GAS FIRED POTTERY KILNS

A.M. SMITHSON

SOUTH AUSTRALIAN GAS COMPANY

January 1976

INTRODUCTION

This book has been written as a concise practical guide for both established and aspiring potters in their pursuit of the art and science of firing ceramic ware.

The potter who is about to either buy or to build a kiln will, in most cases, be confronted with a number of decisions that have to be made before making that final selection. This book should help to sort out the questions that need to be answered; and having sorted out the questions, the book will assist in answering them.

A series of questions is posed at the end of the book. Your answers should help you to decide on the best kiln for you.

Another important objective of the book is to give the potter sufficient knowledge to operate a gas fired kiln safely and with well placed confidence that is only gained through recognizing the hazards and knowing how to avoid them. A gas fired kiln is safe to use providing the potter always observes a few simple rules.

In line with modern practice the International System (S.I.) of metric units are used throughout the book with the imperial equivalent added in parentheses.

The term "pottery" is used to cover a whole range of fired clay artifacts which may be divided into different classes of ware. The various classes of ware require to be subjected to different temperatures in order to produce the final product.

Earthenware which is the most simple ceramic product to work with and to fire. It is made from the common red clay without the addition of any other materials. The simple earthenware pot is fired to a temperature in the vicinity of 950°C to 1050°C. In this temperature range the finished product is comparitively soft on a ceramic hardness scale and is somewhat porous. Earthenware is often coated with glaze before firing to seal the surfaces in order that the pieces that are in the form of pots are able to hold liquids.

The more ambitious and skilled potters will be attracted and eager to try their hands at stoneware. Whilst stoneware is often made from one clay alone, it is often a result of the careful blending of two or more clays and often combined with additives so that it can be eventually fired at a temperature of at least 1250°C. The finished product is hard and will ring like a bell, if struck. A stoneware pot, after firing will be fully vitrified and will hold a liquid without any being absorbed through the pot walls.

GENERAL INFORMATION

One inch (1")	=	25.4 millimetres (mm)
	=	2.54 centimetres (cm)
One foot (1ft)	=	0.3048 metres (m)
One square foot (1 sq.ft)	=	0.0929 square metre (m^2)
One cubic foot (1 cu.ft)	=	0.02832 cubic metre (m^3)
One pound (1 lb)	=	0.4536 kilogram (kg)
One therm	=	100,000 British Thermal units (BTU)
	=	105.5 megajoules (MJ)
One gigajoule (GJ)	=	1000 megajoules (MJ)
One pound per square inch (1 psi)	=	27 inches water column or gauge (wg)
	=	7 kilopascals (kPa)

Calorific Values:

Natural Gas	=	1050 BTU per cu.ft
		39.3 MJ/m^3
Liquefied Petroleum Gas (LPG) also known as Bottled Gas	=	21,500 BTU/lb.
		50.5 MJ/kg
		2500 BTU/ cu.ft
		25.4 MJ/litre

CONTENTS

China generally refers to artifacts made from kaolin or china clay to which has been added a variety of ingredients designed to allow very fine and thin walled pieces to be formed and fired without breaking or cracking. The resulting product is usually white in colour. It is fired at least twice. The first firing is at the highest temperature; 1300°C or more. The second firing for fluxing purposes is usually carried out at about 1160°C. Subsequent firings may be required after the pieces are decorated.

Porcelain is a refined form of china; the dividing line between the two products is somewhat ill defined. Often porcelain is glazed whilst in the green unfired stage and the artifact is fired only once at a temperature approaching 1400°C which results in one monolithic vitrified piece, extremely hard and with great resistance to thermal shock. Thermal shock can result from sudden and extreme changes in temperature. Porcelain can be made much lighter and thinner than other forms of ceramic products.

Whilst it is useful for the potter to know of these various types of ceramic ware, practical application of the art of pottery should be restricted to earthenware and stoneware.

WHY USE A GAS FIRED KILN?

Many potters have only sketchy ideas of the technicalities of the different fuels available for firing kilns. Potters should know something of both the advantages and disadvantages of each fuel. Remember, that for every advantage there is, unfortunately, a corresponding disadvantage.

There are quite a number of different fuels available for firing pottery kilns ranging from wood, coal, oil, electricity right through to reticulated and bottled gas.

Solid fuels, wood and coal, are for the most part cheap to use, but present a number of operating and control problems. A considerable degree of skill is required to obtain adequate control and the work involved in firing the kiln can be both laborious and dirty.

Oil fuels, usually distillate or light industrial fuel oil, are reasonably safe to both store and use providing basic safety precautions are observed. They are generally cleaner to use than solid fuels.

Oil fuels are however more expensive to buy and are difficult to burn successfully in small burners. Unless the extremely crude and inefficient drip feed system is used, a fan is necessary to provide air for the combustion of the oil. A fan is expensive to buy, noisy, and also an electric power outlet is necessary for the fan motor. In addition, the low heat input or firing rate required to dry the ceramic ware at the beginning of the firing cycle is very difficult to obtain. Carboning up of the burners, with its attendant problems can be a continuing nuisance.

Electricity is the cleanest and easiest of all the fuels to use. It has a thermal efficiency approaching one hundred percent. However, it is the most expensive of all fuels, even allowing for its very high efficiency. Initial electrical installation and subsequent maintenance costs for the elements can involve considerable expense.

The greatest disadvantage with electric kilns, however, is the severe limitation of glaze varieties available. This is due to the impractability of introducing a carbon rich reducing atmosphere into the kiln space.

Whilst gas fired kilns are reasonably expensive to build and even more expensive to purchase and the gas price ranges from moderate to reasonably high, they are however,in most cases, the only practical type of kiln for the serious potter. This is particularly so if glazed stoneware is to be produced.

Providing that basic safety precautions are observed, gas fired kilns are both safe to use and easy to operate.

Gas is an extremely clean fuel and the reducing atmospheres obtainable enable a wide variety of glazes to be used successfully.

The gas can be either reticulated from street mains or the so-called bottled gas can be used. The operation of the kiln and the results obtained should be the same whichever gas is used.

WHAT HAPPENS INSIDE A KILN

A pottery kiln can be considered in one way, as a machine that converts fuel into heat energy which in turn reacts with clay and glazes to produce vitrified ceramic ware. As such, it obeys the laws for machines; it has an efficiency factor. In other words we do not get as much energy out in the form of converted ceramic ware as we put into the kiln in the gas that flows through the burners.

Most of the energy from the fuel is in fact lost in the form of waste heat. It escapes in the form of radiated heat from the kiln walls and in the flue gases.

Only a small part of the heat energy is eventually used to convert the raw clay and glazes into finished ceramic ware.

Heat is measured in two ways; quantity of heat and intensity of heat. It is important to differentiate between the two.

The quantity or amount of heat is measured under the metric system in megajoules of input to the kiln. The imperial measurement is in British Thermal Units (BTU). The more commonly used measurement is the rate of heat input; megajoules per hour (BTU's/hr).

Intensity of heat or temperature is measured in degrees Celsius (^{o}C). The temperature will increase steadily so long as the rate of the combined quantity of heat escaping through radiation and contained in the flue gases is less than that of the fuel being burned.

The maximum flame temperature of natural gas is in the vicinity of 1880^{o}C irrespective of the size of the actual flame. It should be recognized that flame temperatures are comparatively unimportant as far as the potter is concerned. The rate of heat input measured in megajoules per hour (BTU's/hr) is the important thing.

Heat can only be transferred to the ceramic ware in three ways:-

* Conduction which plays only a comparatively small part in the operation of a pottery kiln.

* Convection, which is very important. The greater the speed that the fired gases pass the ware, the faster the heat transfer. At the comparatively low temperatures experienced at the beginning of the firing cycle, almost all of the heat is transferred by convection currents, but at a low rate of transfer.

* Radiation is the other important way that heat is transferred. It is especially efficient at the higher temperatures that normally occur in the latter part of the firing cycle. A kiln is more efficient in the transfer of heat, especially radiant, when it is fully filled with ware. The pieces of ware themselves act as baffles to absorb the heat and they also act as reflectors bouncing the radiated heat to all parts of the kiln.

Electric kilns liberate almost all of the energy as radiant heat but they are somewhat poor in transferring heat by convection because of the very low speed of the air currents circulating inside the kiln. However, in electric kilns, there is no flue gas heat loss which, in the case of all other types of fuels is the single biggest source of heat loss.

All kilns burning fossil fuels, such as wood, oil or gas, must have substantial losses through the heat contained in the escaping flue gases if they are to operate successfully.

The flue gases are always at a higher temperature that the ware inside the kiln. The higher the kiln temperature and its ware, the greater is the amount of heat lost in the flue gases and hence the smaller the thermal efficiency of the kiln. A kiln becomes less efficient, thermally, as it becomes hotter. If the escaping flue gases for example, are at a temperature of 1400°C the actual available heat for use to vitrify the ware or cure the glazes is only in the order of 17 megajoules per cubic metre (450 BTU/cu.ft) for natural gas which has a calorific value of 39 megajoules per cubic metre (1050 BTU/cu.ft). When bottled gas is used with a calorific value of 96 megajoules per cubic metre (2500 BTU/cu.ft) the available heat at this temperature would only be in the order of 38 megajoules per cubic metre (1000 BTU/cu.ft).

The actual overall thermal efficiency of a typical gas fired kiln when it reaches maximum temperature of say 1280°C is only in the order of 15% compared with an efficiency in excess of 80% when it is first lit on a low warming rate.

A typical total heat balance for the entire firing cycle could look like this:–

Useful heat to vitrify ware to cure the glazes.	20
Heat lost in cooling the kiln, kiln furniture and ceramic ware.	13
Heat lost in flue gases	35
Heat radiated from the walls of the kiln.	15
Heat stored in the kiln walls and eventually lost.	10
Heat used to dry ware.	5
Heat value in unburned gas lost due to inefficient combustion and incomplete combustion caused by producing reducing atmospheres.	2
Total heat input	100%

The heat input required at maximum firing rate is in the order of 900 – 1100 megajoules per cubic metre (25,000 – 30,000 BTU/cu.ft) of kiln working space. Naturally, all gas burners must always be designed for maximum firing rate which occurs towards the end of the normal firing cycle.

When burning gas, or any other fossil fuel, any one of three atmospheric conditions can exist inside the kiln:

* Oxidising condition, which is the term used when more air is mixed with the gas than is required to burn it completely. The excess results in free oxygen inside the kiln which can have a chemical reaction with the ware. The thermal efficiency will be lowered due to the mainly useless heating of the extra air. However during the very early part of the firing cycle excess air is beneficial because the convection currents within the kiln have a higher velocity and a larger volume of gases are available to dry the ware. Some excess air is beneficial in the middle of the firing cycle, at around 700°C, to allow the combustibles in the clay and glazes to burn off. This should be completed by the time the kiln reaches 900°C.

