Measuring CO2 can be used in place of measuring O2 – but there is no need to measure both.

vii) Measuring CO gives an indication of whether the air: fuel mixture to the burner is running rich or not – the richer the mix (i.e. the higher the ratio of fuel to air), then the more unburnt carbon there will be in the form of CO. But if flow meters have been fitted, then it should be possible to check the mixture from the flow readings.

viii) Measuring flue gas temperature at exit from heating zone – this would provide a way of monitoring over time whether opposite burners were balanced or not – if they went out of balance, then this would suggest that the air:fuel ratio for the burners had moved away from the optimum, and needs to be re-adjusted. However, if air and fuel meters are fitted then this is not necessary – reference can be made to the meters alone.

Carrying out an air flow balance

This should not be carried out until the air flow meter has been fitted to the burner. Once this has been done, then it will be possible to calculate the amount of air going to the air curtains, by subtracting the burner air from the total air measured going into the blower.

At present, with the current configuration of tunnel kilns at Khurja, air is entering the kiln primarily from 2 places.

1. Kiln entrance and exit
2. The blower (which is supplying both the burner and the air curtains, with the current arrangement)

There may also be some air leakage.

Air is exiting the kiln through the exhaust stack, and the burner flues.

The ideal air flow balance will look at the flow to each air curtain separately.

The air going in via the blower can be measured using a propellor type anemometer. PCRA have already taken these readings for the kilns studied.

Assuming the air supply to burner is known, from flow meter, the most important things to measure are as follows:

i) Air flow in manifolds supplying air curtain – should take pitot tube reading in positions shown below

ii) Anemometer for measuring air input to blower (which currently supplies both burners and air curtains)

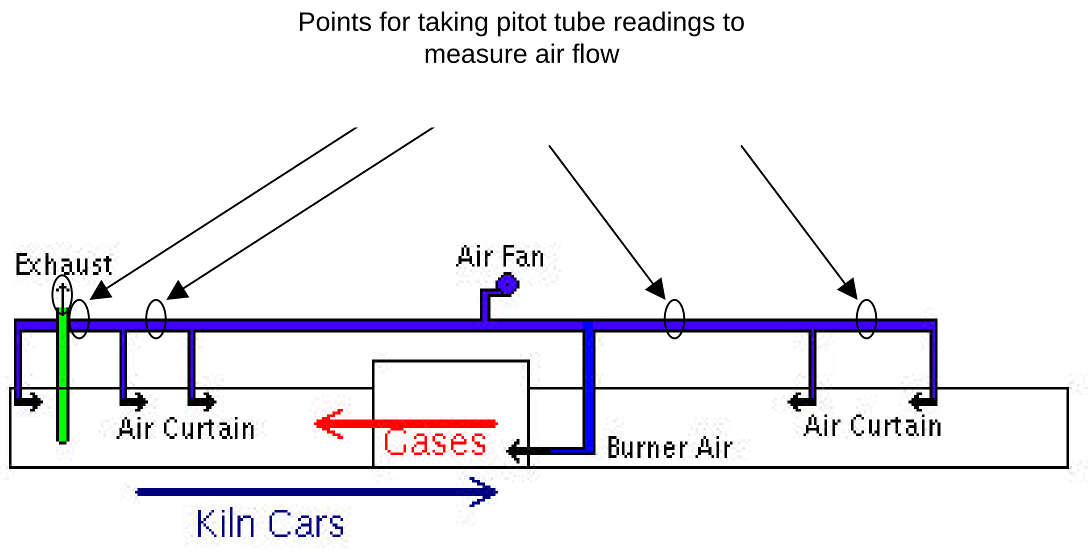
iii) Air flow in exhaust stack using pitot tube

