# Low thermal mass furnace linings

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## Introduction

Originally heat treatment furnaces were lined with dense fireclay bricks with insulating materials as a backing. Since the development of hot face insulating firebricks in the 1930's, most heat treatment furnaces have been lined with this material to take advantage of its lighter weight, lower heat storage and lower thermal conductivity. Over the last ten years or so, ceramic fibres, mainly in the form of blankets, have become increasingly used as heat treatment furnace linings. Ceramic fibres have even lower densities, heat storage and thermal conductivity than insulating fibrebricks. Refer to Appendix 2.

Ceramic fibre is made by blowing molten naturally occurring alumina silicate clays or synthetic alumina/silica mixes. The fibres can be formed into many different products, the most important one for furnace linings being blankets. Alumina silicate fibre for maximum use temperatures of 1260°C and 1400°C and a pure alumina one for 1600°C can be produced. These blankets retain their resiliency throughout most of their thickness when exposed to these maximum usage temperatures. They are formed in thicknesses from 6mm to 50mm, 610mm or 1220mm wide and 7,3m long. The density of blankets ranges from 48kg/m³ up to 160kg/m³ with the most

*This Paper deals with the progression of furnace linings from firebricks through insulation bricks to ceramic fibre. The light weight of ceramic fibres and the resulting advantages in thermal conductivity, thermal storage, ease of installation and reduced structural loading is discussed. Ceramic fibres have other major advantages; for example, they do not suffer from thermal shock, exhibit no thermal expansion, are flexible and resilient and resistant to most acid and alkali attack. These are some of the reasons why ceramic fibres are replacing conventional refractories in heat treatment and reheating furnace linings.*

*The use of veneer linings, i.e. ceramic fibre attached to existing refractory furnace linings, is also discussed.*

*The results of using either full ceramic fibre or veneer linings are fuel savings of between 10% and 50% and in intermittent furnaces, faster heating up and cooling down of the furnace. The paper illustrates these results with typical actual case histories.*

popular one for furnace linings being 128kg/m$^3$. Unlike conventional refractories where thermal conductivity increases with density, the 'k' value of ceramic fibres decreases with density up to a density of about 300kg/m$^3$. See Appendix 1.

## Advantages of using ceramic fibre

The low density of the ceramic fibre blanket, either directly or indirectly, gives it many advantages over conventional solid refractories. The lighter weight of the lining allows a reduction in the structural steel normally used to support furnace linings. Since the amount of heat stored in a heated lining is a function of specific heat multiplied by mass, the use of the lightweight ceramic fibre reduces the heat storage of the lining considerably. Refer to Appendix 2.

Besides reducing the amount of fuel required to fire the furnace, the lower heat storage means that the furnace can be brought up to temperature faster and cooled faster. This allows faster cycling and quicker access to the furnace if it must be cooled down for repairs.

The very low thermal conductivity of this lightweight ceramic fibre allows a lining to be more thermally efficient or, more commonly, allows a thin fibre lining to achieve the same casing temperature and heat flow as a thicker insulating firebrick lining. Refer to Appendix 2. The fibre lining not only weighs less per cubic metre of lining but it is also thinner, requires less floor space and allows an even greater saving in structural steel.

The ceramic fibre blanket lining is very easily installed by plant personnel. The installation requires no special skills except in the welding of the anchor system. The blanket is easily cut with a knife to the correct configuration to fit into complicated areas. The flexibility of this product allows it to fit over curved surfaces, extend around corners or cover odd shaped protrusions into the furnace. Since any expansion of the individual fibres is taken up within the blanket stucture, expansion joints are not required with ceramic fibre linings.

Both during and after construction, the flexibility and resiliency of the ceramic fibre allows it to withstand bending, flexure or indirect mechanical shock such as a blow to the steel casing. This ability makes ceramic fibre an ideal lining material for furnaces which are fabricated at one location and shipped to another site before being used or furnaces which are designed to be moved to facilitate loading and unloading. This latter movement may be horizontal, the furnace running on tracks, or vertical, the furnace or cover being lifted.

Special cold weather precautions, conditioning procedures and start-up schedules which are required with brick and castable linings are not necessary for furnaces lined with ceramic fibre. The furnace can be fired as soon as the last blanket is installed or delay in firing can be as long as necessary without affecting the ceramic fibre lining.

When the furnace is fired, it may be raised in temperature, as far as the fibre lining is concerned, as fast as the burner system will allow since the ceramic fibre is not subject to thermal shock. In any cycling furnace the resistance to thermal shock and the low heat storage, which means less heat going into the lining each cycle, are quite probably the most important qualities of the ceramic fibre linings.

Without doubt, ceramic fibre materials for lining furnaces are much more adaptable than the now out-dated alternatives of solid refractories. What other refractory material can you cut with a knife ? or bend round corners ? These advantages, of course, make the design of the furnace lining much easier as no special shapes or complicated anchor designs are required.

Ceramic fibres are unaffected by most acids and alkalis which is an advantage when dealing with special atmosphere furnaces or furnaces fired on fuel which contains a high sulphur content.

The advantages of using ceramic fibres in furnace linings from the point of view of the furnace designer, the lining installer and the furnace user may be summarised as below in Table I.

TABLE—I

| Feature | User | Installer | Designer |
|---|---|---|---|
| Resilient. | No damage in use. | Easy installation. | Simpler designs Lighter structures. |
| No thermal expansion. | Reduction in repairs. | Quicker installation. | Simpler designs. Lighter structures. |
| Very low thermal conductivity. | More efficient energy use and higher productivity. | | Smaller furnaces. |
| Low weight (heat storage). | Easier handling. Reduced fuel bills. Increased productivity. | Easier installation. | Light structures with reduction in support structure. |
| No thermal shock. | Quicker cycling· fewer repairs. Longer life. | | Simpler control systems. |
| Good resistance to mechanical shock. | Fewer repairs. Longer life. | Less materials wastage. | Simpler designs. |
| Excellent chemical stability. | Fewer repairs. Longer life. | | Simpler designs. |

## Limitations to the use of Ceramic Fibres

As mentioned previously, the ceramic fibre can take indirect mechanical shock and vibration but it cannot withstand direct mechanical damage. Continuous scraping across the surface of the blanket, which could result in the fibre being abraded away, may be handled by covering the surface of the blanket with a woven wire mesh or expanded metal lath of a suitable alloy. A heavy blow hitting directly on the surface of any type of lining material would probably cause damage; however, the fibre lining shows an advantage here as it can be quickly cooled down and is more easily repaired than other linings when such damage occurs.