* Stoichiometric combustion, which is the perfect state of having exactly the right amount of air, and therefore oxygen, for all of the gas to be burned completely. This condition is very difficult to achieve in the comparatively "hit and miss" burner operation of the average pottery kiln.

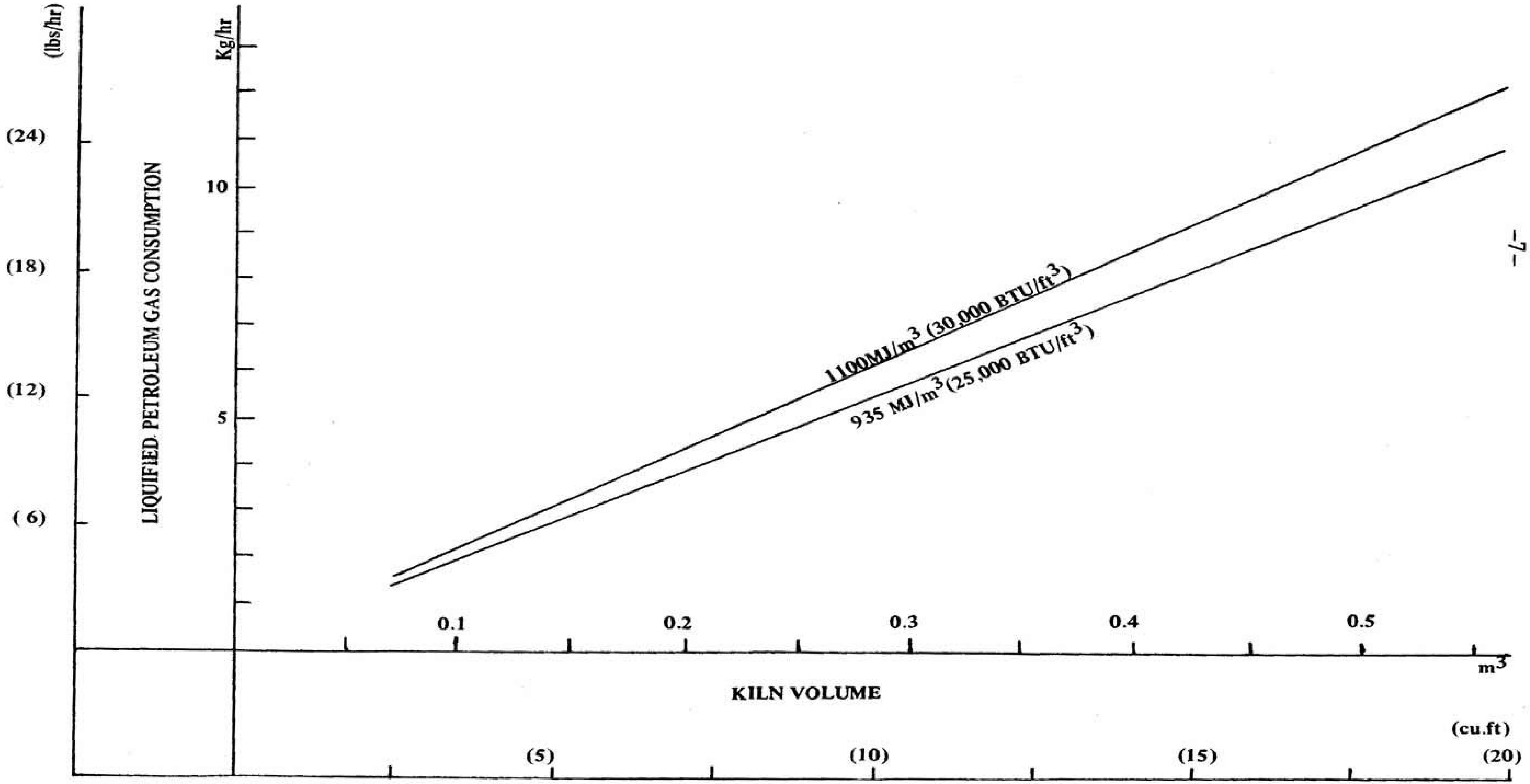
* Reducing atmosphere, which occurs when there is insufficient air to burn all the gas issuing from the burner nozzle. This condition is required when glaze firing, towards the end of the firing cycle in order to provide free carbon from the cracking of the unburned gas. The carbon percolates through the kiln and gives the variety of hues and colours to the glazes that the potter is trying to obtain.

Flue gases from burning one cubic metre (cu.ft) of natural gas under stoichiometric conditions contain:

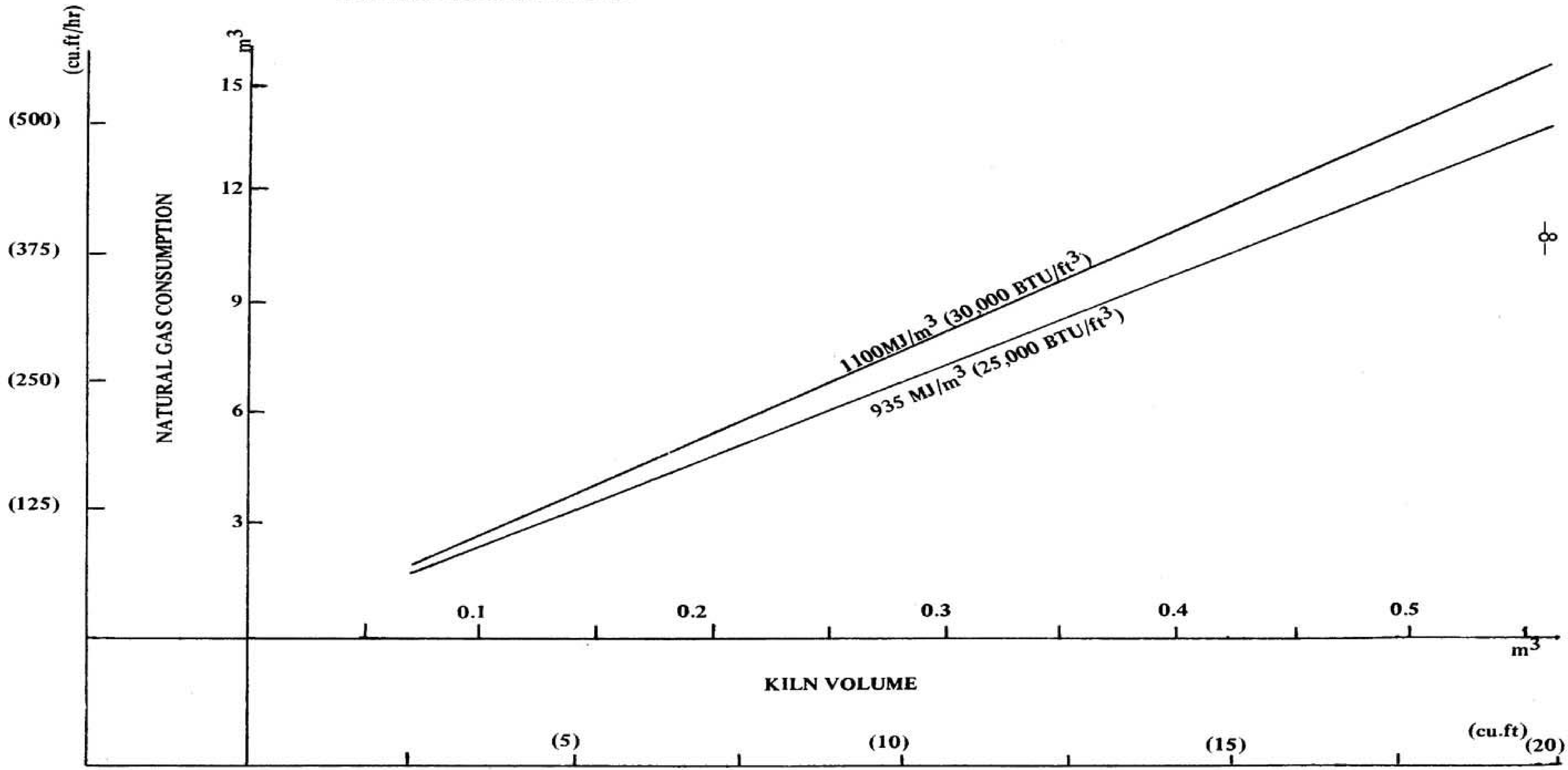
Carbon dioxide	(CO_2)	1.11 cubic metre (cu.ft)
Water vapour	(H_2O)	1.97 " " " "
Nitrogen	(N_2)	8.2 " " " "
		11.28 cubic metres (cu.ft)

All of these gases are non toxic. The very interesting point to note is the quantity of water produced; approaching 1.6 kilograms (one gallon) for every cubic metre (100 cu.ft) of gas burned.

LIQUIFIED PETROLEUM GAS (LPG) FIRED POTTERY KILNS
Consumption at Maximum Fire.



NATURAL GAS FIRED POTTERY KILNS.
Consumption at Maximum Fire.



8

It must be realised however, that the vapour is well above its dew point. This means that it is not normally detectable and has no detrimental effect on the operation of a kiln. All fossil fuels produce water vapour when burned.

The same products of combustion result when burning liquefied petroleum gas (LPG). The proportions of the gases vary slightly compared with natural gas.

In actual practice when gas is burned, either excess air is always present in the flue gases, which has no detrimental effect to human health, or under reducing conditions, carbon monoxide will be present which can be dangerous to health, if breathed in above what is only a minute concentration level. Great care must be taken to avoid this happening.

IT IS OF THE UTMOST IMPORTANCE THAT ADEQUATE PERMANENT VENTILATION BE PROVIDED TO ENSURE SUFFICIENT AIR FOR BOTH COMBUSTION AND FOR THE ESCAPE OF THE FLUE GASES TO THE OUTSIDE ATMOSPHERE.

When a kiln is installed in a room or enclosure of any kind, failure to provide adequate ventilation can cause hazards to both health, due to breathing impure air, and property, because of the risk of explosion and fire.

THE ELEMENTS OF KILN DESIGN

Most present day kilns are the result of gradual development over hundreds, possibly thousands of years. Historically, designs have been largely controlled by the firing techniques that have been developed, the fuels that have become available, and the new materials that have been invented. However, too many kiln designs are the result of the constricting slavery to tradition and bear little relationship to logical thought. They are being based on old fuels, outmoded firing techniques and obsolete building materials.

When considering the elements of good kiln design a few points should be kept in mind:

* Heat transfer by convection currents; whilst updraught currents tend to give the best heat transfer, downdraught currents will enable better thermal efficiencies to be obtained because the currents can be controlled more precisely.