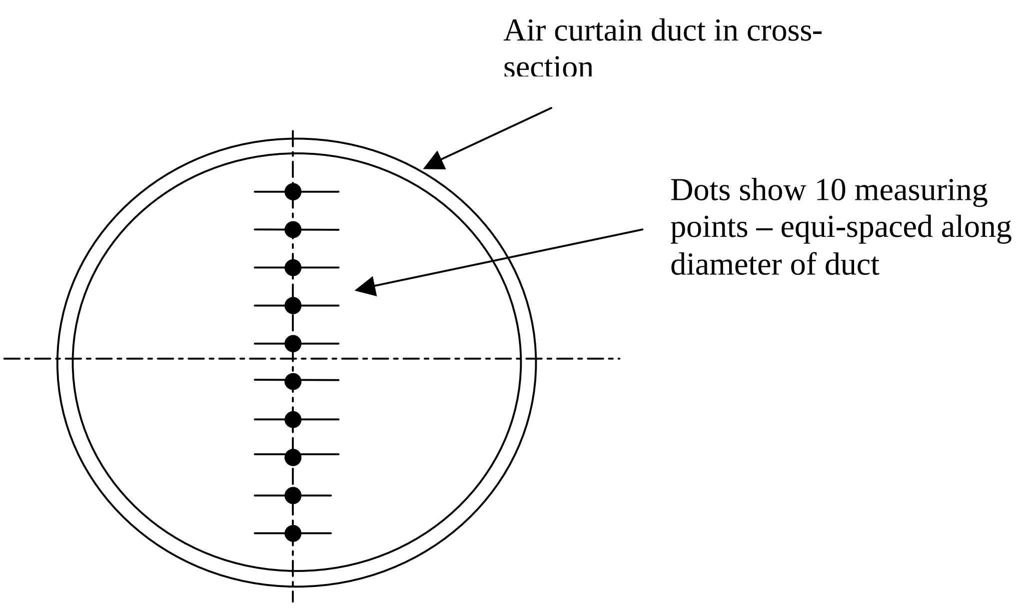
The air flow in the burner flues can be calculated, if the excess air value is known (as PCRA have done in their report), so it is not necessary to measure this.

Measuring the air flow into exit and entrance is less important and more difficult to do, as the flow velocity is so low, and need to calculate/estimate the flow area – it's worth trying to do though, with the anemometer.

For the pitot tube measurements, about 10 readings should be taken across the diameter of the duct – it's enough to just do one axis (as shown below). This should be done 3 times to get an average. The type of pitot tube to use is the one that also has a static tapping as well – then the differential manometer (preferably digital as easier to use) can be used to measure the difference between the two (a local expert/ supplier should be familiar with all this).

Sketch showing positions for pitot tube readings





Note: pitot tube to point **into** direction of oncoming flow

Determining pressure profile

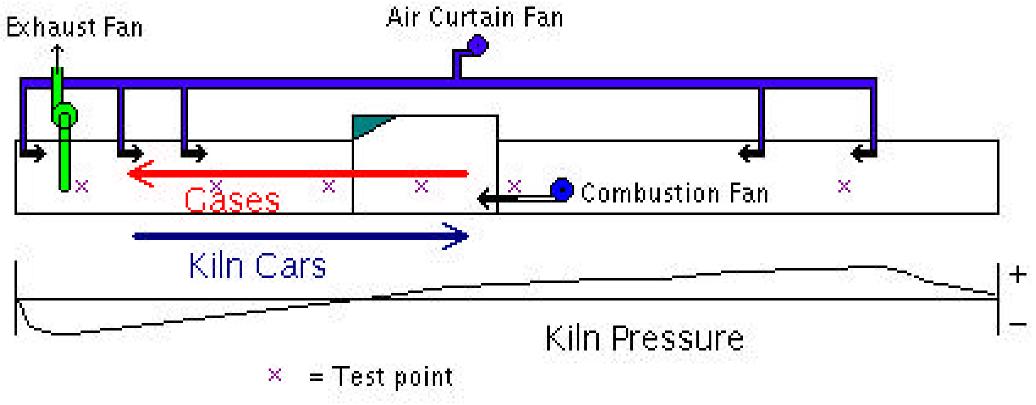
The pressure profile in the preheat zone should be negative, to draw back hot gases from the firing zone, and positive in the post firing zone, for the same reason.

The correct pressure profile is one where there is neutral (zero relative to atmosphere) pressure at the entrance to the main firing zone. This is more important than the absolute values of positive and negative pressure.

To give an idea of the range of pressures, Carl suggests a positive pressure limit of 2-3mm of water to avoid causing damage to the undercar. Too high a negative pressure will draw in too much cold air to the entrance of the kiln. The maximum negative pressure achievable will be determined by the size of the exhaust blower.

The pressure profile is determined by taking static pressure tappings at various points along the length of the kiln – suggested tapping points are shown below:

Sketch showing position of test points for measuring pressure profile in kiln:



To do this, need to drill hole in side of kiln wall, and insert a tube, about 10mm internal diameter. The tube should be ceramic, ideally, if permanent, otherwise it can be stainless steel, if temporary. The tube should protrude about 2" into the kiln from the inside wall – as shown in sketch below. The tube is then connected to a manometer by a rubber hose, and readings taken. The tube can be blocked up with fibre afterwards.

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