It is difficult to measure velocities of gases moving into or across furnace linings and for this reason it is not easy to define the velocity limitations for the use of ceramic fibre blanket linings. Where velocities are known to exceed 15m per second and turbulence may be expected, some form of surface protection is normally used. The woven wire mesh covering will handle many low temperature marginal velocity conditions, while an expanded metal lath with the diagonals oriented to direct the flow away from the blanket face may be required for more severe velocities at low temperatures. More commonly, the banket is rigidised by the use of a colloidal silica solution. For higher temperatures, the vacuum formed board or wet felt may have to be used. The hardened forms naturally lose the flexibility and resiliency of the soft blanket and should not be used unless required.

For directional gas flow with moderate velocities which are not of the magnitude to tear the blanket surface but could cause joint disruption, the hot face layer or exposed blanket is placed in an overlapping pattern to prevent any butt edges from being fluffed up by the velocity. See Appendix 3.

Reducing atmospheres may or may not be a problem depending on the temperature, the make-up of the atmosphere and the percentage of hydrogen and carbon monoxide present. Using the high duty 1400 fibre blanket can eliminate most of the reducible oxides present in the lining material and is, therefore, suitable for reducing atmospheres. Carbon monoxide has a thermal conductivity similar to that of air and should not noticeably affect the thermal conductivity of the lining. Hydrogen has a much higher thermal conductivity and can considerably raise the thermal conductivity of any refractory. The amount of increase in thermal conductivity is directly proportional to the percentage of hydrogen in the atmosphere and inversely proportional to the density of the lining material. Therefore, the increase in a low density ceramic fibre lining is much greater than the increase in a higher density insulating firebrick lining. This makes the use of ceramic fibre blanket linings in atmospheres containing high percentages of hydrogen open to question. This does not apply to furnaces such as coil annealing furnaces where the atmosphere is contained within an inner shell and does not come into contact with the lining.

## Typical lining arrangement

Most fibre linings are not made up entirely of ceramic fibre blanket. A less expensive form of insulation is normally used behind the ceramic fibre blanket to reduce the cost of the lining. The most common form taken by these linings is, starting from the hot face, one or more layers of ceramic fibre banket backed up with mineral wool block insulation or, more commonly now, ceramic fibre L. T. blanket suitable for a temperature of 950°C. See Appendix 4. The lining is attached to a steel shell or casing by a metal anchor system. The mineral wool block may be replaced by mineral wool blanket in areas involving sharp directional changes or curvatures. Linings should be designed so that the interface temperature does not exceed the working temperature of the mineral wool or L. T. blanket. The joints in successive layers of blanket should be staggered to prevent radiant heat from having a direct path to the backing lining in case any of the joints open.

For furnaces in which the atmospheres may be harmful to mineral wool ( e.g. sulphurous ), but not to ceramic fibre, the back-up material should be lower density ceramic fibre blanket or L. T. blanket. The lower density blanket should not be used as the hot face or exposed blanket but it is more economical than the 128kg/m$^3$ density blanket for back-up layers.

The normally accepted use limit of the ceramic fibre blanket is 1260°C or 1400°C in the case of high duty fibre but the metal stud system used to anchor the fibre must be selected with working temperature in mind. Inconel 601 steel is required for anchors at the highest temperatures. Any corrosive contaminants in the operation should be considered while selecting anchoring materials.

## Anchoring

The most common anchoring system for ceramic fibre blanket linings uses a metal stud of the proper alloy which is attached to the metal casing by either stud gun welding or hand welding. The lining materials are impaled over this stud and a retaining device is attached to hold the lining materials tightly against the casing. The retaining device is normally a washer which fits over the stud and is held in place either by a nut, in which case the stud must be threaded ( see Appendix 5), or by the washer and stud being designed to have the washer twisted to fit into a locking notch in the stud (see Appendix 6). In the latter case, the stud is generally rectangular instead of round in cross section and the washer has the sides bent upward to facilitate the twisting required.

The locking washer system requires much less time to install than the threaded stud system since placing the locking washer over the stud and twisting it to lock is much faster than screwing a nut onto a threaded stud. However, the washer can only be locked at predetermined locations normally in $\frac{1}{2}$" increments along the length of the stud while the nut and washer can be placed at any depth along the threaded stud. The locking washer system also requires some compression of the ceramic fibre blanket so it cannot be used if the lining consists of only block or board form of material.

Since these anchors are welded to the casing before the lining materials are placed, an anchor location pattern must be laid out on the casing based upon the width of the blanket to be used and the orientation of the blanket placement. The anchor pattern should be based upon compressing the blankets together at the joints to ensure a good tight fit. Therefore, 610mm wide blanket should be assumed to cover only 600mm. The stud location layout should be based upon the exposed or hot face layer of blanket and the joints in any back-up layers of blanket should be offset. Refer to Appendix 3 and see Appendix 7.

After the stud layout is marked on the casing, the location of each stud can be checked and the casing cleaned of grease, rust, etc. where required before the welding of the studs is started.

In difficult atmosphere furnaces or at temperatures too high for the metal from which the anchors are made, patches of blanket may be placed over the end of the stud or a ceramic anchor ( e. g. cuplock ) used. See Appendix 8.

### Veneer Linings

In many cases, existing brick linings in furnaces are in good condition and it is not considered economic to take out the lining to replace it with complete low thermal mass ceramic fibre linings. It is still possible; however, to save fuel and time by placing ceramic fibre in blanket form or stack bonded module form on top of the existing refractory. Blankets are placed using studs driven into the existirg refractory, and stack bonded modules by sticking with cement.

Let us consider the veneering of an existing brick lined furnace with a thin layer of ceramic fibre. Because of its low thermal mass and its low thermal conductivity, the installation of a ceramic fibre veneer offers three main benefits to the furnace operator.

1. By restricting the heat flow and reducing the actual brick temperature the heat absorbed by the furnace lining is considerably reduced. This results in major fuel economies.

2. By restricting the heat flow to the lining the time taken for the furnace to reach working temperature is reduced and so output is increased.