* Temperature zoning; updraught currents tend towards temperature stratification, and lead to temperature differences at different levels within the kiln. Usually the top and bottom of the kiln are hotter than the middle level. Also, any hot spots tend to cause a chimney effect, so that a particular hot vertical zone will get even hotter as the hot gases are attracted by the strong upward convection current.

* On the other hand, the downdraught design tends to be self balancing. This gives more even temperatures throughout the kiln space.

* Radiation losses are directly proportional to the area of the outer surface of the kiln. It can be demonstrated, in the case of a rectangular prism kiln, that a cube shape presents the minimum surface for a given volume. A catenary shape gives an even smaller surface.

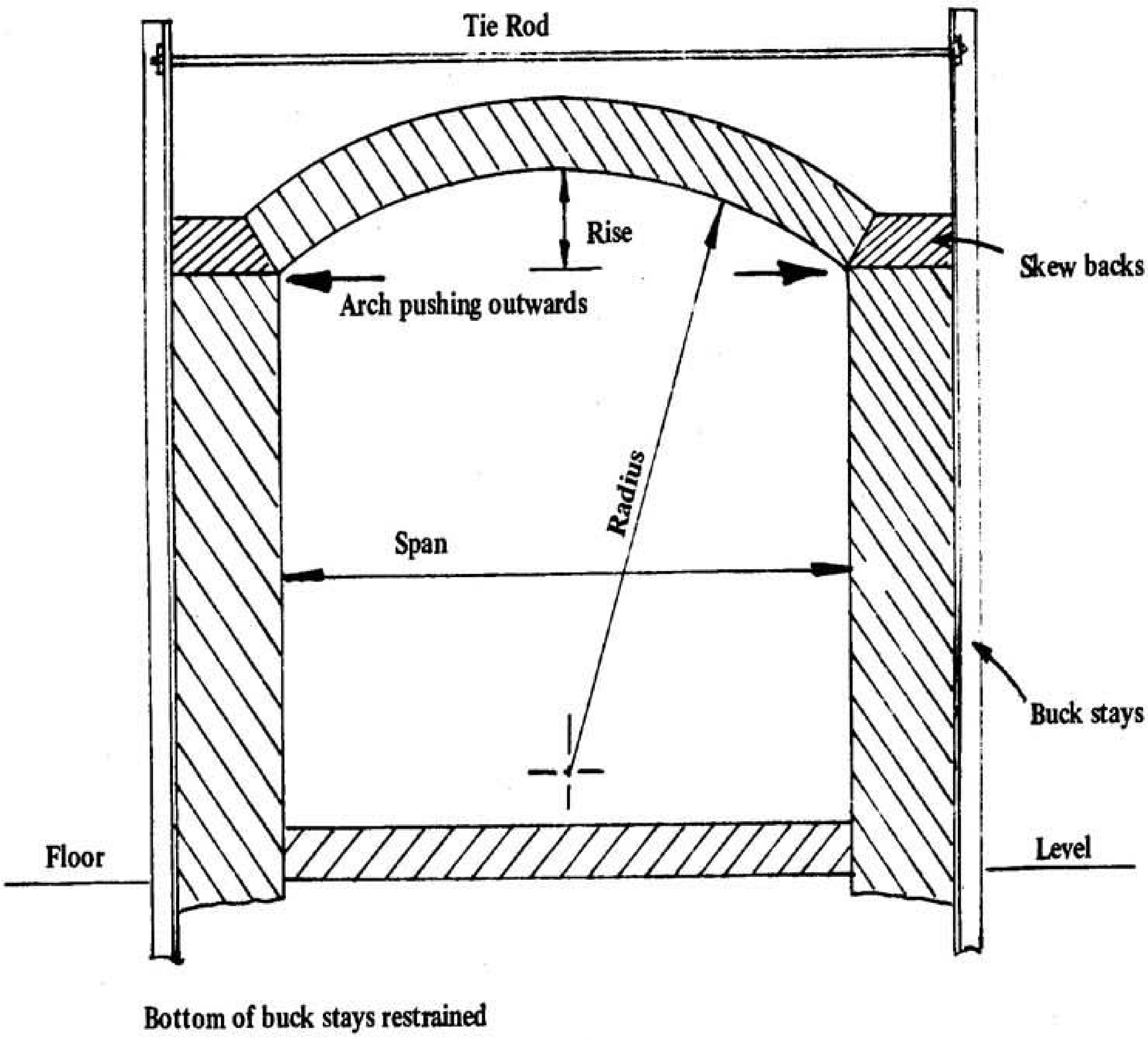
* Heat stored in the kiln walls should be carefully considered. A balance must be struck between the choice of thick and thin walls. Thick walls can have low radiation losses because the heat has a greater distance to travel to reach the outer surfaces. On the other hand they do store a considerable amount of heat. This heat is eventually wasted when the kiln is cooled to discharge the ware.
  Thin walls have higher radiation losses but they store little heat.

The use of insulating bricks, which are made of special low heat holding capacity material and permeated with air bubbles, is a practical method of keeping both radiation losses and heat storage to a minimum. The disadvantage of insulating bricks is that they are very expensive to purchase. The better the insulating qualities of the brick the higher the cost will be.

A reasonable compromise is to have 115mm (4½") of hot face insulating brick on the inside of the kiln and 115mm (4½") of refractory fire brick for the outer leaf; giving a total wall thickness of 230mm (9"). Some kiln builders incorporate a further insulating barrier by separating the two brick leafs and filling the cavity usually about 50mm wide (2") with an expanded mica pellet material called vermiculite.

Arches must always be buttressed against outward movement. The only exceptions to this rule are catenary arches. The buttresses are usually in the form of sheet steel boxes, angle iron frames and in the case of larger kilns, buck stays. Buck stays are individual vertical columns placed at intervals along each side of the kiln and each pair restrained by a tension rod across the top.

The rise of an arch should be calculated at the rate of between 25mm and 60mm (1" and 2.5") per 300mm (12") of internal span.



TYPICAL ARCH

Flues should be carefully designed to ensure adequate passage for the gases both from a safety and functional point of view. The minimum flue area should be at the rate of $100mm^2/m^3$ (4 sq. ins/cu.ft) of kiln operating space. Remember, it is easy to reduce the flue area if it is found to be too big, but it can be difficult to enlarge it.

The fundamental purpose of the vertical protective tile, or, to give its correct name, curtain wall in a down draught kiln is to act as a chimney. The chimney induces and guides the hot gases to the top of the kiln ready to start their working journey downward through the ware.

The stack or chimney on a kiln should have at least the combined area of the flue passages. The higher the stack, the greater will be the draught pulling the flue gases out of the kiln. If it is too high, however, the thermal efficiency of the kiln will be reduced because the gases will travel through the kiln too quickly. All stacks are required to be a minimum of two metres (6'0") high, measured from the operating floor. This is to minimize the risks of burns and asphyxiation of the operating personnel.

Dampers are a cause for concern in gas fired equipment. Normally, a Gas Authority requires all gas fired equipment to either have a specified minimum damper opening or to have an interlock that will shut down the burners automatically when the damper is closed beyond a predetermined point. This requirement is for reasons of safety. However, with pottery kilns it is realized that there are considerable complications in complying with this requirement. Therefore Gas Authorities usually reach a decision regarding pottery kiln dampers by treating each installation on its merit. It must be emphasized that great care must always be taken to ensure that the damper is open before an attempt is made to light the burners.

Butterfly type dampers must not be used because a positive observation cannot be made of the actual position of the damper. Plate type dampers should always be used because it is reasonably easy to check the operating position.

Standardization should be considered. It is more expensive and difficult to build a kiln if the material sizes are non-standard. If you are not familiar with the standard sizes of the various kiln building materials, considerable savings in time, effort and money can be made by first doing some research and asking questions.

Repairs and maintenance are important factors. Always design and build the kiln so that any repairs to floors, walls and other parts can be carried out with the minimum amount of dismantling of the kiln.

Spyholes, usually about 40mm square(1½") should be provided to view both the ware and also the segar cones, if they are used. They can be closed when not in use, by brick plugs cut with a slight taper so as to form a reasonably effective seal. Care should be taken to ensure that the spyholes are located in positions that allow the interior of the kiln to be viewed to best advantage whilst the viewer's head is far enough from the kiln wall to be unaffected by the escaping hot gases.

When considering the size of the kiln which would best suit you it is important to remember that there are minimum practical limitations. A kiln under $0.07m^3$ (2.5 cu.ft) is hardly worth building and the capital costs would be relatively high. On the other hand when considering a large kiln, it should be remembered that to obtain operating economies a kiln should be filled to capacity. The potter should consider the number of pieces of ware required to fill a particular size kiln and how many days or weeks of work it will take to produce that amount. A kiln of $0.15m^3$ (5 cu.ft) nominal capacity is a very popular and practical size. It is a good working size for most potters, the capital costs are kept within reason, and it can be filled and refilled within a reasonable time.

When deciding on the location of the kiln keep in mind that there should be a comfortable and safe working space on a sufficient number of sides for both loading and operating purposes.

The suitability of the floor on which the kiln is to stand should be checked. The floor, obviously should not be of timber or any other material that may present a fire hazard. A concrete floor may crack with the conducted heat if the kiln is not placed on an efficient heat insulation barrier.

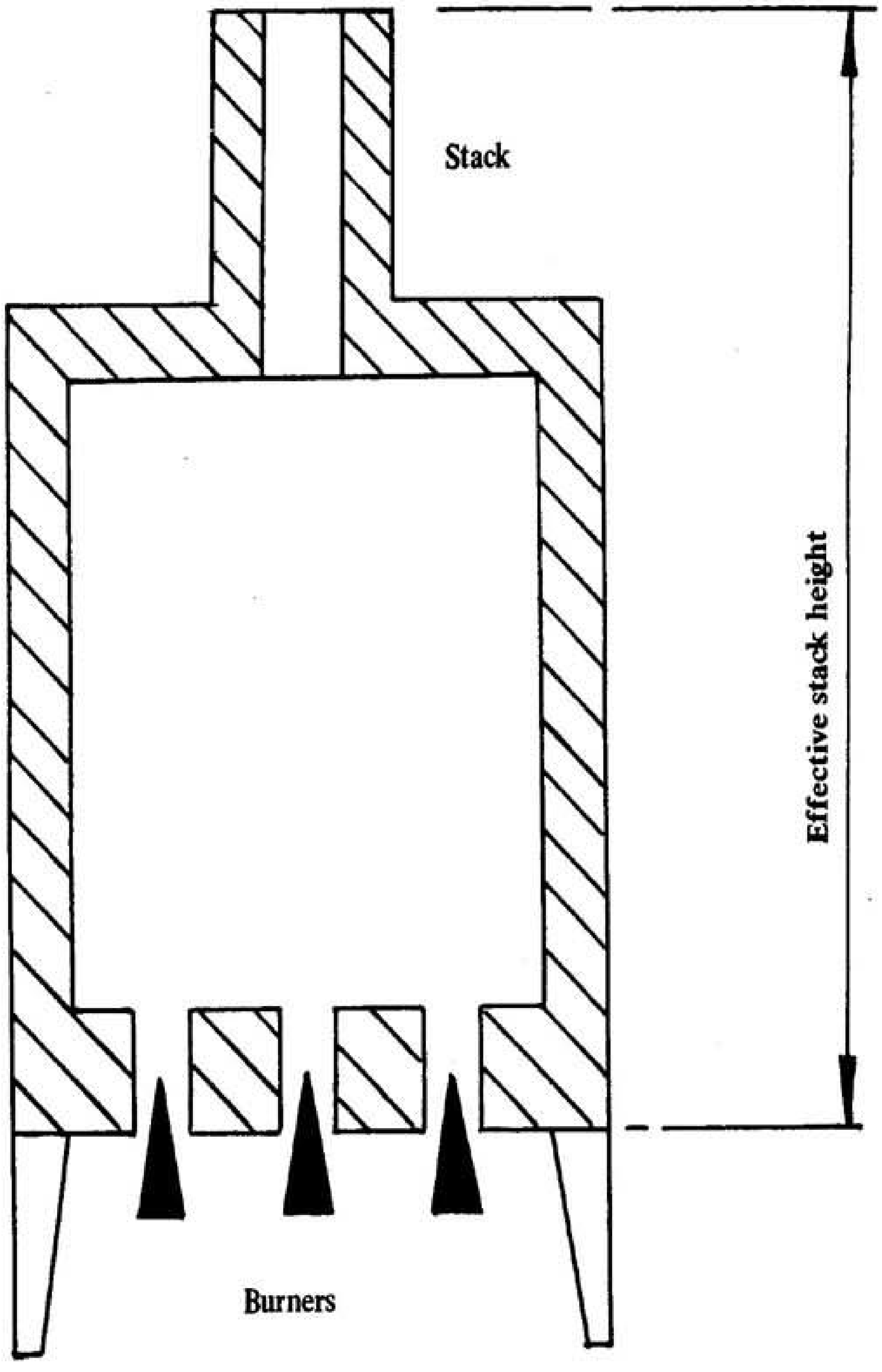
KILN TYPES AND STRUCTURES

Whilst there are many types of kilns in existence, ranging down from large continuous tunnel kilns and through the multitudinous kilns used for special industrial purposes, we will only consider the simple batch type which is familiar to the average potter.

Basically, batch type kilns suitable for the production of ceramics may be divided into two general types: updraught kilns and downdraught kilns.

Updraught kilns have the advantage of being simple and therefore relatively cheap to build. The compensating disadvantage of this type of kiln is a tendency to burn with more uneven temperatures and it is also more difficult to obtain satisfactory atmosphere control.

A technique sometimes used in an attempt to overcome these disadvantages is to design the kiln with a number of burners in order to spread the liberated heat more evenly over the horizontal plan This tends to avoid any localized chimney effect.



UPDRAUGHT KILN

Downdraught kilns always have their flue outlets at or near the floor level. Traditionally, the burners are also located at or near the floor level. In larger gas kilns, there is little practical reason why they should not be at or near the top of the kiln. If the burners are located in the top of the kiln the curtain wall can be dispensed with giving more working floor area on which ware can be set.

Downdraught kilns rely on the draught created by the difference in height between the top of the kiln and the top of the stack. The draught potential of the kiln is proportional to this vertical difference. The greater the effective stack height, the greater the draught.

Most Gas Authorities recommend or require a minimum height of the stack from the operating floor in order to minimize hazards to the kiln operator. This minimum height should not be confused with the minimum height calculated to obtain a desired draught. It often happens that the calculated minimum height has to be increased to meet a minimum safety height requirement.

The main advantage of a downdraught kiln is that it tends to produce much more even temperatures throughout the ware setting due to the self balancing effect of the convection currents within the kiln. Any one horizontal plane tends to be at the same temperature. Higher localized temperatures due to chimney effect, as experienced in updraught kilns, do not occur in downdraught kilns. Another major advantage of this type of kiln is that it is much easier to obtain an accurate control of the kiln atmosphere, which is so important in obtaining the more sophisticated colours in glazed ware.

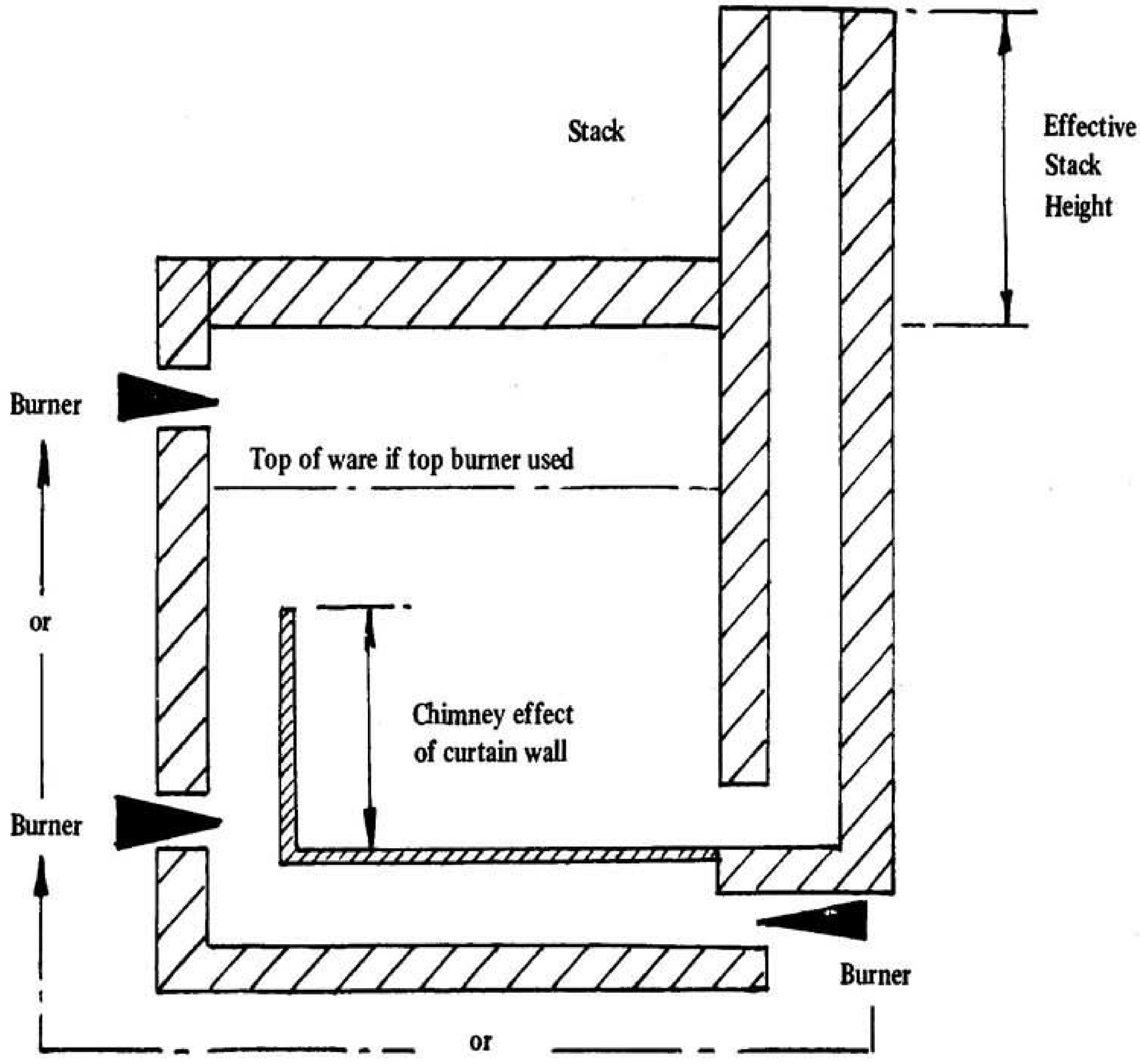
On the other hand, downdraught kilns are more complicated than updraught ones and therefore require somewhat greater skill to construct and are generally more costly to build.

A special type of kiln that should be mentioned, because of its increasing popularity is the Raku kiln.

Raku ware had its origin in Japan and dates back to the 16th century when a Korean immigrant potter named Chojiro used the Chinese character "Raku" which translated means "happiness" as his seal. Since that time ware made by the method he used has been known as Raku ware. The ware is hand modelled rather than thrown. It is fired at lower temperatures than stoneware and usually pulled from the kiln while red hot and cooled very rapidly, usually in a box of sawdust, which also has a carbonizing effect.

This produces the characteristic flaws of Raku and gives it its softness and warmness.

Having decided on the type of kiln; updraught or downdraught, a decision has to be made on the type of structure that will suit the particular needs of the potter.



Curtain wall required only if
burners are located at bottom of kiln

DOWNDRAUGHT KILN

The first point to consider regarding the structure of a kiln is the method of loading; top or front.

A top loading kiln lends itself to an extremely simple structure which is relatively cheap to construct. However, it has the disadvantage that loading of the kiln is more awkward due to the fact that it must be carried out from a position above the kiln.

The design of a top loading kiln lid needs careful thought because of the weight and stresses involved. The weight especially, can cause considerable difficulties.

One of a number of kiln lid designs can be used. Lift off sections is one popular method. Each section is usually held together by two tie rods. It is strongly recommended that the tie rods be of heat resistant stainless steel. Mild steel rods will carburise very quickly after repeated firings and eventually fail, and allow the lid to collapse.

Removable sections present the problem of sealing the cracks between them. One way to overcome this is to place a Kaowool insulating blanket over the entire top after the sections are in place.

Another method used to seal a top loading kiln is to fit a hinged, steel encased lid fitted with a counterweight. However, this involves extra cost, a mechanically strong design and extra space alongside the kiln to accommodate the counterweight.

A cheaper and yet effective variation of the hinged lid is to have a removable lever in lieu of the counterweight. There is a potential problem and danger in this method of opening the lid; it must be effectively and safely propped open while loading and unloading.