3. By reducing the average temperature of the brickwork and also the temperature profile within the bricks, the risk of spalling is

greatly reduced and so maintenance costs are saved

The effect of installing a ceramic fibre veneer is illustrated below :

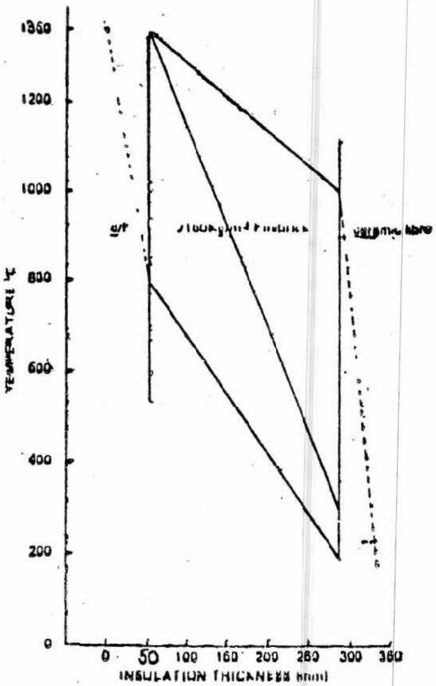



Fig. 1—Effect of adding 51mm ceramic fibre veneer to either the hot face or cold face of 229mm brick at thermal equilibrium.

Fig. I shows the temperature profile through a 229mm brick lining with a hot face temperature of 1350°C at thermal equilibrium. The cold face temperature is about 280°C and the mean brick temperature about 800°C. The effect of adding a 51mm veneer of ceramic fibre to the hot face or the cold face is illustrated. In both cases the veneer reduces the cold face temperature to about 200°C. When ceramic fibre is added to the hot face the maximum brick temperature falls to 800°C and the mean brick temperature to about 500°C.

When the veneer is added to the cold face the maximum brick tempera-

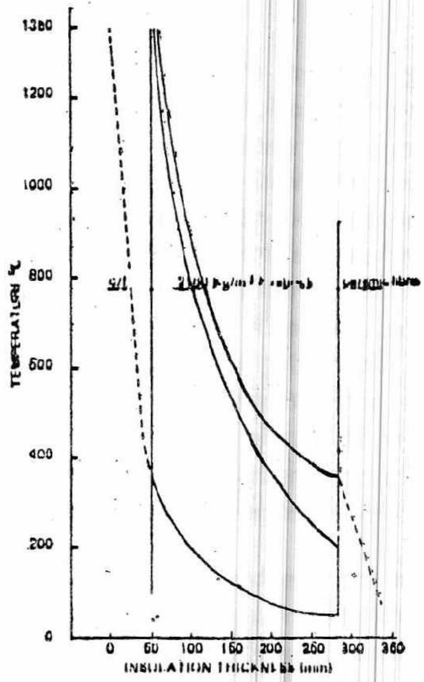



Fig. 2—Effect of adding 51mm ceramic fibre veneer to either the hot face or cold face of 229mm brick after 12 hr. heat up to 1350°C.

ture remains at 1350°C but all intermediate temperatures rise, the mean temperature becoming about 1175°C. This demonstrates quite clearly that the installation of a veneer on the cold face increases the heat stored in the lining and can take the backing brickwork above its maximum working temperature. The non steady-state temperature profiles when the lining is heated up to a 1350°C hot face during 12 hours are shown in Fig. 2.

By comparison with Fig. 1 you can see that thermal equilibrium is not achieved either with or without the veneer. You can also see that the addition of 51mm ceramic fibre on the hot face has a dramatic effect on both the maximum and the average brick temperature reducing these to 400°C and 200°C respectively.

Concentrating on the fuel savings aspect of veneering, the savings achieved depend on the amount by which the mean brick temperature is reduced by the veneer. Table 2, which summarises the graphs, shows that the addition of a ceramic fibre veneer produces a greater reduction in the mean brick temperature under non steady-state conditions than when the lining is at thermal equilibrium.

The savings also depend on the thermal mass of the brickwork and the thicker and denser the furnace brickwork, the greater will be the savings achieved by veneering.

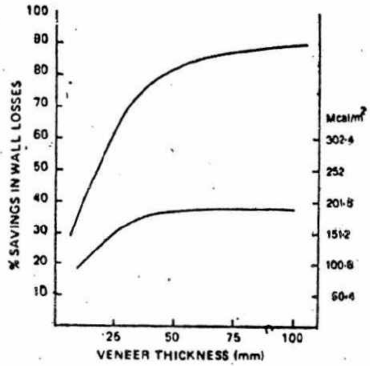



Fig. 3—Fuel savings v. veneer thickness heat up 0—1350° C during 12 hours 229 mm of 2160kg/m³ firebrick

Veneer thickness is also important and the way in which fuel savings increase with increasing veneer thickness is illustrated in Fig. 3. You can see that the installation of a 51mm veneer of ceramic fibre onto 229mm of 216kg/m³ brickwork which is heated to a hot face temperature of 1350°C during 12 hours reduces the heat flow

TABLE—2
Reduction in brick temperature on adding veneer lining

| Conditions \ Reduction in brick temperature °C | Maximum | Mean |
|---|---|---|
| Equilibrium | 550 | 400 |
| Non steady state (heat up over 12h) | 950 | 500 |

Reduction in brick temperature on adding 51mm ceramic fibre veneer to the hot face of 229mm of 2160kg/m³ brick for a furnace temperature of 1350°C.

As a result the best fuel savings are achieved when the cycle time is short and the furnace working temperature is high because under these conditions the lining is furthest from its equilibrium temperature profile at the end of the cycle.

into the lining by about 85%. Taking account of the other heat flows ( to the charge, flue, ètc ) this gives a saving of about 45 –50% in the total energy consumed by the furnace You can also see from Fig. 3 that the actual savings achieved are 152—176 M. cal/$m^2$.

This is, of course, theoretical but we can now examine one particular furnace lining veneer which illustrates actual savings in fuel and throughput.

Firth Brown Castings Limited of Scunthorpe in the U. K. have reduced their fuel bill by an overall 24% by veneering four bogie hearth heat treatment furnaces, each 4.57m long x 2.9m wide x 2.13m high. The veneer consists of two 25mm layers of 128kg/$m^3$ blanket impaled on stainless steel anchors.

The furnaces are used for tempering, normalising, annealing and austenitising of steel and alloy iron castings at temperatures between 300°C and 1050°C. Each load varies between 4 and 8 tonnes and a typical treatment requires 10 hours gradual heating followed by up to 10 hours at soak temperature.

Table 3 details the consumption of natural gas fuel for one furnace before and after veneering.

TABLE—3

Consumption of natural gas before and after veneering

| Treatment temperature ( °C ) | ( complete cycle ) Fuel consumption ( Joules x $10^8$ ) | | Fuel Savings |
|---|---|---|---|
| | Original Lining | Veneered Lining | |
| 1050 | 750 (Est) | 464 (Est) | 38% |
| 950 | 530 (Est) | 366 | 31% |
| 920 | 490 | 356 | 27% |
| 890 | 428 (Est) | 303 | 29% |
| 850 | 400 (Est) | 261 | 35% |
| 650 | 254 (Est) | 127 | 50% |
| 540 ( i ) | 207 | 121 | 42% |
| 540 ( ii ) | 197 | 118 | 40% |
| 400 | 98 (Est) | 42 | 57% |
| 300 | 37 | 19 | 49% |

Overall fuel saving : 24%

Figures marked (Est) were calculated by interpolation or extrapolation from measured consumptions.

## Fuel savings in full low thermal mass lined furnaces

As a further example of actual fuel savings, let us now examine an actual case history of a full ceramic fibre re-line.

Distington Engineering Company Limited of Workington in the U. K. have a bogie hearth heat treatment furnace which is fired on gas oil to temperatures in the range 600°C—1000°C. The furnace is 9.76m long x 4.27m wide x 4.77m high and is used for the stress relieving and annealing of mild steel fabrications and S. G. iron ingot moulds.

When a complete furnace re-line fell due, the respective quotations for re-bricking and an alternative low thermal mass lining were only £400 apart. It was decided to opt for the attractions of ceramic fibre with its advantages of easy installation and low thermal mass.

The lining consists of two hot face layers of 25mm of 128g/m³ TRITON KAOWOOL ceramic fibre blanket backed with 50mm of mineral wool impaled on stainless steel anchors.

Tables 4 and 5 summarise the resulting savings derived from this installation. The saving in heating time has proved to be a great advantage since the furnace is basically in use every day, seven days a week. The figures in Table 5 allow for 10% inflation in fuel costs every year up to 1983 and indicate that by 1978 these will be sufficient to completely pay back the cost of the ceramic fibre lining.

### Savings

TABLE—4

Savings derived from using full low thermal mass lining

| Heat Treatment Group | Number of Treatment | BRICKS | | T. K. C. F. | | SAVING | |
|---|---|---|---|---|---|---|---|
| | | Time Hrs. | Galls Oil | Time | Oil | Time | Oil |
| Stress Relief General Eng. Products | 25 | 199 | 7002 | 181 | 6300 | 9.5% | 10% |
| Stress Relief Large Vessels | 10 | 28 | 1172 | 20 | 882 | 26% | 24% |
| Full Anneal S. G. Iron Moulds | 14 | 19 | 941 | 15 | 840 | 21% | 11% |

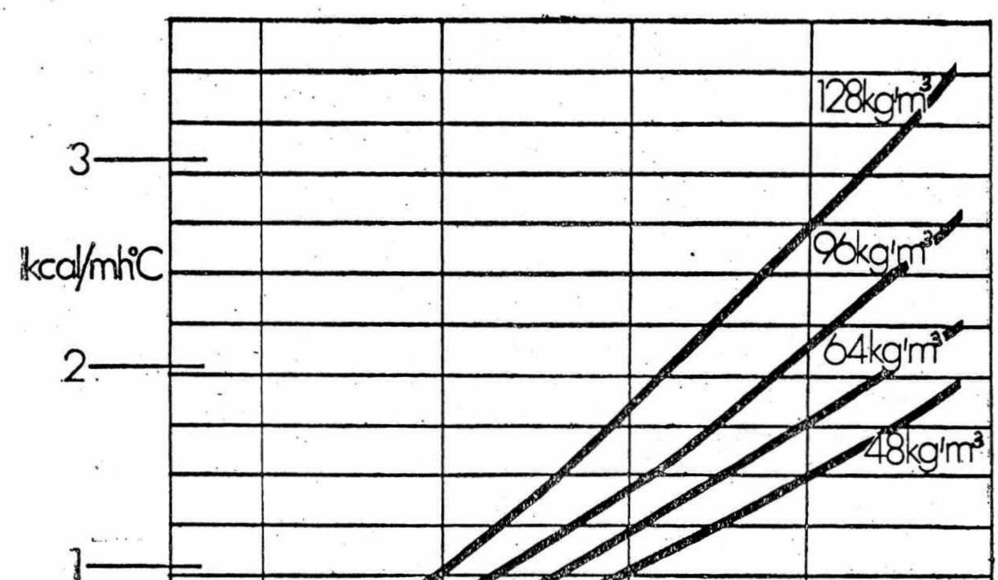
TABLE—5. **Monetary Savings per year**

| Year | Saving—£ |
|---|---|
| 1973 | 832 |
| 1974 | 1,172 |
| 1975 | 1,289 |
| 1976 | 1,417 |
| 1977 | 1,558 |
| 1978 | 1,613 |
| 1979 | 1,774 |
| 1980 | 1,951 |
| 1981 | 2,146 |
| 1982 | 2,360 |
| 1983 | 2,596 |
| 11 years | 18,708 |