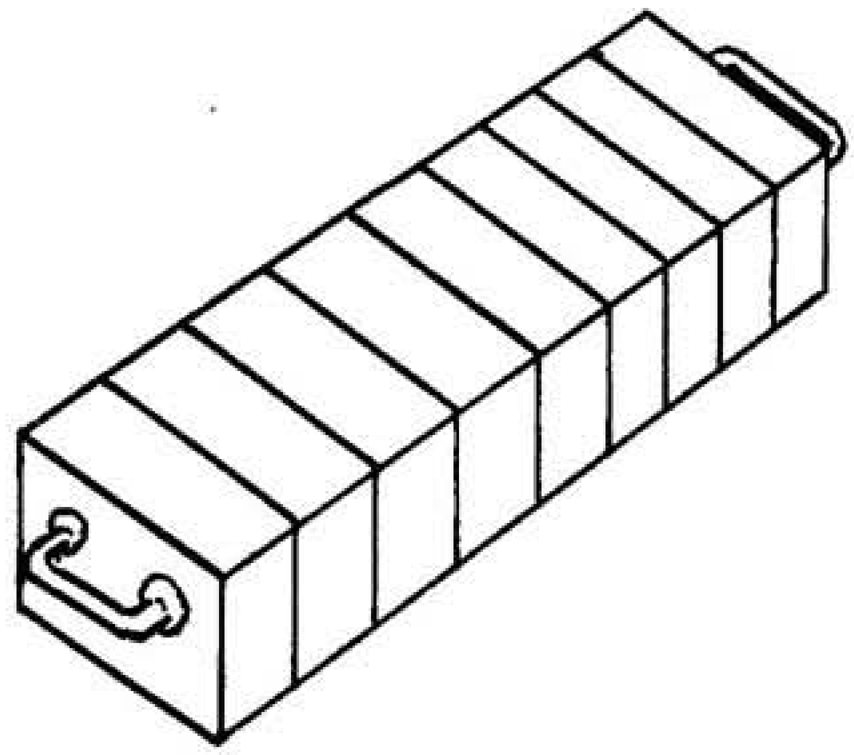
The lid can also be lifted by a set of rope blocks or pulleys suspended above the kiln.

It is possible to design an effective lid to slide to one side of the kiln. The lid should be fitted with rollers and track designed to allow it to rest hard on top of the kiln when in the closed position.

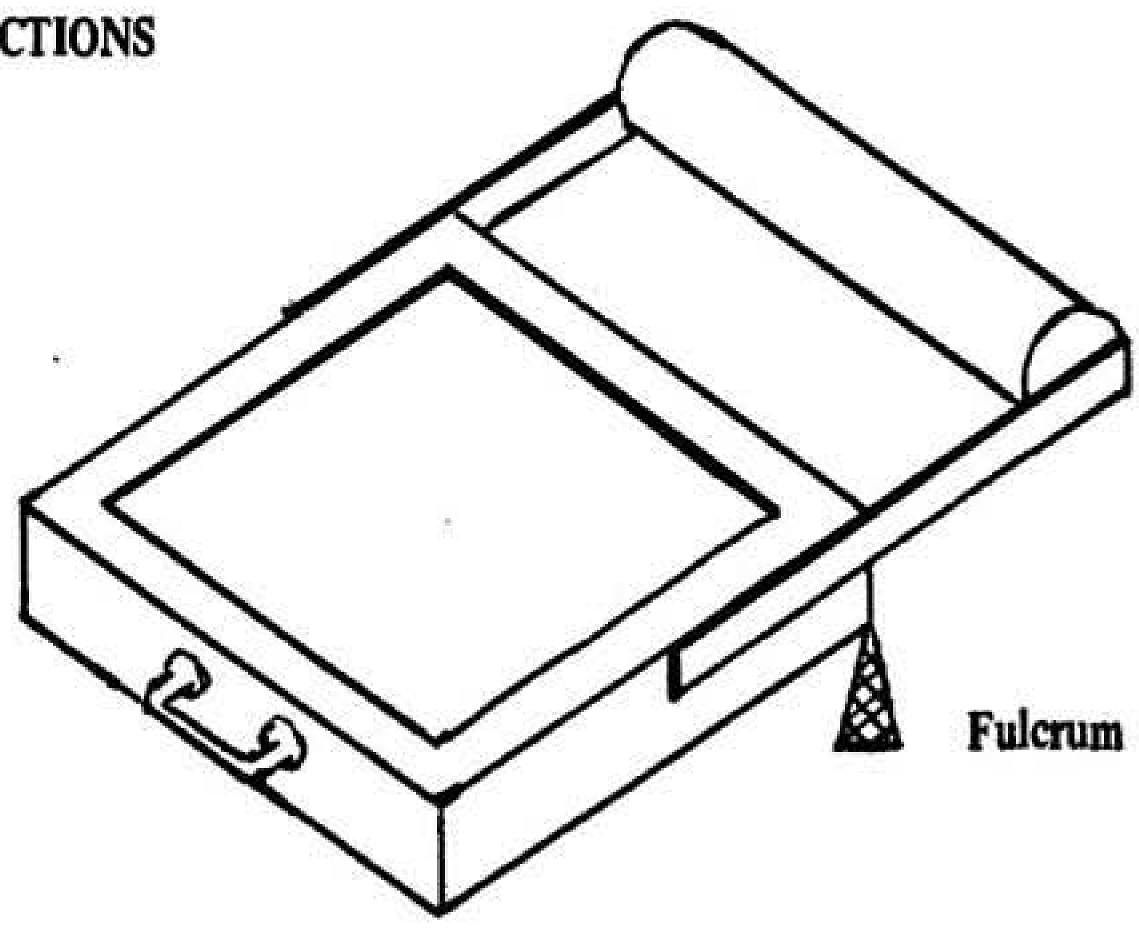
No matter which type of lid is used, there is always a tendency for small chips and flakes to break of, fall into the ware and spoil it.

Now let us consider front loading kilns. They have the advantages of facilitating easier loading of the kiln and are much easier to close and seal.

In many instances a door is built up of firebricks enclosed in a steel frame. The frame is hung on the kiln by means of hinges and some form of door fastening is fitted.