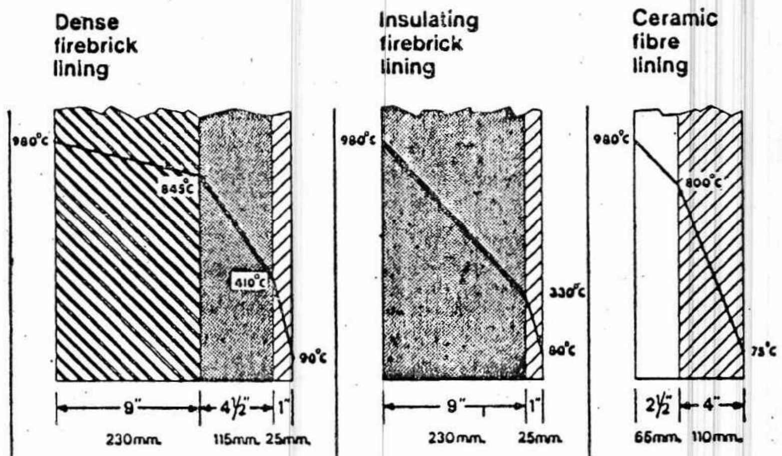
## Conclusion

The advantages to be gained by the use of full ceramic fibre linings are so great that furnace builders and industry in general are changing to this technique very rapidly. Even the use of fibre veneers offer highly measurable savings in fuel and time. It is likely in the near future that, as fuel costs increase, all furnaces of a suitable nature, such as heat treatment furnaces, will be built exclusively with ceramic fibre linings. In many countries that day is already here. The advantages of easy design and installation coupled with savings in fuel and time cannot be ignored as they all result in a saving of money.

# Appendices

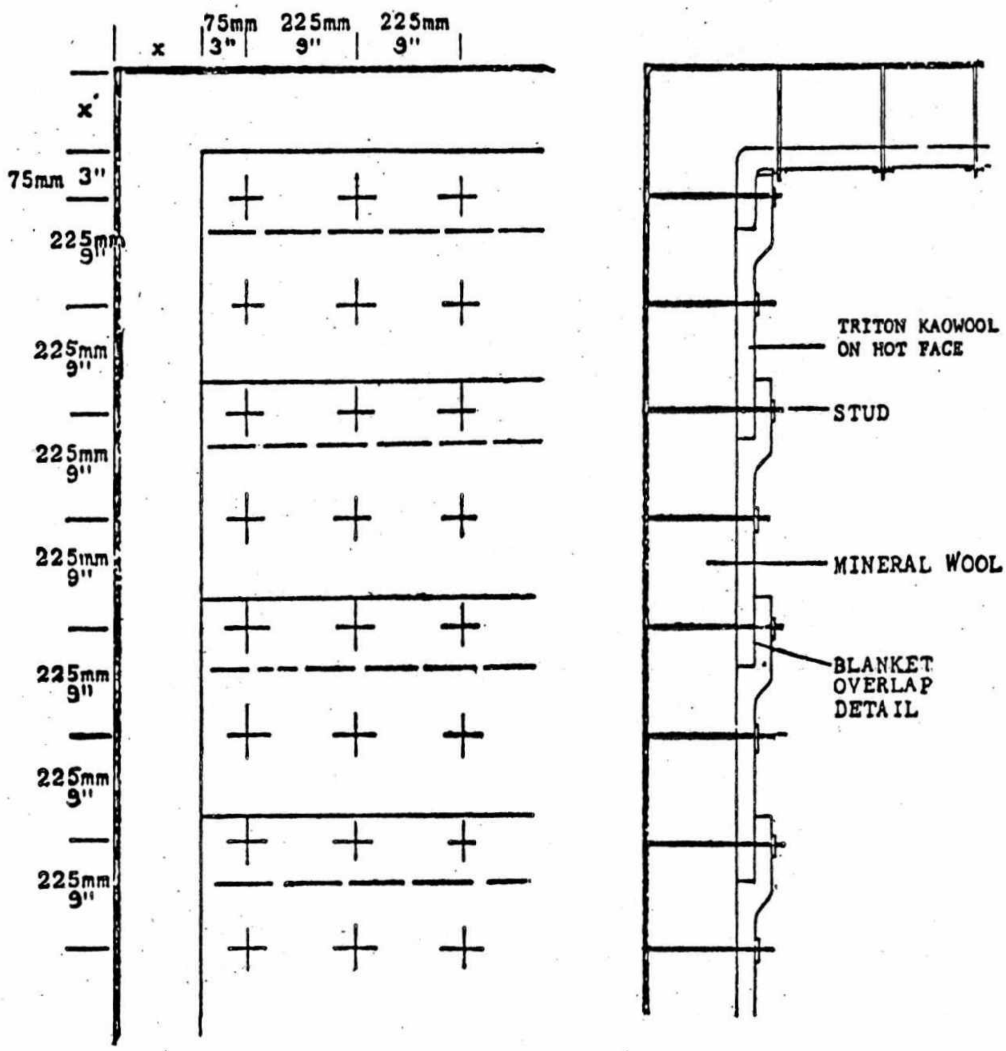



Appendix 1—Thermal conductivity of ceramic blanket



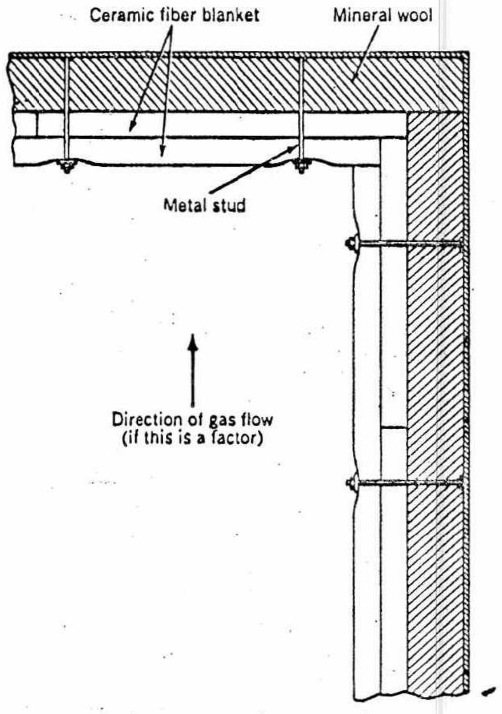

| | Dense firebrick lining | Insulating firebrick lining | Ceramic fibre lining |
|---|---|---|---|
| HEAT LOSS Btu/ft²/hr (kCal/m²/hr) | 195 (528) | 178 (482) | 175 (474) |
| HEAT STORAGE Btu/ft² (kCal/m²) | 48,381 (131,000) | 5497 (14,900) | 1824 (5000) |
| WEIGHT lbs./ft² (kgs./m²) | 116 (566) | 23·2 (113) | 7·33 (36) |

Appendix 2—Ceramic fibre lining compared to other wall constructions for equivalent furnace shell temperatures. Note the thinner wall, and significant reduction in weight and heat storage.



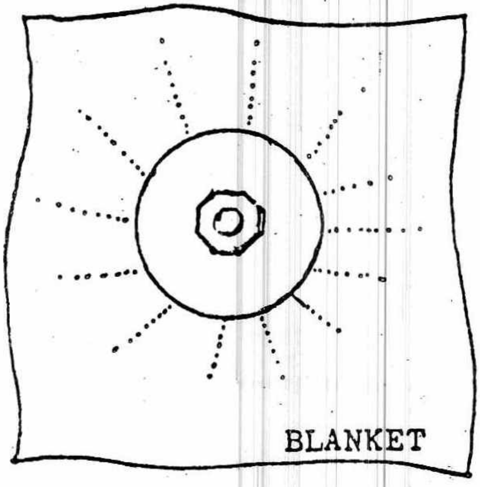

x x' allowance for lining thickness on adjoining wall or roof.

Appendix 3—Stud positions for 610mm. 2ft. wide blanket

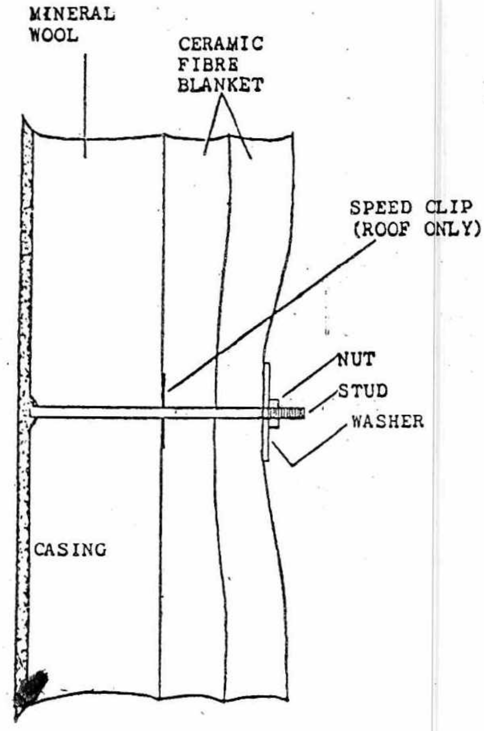



Appendix 4—Lap joint blanket intersection at a corner

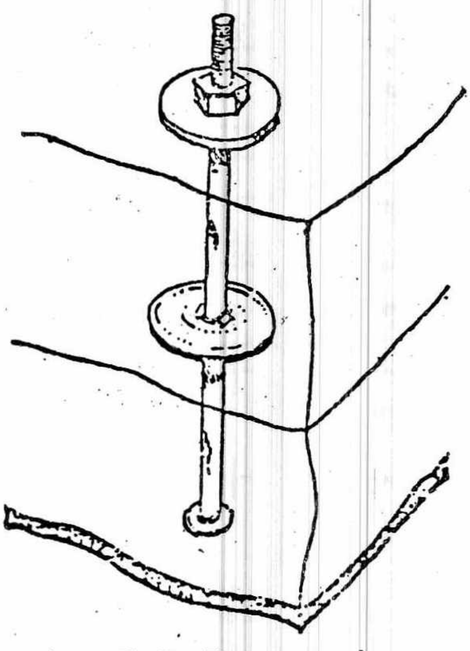
Appendix 5—Threaded stud systems.