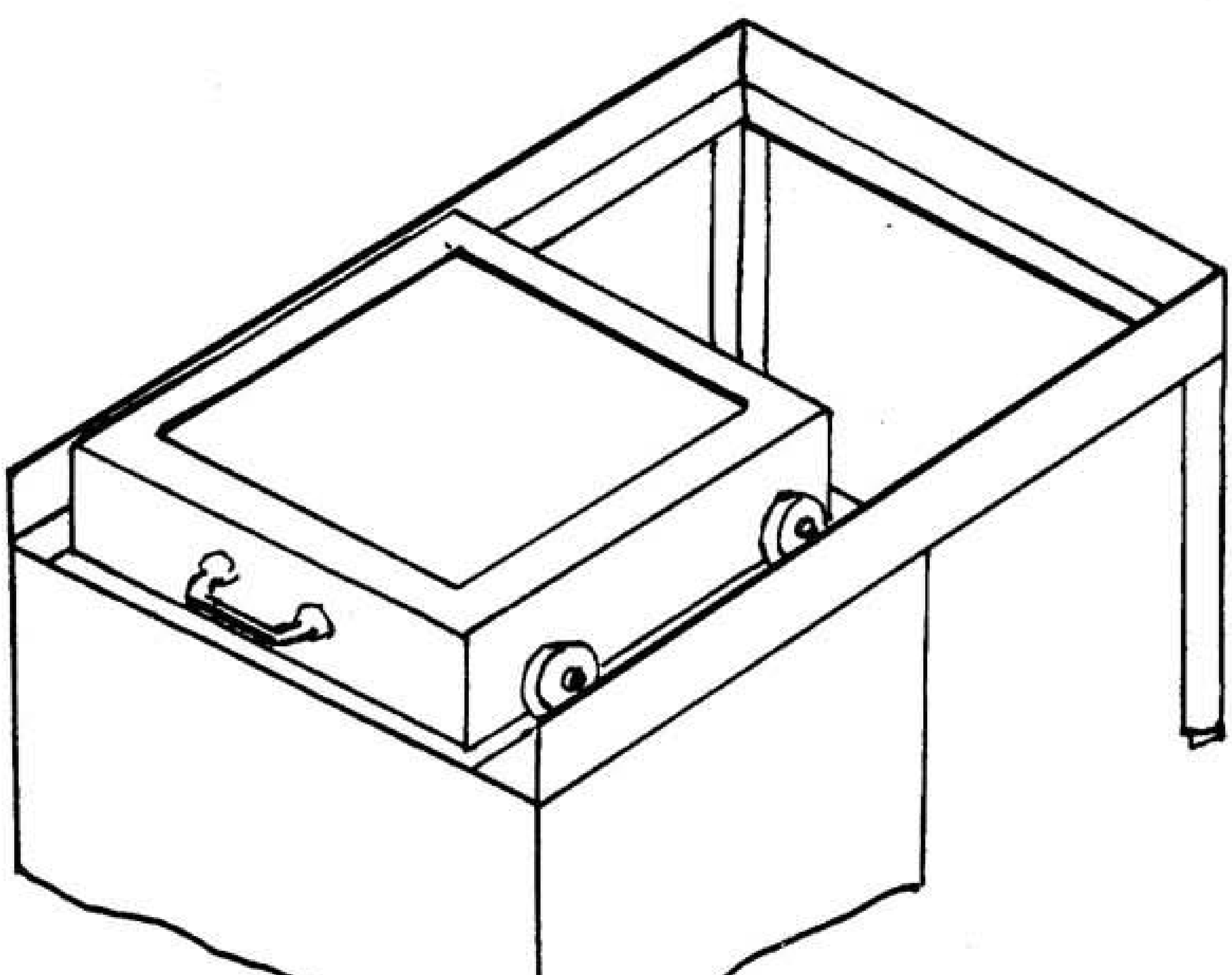


LIFT OFF SECTIONS

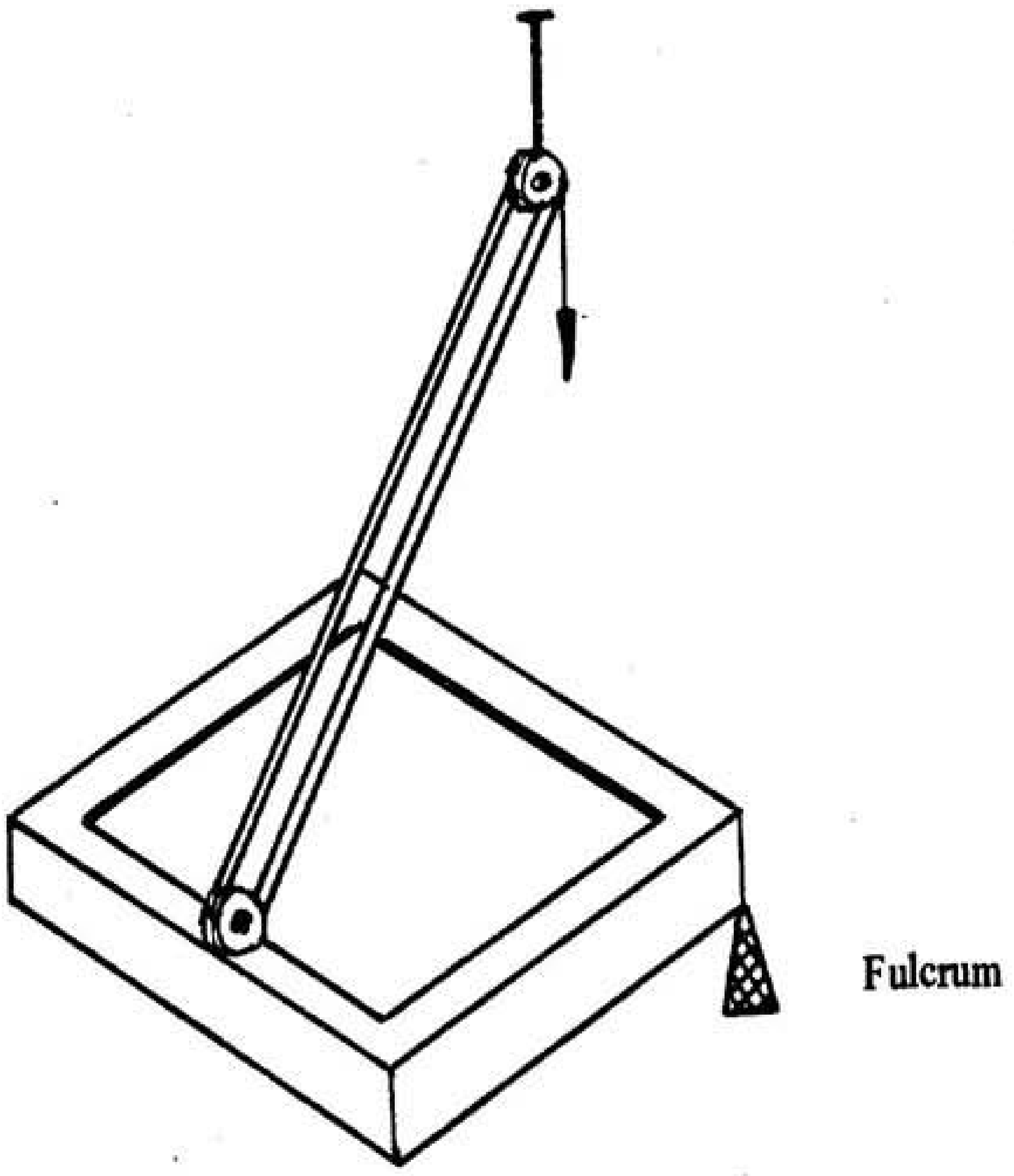


COUNTERWEIGHTED LID

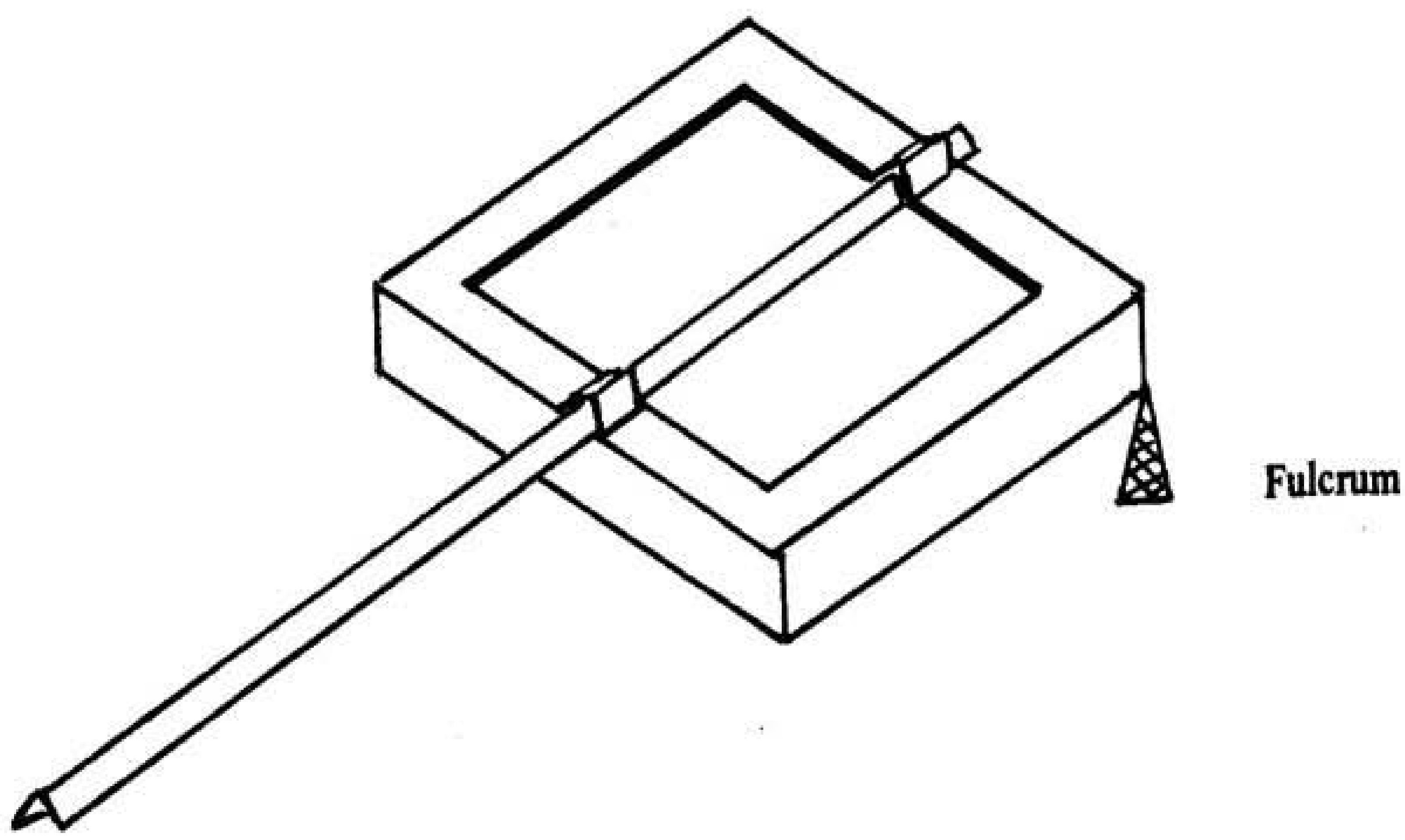
Axles of wheels mounted on eccentrics to allow lid to rest on top of the kiln and make a seal.



SLIDING LID



ROPE BLOCK LIFTED LID



REMOVABLE LEVER LIFTED LID

An alternative method of closing the opening is to use individual bricks stacked to form a bonded wall. The cracks between the bricks are then daubed and sealed with very wet plastic clay. The bricks can be used numerous times. They form a quick, effective and practical door closing.

If a front loading kiln has been decided on, the kiln can have either a flat or an arched roof.

A flat roof lends itself to a simple and cheap structure that is very easy to build. The side walls will not require any extra structural support. However, there are definite limits to the roof span than can be safely designed because of its weight and the resulting bending strain. A flat roof is inherently weak and liable to deterioration due to spalling and cracking which could result in an eventual collapse.

An arched roof, on the other hand, has the advantages of being strong, self locking and self supporting. However, an arched roof kiln is more expensive to build because the side walls must be buttressed against outward movement by enclosing them in a steel frame or case,or using buckstays. The arch requires the more expensive shaped arch bricks and a higher standard of workmanship.

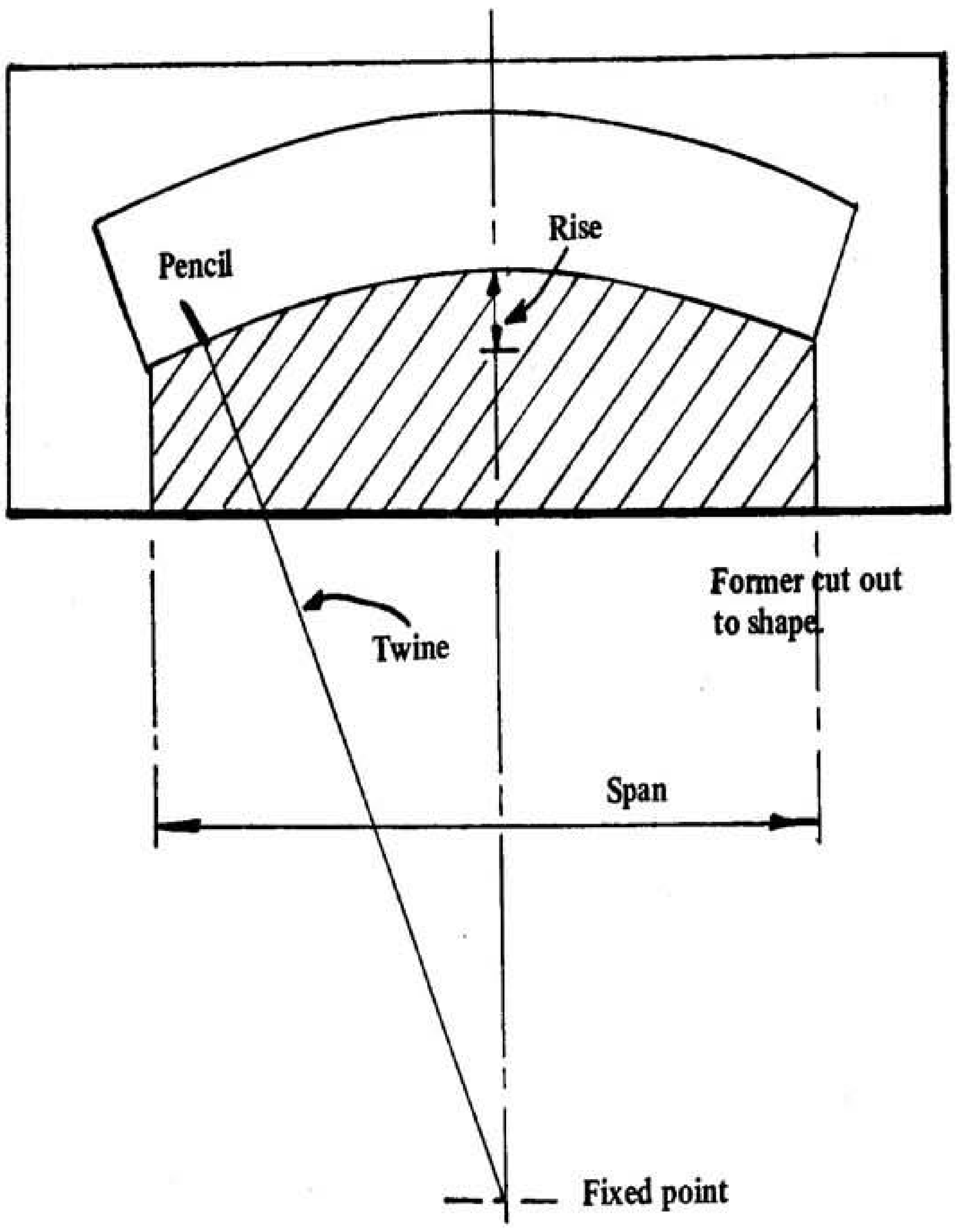
A catenary arch is a variation of the conventional arch and is probably the best compromise because it requires no external supports but has great strength. Whilst the arch can be built from normal sized bricks it is highly desirable to use shaped arch bricks to give it strength and permanence. This, however increases the cost of the kiln. A high standard of workmanship is necessary in building the structure.

A catenary arch can be drawn by simply drawing lines representing the internal dimensions of the base and the height on a board. The board is then inverted and a light chain suspended from the extremities of the base and through the apex. The resulting curve is then transferred on to the board.

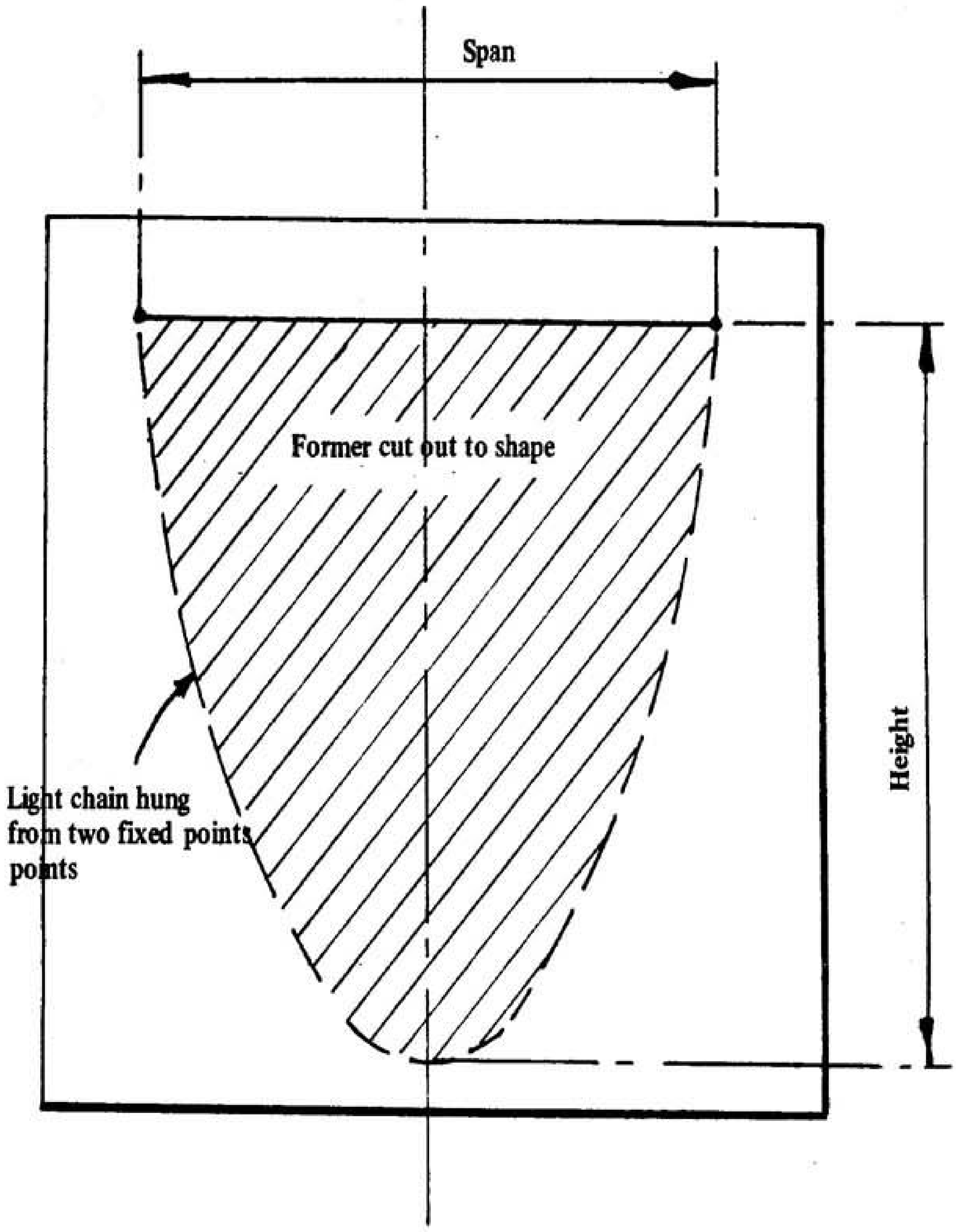
A conventional arch can be designed by setting out full size, both the internal span and the rise on a piece of board. The extremities of the span and apex of the rise give three points which can be joined by using trial and error; using a length of twine and a pencil. The resulting arch on the board can then be cut out to give a former on which to build the arch.

Pottery kiln walls are usually laid dry (without mortar) whilst arches are usually laid with mortar. All kiln joints should be of the very minimum thickness; 1.6mm (1/16") at the most, in contrast to normal 10mm (3/8") joints in normal brickwork.

The internal surfaces should be washed with a sloppy refractory mix to seal the brick joints against the ingress of cold air. It is the ingress of cold air rather than the escape of hot air from the kiln that inhibits adequate temperature rise.



METHOD OF DRAWING CONVENTION ARCH



METHOD OF DRAWING CATENARY ARCH

A FEW WORDS ON BUILDING MATERIALS

Pottery kilns generally do not require any special concrete foundations. In fact concrete can often be a problem because of cracking due to the high kiln temperatures. If it is decided to build a kiln on a concrete floor, such as is found in a shed, special measures must be taken to ensure that the floor does not get unduly hot.
It is perfectly acceptable to build the kiln on good firm earth.

Various materials are available from which to build the kiln. The main properties of these should be recognized and studied so that they may be used to maximum advantage.

The ceramic materials may first be divided into two classes; monolithic and individual bricks.

Monolithic material is used for casting and ramming shapes. Refractory manufacturers sell plastic firebrick materials which can be formed into any shape and used both for construction or repair Such material is a well sized and mixed combination of grog and raw clay. This plastic material, essentially stiff, grogged clay, may be rammed or cast into moulds, or used to patch parts of the kiln which have deteriorated from long use.

It is a tempting idea to cast all the parts of the kiln, including the arch, but certain practical considerations usually rule this out. The containing form work can be complicated and expensive, and if the forms to be cast are bulky, the cost of the refractory material may be considerable. Another disadvantage is the great weight of the cast pieces, making them difficult to move and assemble. Of course, the parts of a kiln may be cast right in place. The arch, for example, may be cast over a stout wooden form which, when removed, will leave the arch in place and resting on the kiln walls. Cast monolithic arches will require less bracing than arches made up of individual brick units. When all the factors are considered, the kiln builder will usually decide on conventional brick construction. But for special shapes such as skewbacks, pieces forming the transition from square brick chimneys to round metal stacks, and door blocks, cast refractories may be ideal.

The use of individual bricks and shapes is the more practical method of kiln building. It is desirable for the sake of fuel economy to construct the main chamber of hot face insulating bricks. The insulating qualities of the bricks limit the escape of the heat through the walls.

Insulating bricks are made from refractory fireclays and kaolins. The clay is mixed into a heavy slip into which air bubbles are induced by chemical means. When the material is set and dried, it is fired and later cut and shaped into sized bricks. The entrapped air pockets make a light porous brick, with high insulating properties and, if made from the proper clay, excellent resistance to heat. Porous bricks are also made by mixing wood fragments with the clay. Bricks are graded according to "K factors" and those sold as "K–30," for example, will withstand 3000^{o} F. without melting, bloating or deformation. Other common grades are K-28, K-26, K-23, K-20 and K-16, serviceable at 2800^{o}, 2600^{o}, 2300^{o}, 2000^{o} and 1600^{o}F. respectively. For earthenware firing up to 1200^{o}C the K-23 is ideal. For stoneware firing up to 1350^{o}C, the K-26 is recommended.

In general the insulating value of this type of brick deteriorates as the maximum allowable service temperature goes up. Hence it is false economy to use a brick with a temperature specification much in excess of that likely to be encountered in service.

Hard firebricks have a heat storage capacity in the order of five times that of soft insulating bricks. This means that they can actually soak up more heat and will take that much longer to cool. If a kiln is made of hard firebricks only, much more heat will be required just to heat up the kiln itself, and fuel costs will be higher, even disregarding the loss of heat through the wall of the kiln.

The decision as to whether to use insulating bricks for the construction of part of the whole of a ceramic kiln is largely a matter of economics. The use of insulation in no way improves the product being fired. It is purely a matter of savings in fuel, and of whether the higher cost of insulating bricks will, in time, be offset by the lower cost of firing. If insulating bricks are used for the inside face of the kiln, an additional factor must be taken into consideration, i.e., the shorter life of soft bricks relative to hard firebrick.

Firebricks may fail in one of three ways depending on the stresses that they are subjected to.
They may melt or deform from excessive heat. Failure of this kind seldom occurs in pottery kilns, where the operating temperature is usually far below the melting point of the refractories.
Bricks may crack or spall. When a brick is heated more at one end than the other, as is usually the case in a kiln, a strain is set up because of the greater expansion in the hotter part. This may cause the brick to break, or a portion of it to flake off (spall), especially if the heating and cooling cycle is rapid. Since pottery kilns are usually heated and cooled rather slowly, the bricks are not subjected to severe shock and tend to have a long life.
Bricks may crumble from fatigue. Repeated heating and cooling loosens the bond between the particles and the bricks gradually lose their original strength.

Besides, insulating firebrick, there are a few other materials that can be used for insulating kilns. Aluminium foil is a useful insulating material. Its reflective surface will deflect and throw back radiant heat. If a layer of foil is placed between the inner and outer courses of a kiln wall, it will serve to deflect part of the heat back toward the inner wall, and will prevent the escape of some of the heat which would otherwise penetrate the wall by radiation.

Vermiculite, especially, is very useful. It is cheap and readily available. It is an expanded mica with a very loose structure yielding innumerable air spaces which impede the flow of heat. Vermiculite can be used as a loose fill over the arch of the kiln, or it may be poured into cavities between the inner and outer wall of the kiln. Another possibility is to form a plaster of vermiculite and clay which can be built up on the outer walls or top of the kiln. A good mixture is 85% by weight of vermiculite and 15% clay. The mixture should be formed into a stiff paste and plastered over the kiln surfaces to form a thick coat.

Finally a useful materials is "Kaowool " which is manufactured in the form of a blanket. It is in various thicknesses that can be cut and used as gasket material between kiln walls and floors.