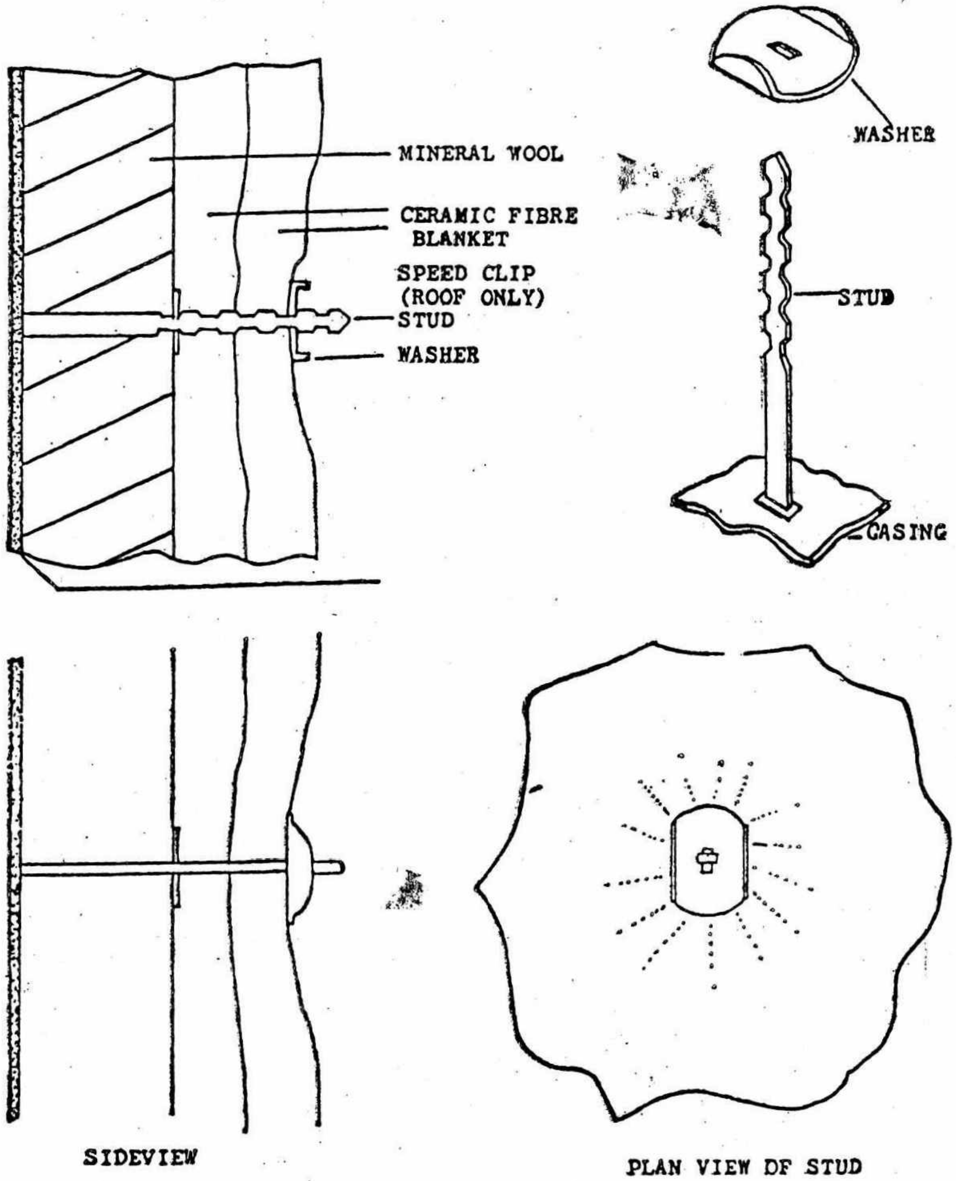

Appendix 5a—Plan view of stud



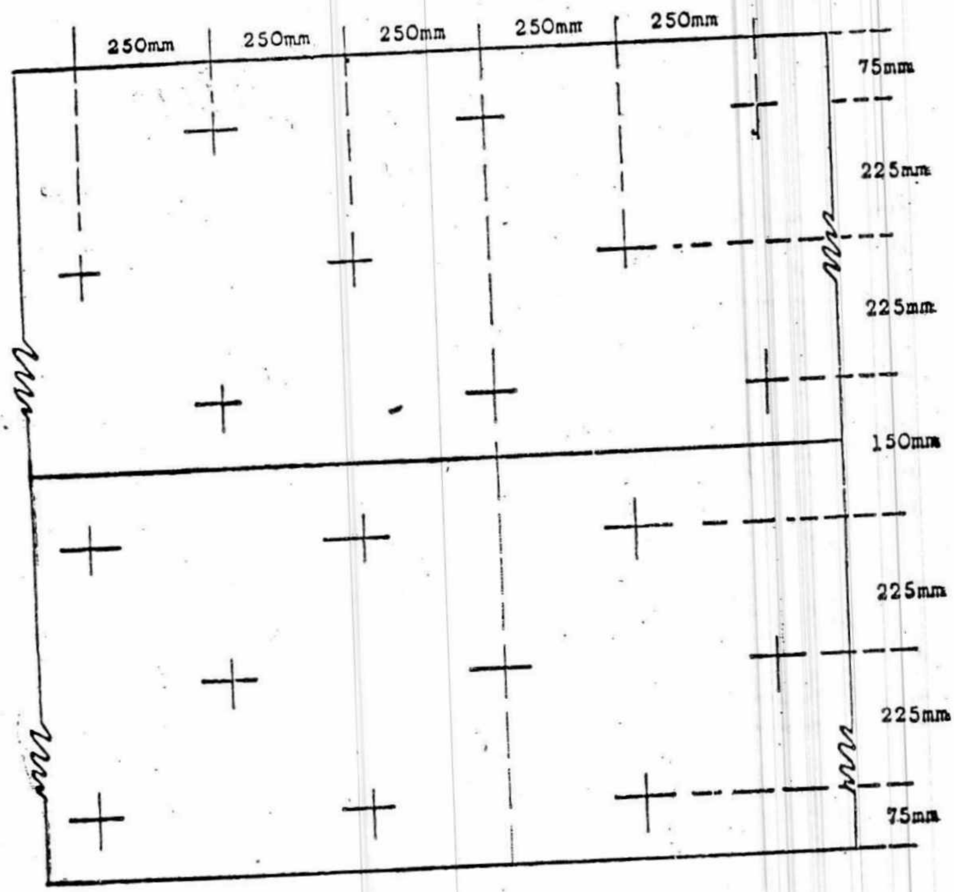

Appendix 5b—Section view



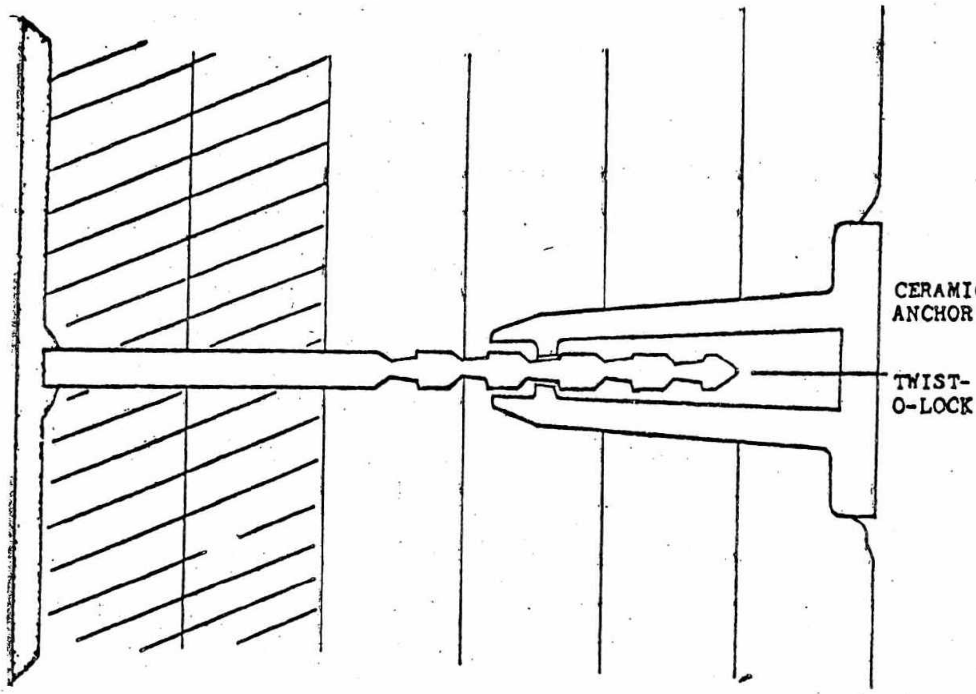
Appendix 5c—Threequarter view



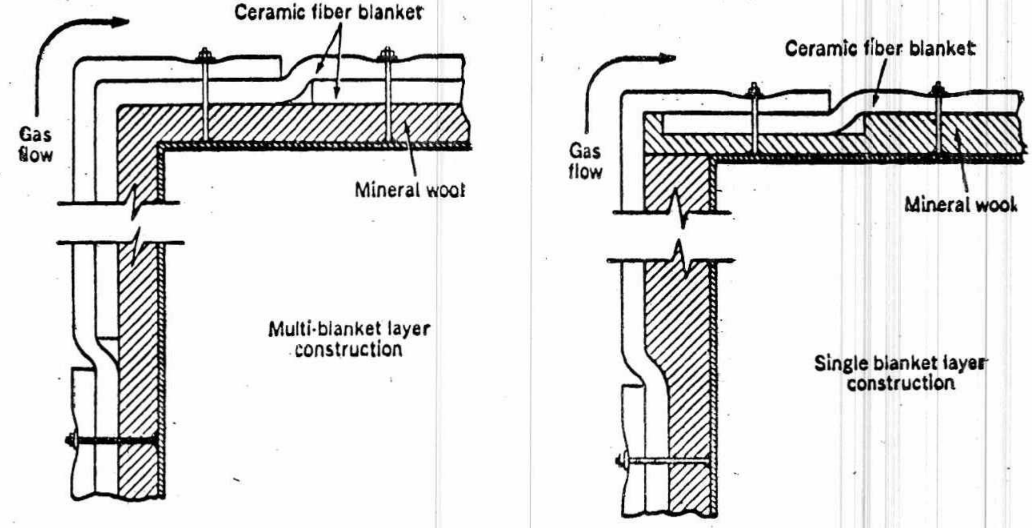

Appendix 6—Twist-o-lock system



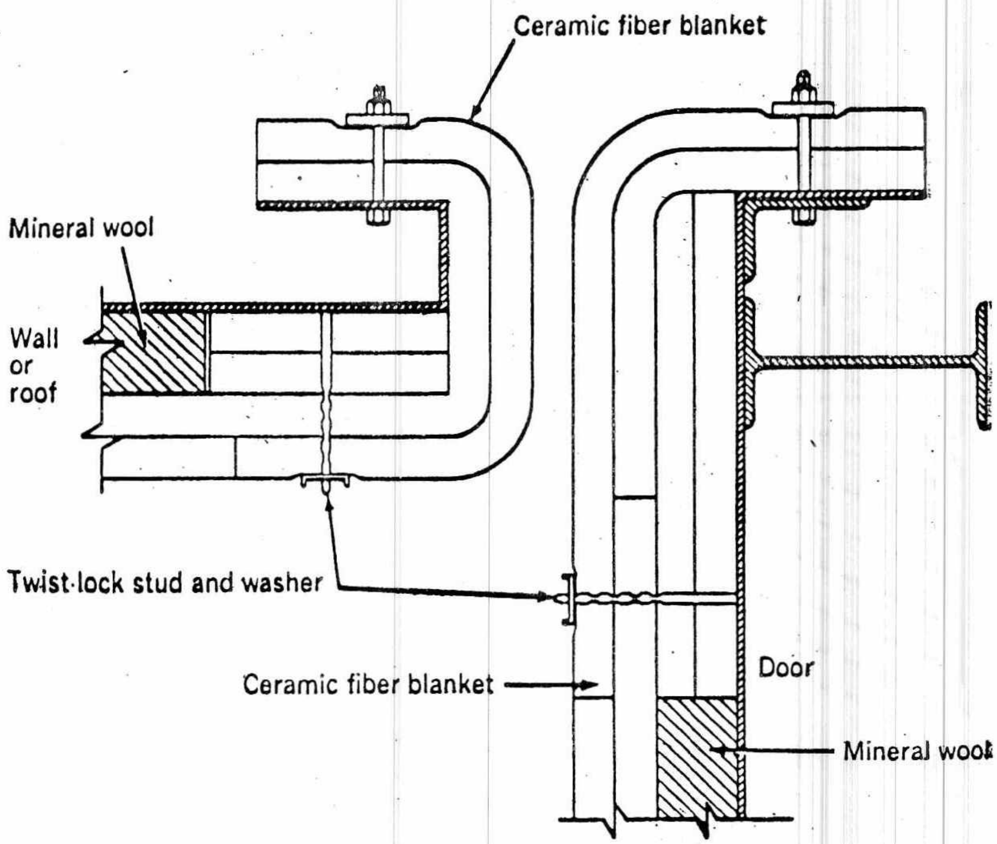

Appendix 7—Anchor positions



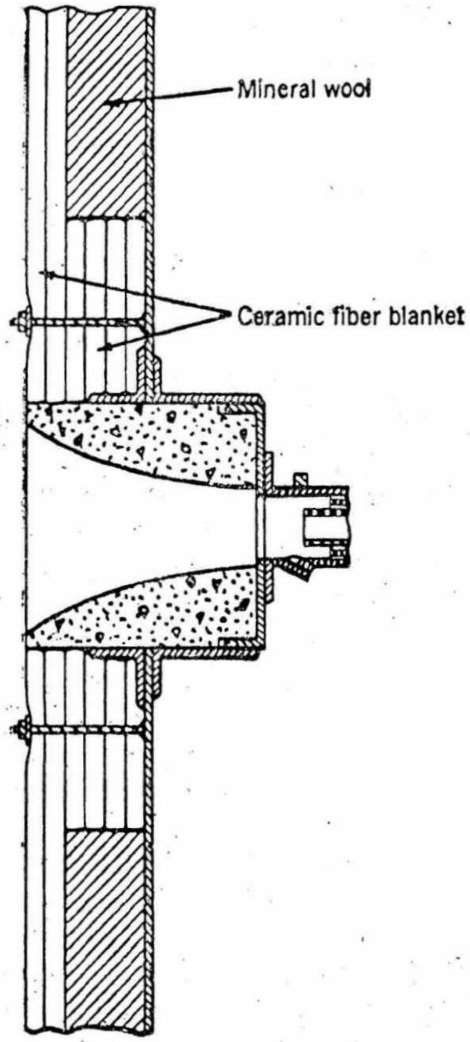

Appendix 8—Ceramic and cap for twist-o-lock studs




Appendix 9—Arrangement for protecting blanket joints against directional gas flow




Appendix 10—Door seal using locking washer stud system




Appendix 11—Burner block surrounded by ceramic fiber blanket