Insulating bricks are easily cut and filed by standard wood working or metal-working tools. The wear of the tools is however very severe, and the type with replaceable blades is recommended, e.g. "Eclipse" sheet saw No.56 and "Stanley Surform" planes and files. The bricks must be dry for easy cutting.

Hard refractory bricks can be cut with a bolster chisel and hammer or with a special circular saw fitted with an abrasive disc.

Stacks and flues do not need to be made of insulating bricks, but may be constructed of common firebrick, with the proviso that different kinds of bricks will not necessarily bond easily because of possible difference in sizes.

Asbestos millboard is almost useless an an insulator and it tends to disintergrate at high temperatures. Its use should be limited to lining the outside of the kiln to stop the ingress of cold air through the brickwork joints.

In very low cost kilns, ordinary house bricks may be placed round the outside of the firebrick walls and the joints daubed with clay. These form a reasonable insulation barrier.

A wide range of kiln furniture is available from most ceramic material stockists, and the potter must have at least a basic supply of shelves and props on hand. The shelves can be of either high alumina clay or silica carbide. The latter are good heat conductors and are preferred. The correct sizes, should be purchased because they are almost impossible to cut without special equipment. A variety of shelf supports or props of various lengths will also be required to accommodate pots of varying heights.

GAS FUELS

Potters are often confused with the various gas fuels that are available. Many have misconceptions regarding a number of aspects; such as correct nomenclature of the different gases and their advantages and limitations.

As discussed previously, potters can ignore any difference in flame temperatures of the various gases. In other words, all the gases generally available to potters will produce identical results providing the burner orifices have been sized correctly. Calculation of orifice sizes should be left to your Gas Authority who will have the necessary data on which to base them.

The gases generally available to potters in Australia, depending on their geographical location include:–

Natural Gas (NG) which is available in the metropolitan areas of most States in Australia. It contains about 90% methane (CH_4) together with small proportions of other hydrocarbon gases.

Manufactured or Towns Gas (TG) which is either produced from the carbonization of black coal in retorts or from liquid feed stock (usually naptha) in catalytic reformers. The feed stock is subjected to the pressure and heat of steam as it flows over a nickel catalyist. This has the effect of converting the liquid to a gas.

Liquefied Petroleum Gas (LPG) which is usually propane (C_3H_8) and is supplied, under high pressure, in liquid form, in either cylinders or ex road tankers into the customers bulk tank. It evaporates into gas as it is drawn off the bottle or bulk tank for use in the burners. Liquified petroleum gas is often incorrectly referred to as Low Pressure Gas.

Simulated Natural Gas (SNG) which is produced by mixing propane and air in correct proportions to make a gas suitable for general street reticulation. It often substitutes for natural gas in some country towns where it would be uneconomical to take normal natural gas.

Like any other commodity, all gases have certain characteristics which are used to identify, describe and measure them.

The main characteristics of gases are:

Gross Calorific Value (C.V.) is the all important measurement of the quantity of heat. It is usually expressed in heat units per unit volume or weight of gas and is generally referred to merely as calorific value. The units are:

Natural Gas – megajoules per cubic metre
Liquefied Petroleum Gas – megajoules per kilogram

Specific Gravity (S.G.) is measured against air which is taken as one (1.0). Most gases are lighter than air and if they escape prematurely they will rise and therefore tend to dissipate easily and in some measure, safely. However, liquid petroleum gas (LPG), is heavier than air and if it escapes will settle to the lowest point. This will cause a potential hazard; especially if it escapes in a confined space.

Flame Speed is a measure of how fast the flame burns back on to the burner port. It is necessary that a flame burns back to the burner port to have flame stability. The greater the flame speed of a gas, the more stable will the flame tend to be. There is however, a limiting factor which occurs if the gas speed gets so low that the flame lights back to the burner orifice. This will occur if a burner is turned down too low. A high flame speed usually indicates that a gas contains a high percentage of hydrogen (H_2) which has the highest flame speed of any gas.

Air–Gas Ratio is the ratio of the exact proportions of air and gas required to provide enough oxygen for complete or stoichiometric combustion. If a lesser proportion of air is provided, a reducing or carbonizing condition will result in the kiln space. Whilst a greater proportion of air will result in an oxidizing atmosphere.

Stoichiometric Air-Gas Ratio is the ratio of the exact proportions of air and gas required to provide enough oxygen for complete combustion. If a lesser proportion of air is provided, a reducing or carbonizing condition will result in the kiln space, whilst a greater proportion of air will result in an oxidizing atmosphere.

GAS	SYMBOL	GROSS CALORIFIC VALUE (CV)	SPECIFIC GRAVITY (SG)	FLAME SPEED	STOICHIO-METRIC AIR GAS RATIO	IGNITION TEMP. °C.
NATURAL GAS	NG	39.3 (1050)	0.6	0.3	10:1	615
LIQUID PETROLEUM GAS	LPG	93.6 (2500)	1.5	0.46 (1.5)	24:1	485
SIMULATED NATURAL GAS	SNG	50.5 (1350)	1.4	0.45 (1.47)	12:1	485
MANUFACTURED OR TOWN GAS	TG	18.7 (500)	0.5	1.13 (3.7)	5:1	530

GROSS CALORIFIC VALUE: Megajoules per cubic metre (BTU/ft^3)

FLAME SPEED: Metres per second (ft/sec.)

GETTING THE GAS TO THE KILN

Gas may be supplied from either underground street mains as is the case with natural and manufactured gases, or bottles and tanks as with liquid petroleum gas (LPG)

Mains gas is usually supplied at the customer's front boundary at a pressure of 1 kPa (4" wg). If the customer is already using gas for domestic purposes it will be most likely that the gas meter will have to be changed, and a larger one installed.

Normal domestic gas outlet pipes from the meter are usually too small to carry sufficient gas for most pottery kilns. A larger diameter pipe must then be installed to carry both the domestic and the pottery kiln supply. The outlet service to the kiln should be installed underground although in some circumstances gas authorities will permit the pipe to be installed above ground.

Potters should get advice from the Gas Authority regarding the minimum size pipe that can be installed. The greater the gas consumption of the kiln and the longer the length of pipe from the meter to the kiln, the larger must be the diameter of the gas pipe. If the pipe is too small in diameter the gas pressure at the kiln will be too low for satisfactory operation of the burners.

Liquefied petroleum gas (LPG) supply must be installed in accordance with the respective State Government Regulations. In South Australia these are set out in "Regulations under the Liquefied Petroleum Gas Act – 1960". Your Gas Authority will advise you.

Whilst the regulations under the Act cover the installation of quite large storage tanks, because of rigid safety standards, the only practical storage facilities that meet the requirements are manifolded 45kg (100 lb) bottles, up to a maximum of four bottles or 190kg (400 lb) storage tank.

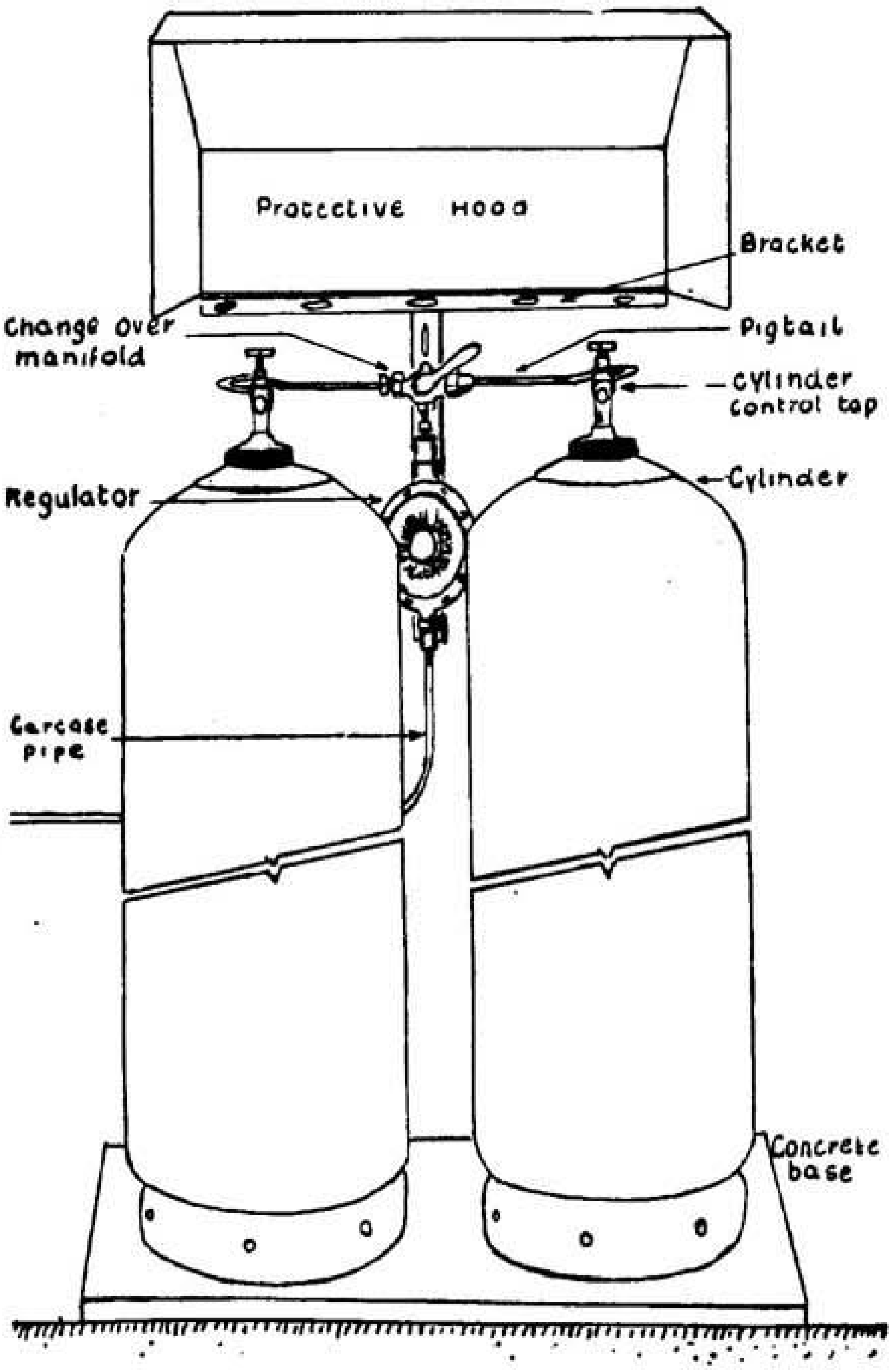
The gas, while in the cylinders and tanks is actually in liquid form and has a vapour pressure of approximately 830 kPa (120 psi). As the gas is being used the vapour is boiled off the surface of the liquid and leaves the vessel through a regulator valve which controls the pressure of the reticulation system.

It is most important that the storage vessel is correctly sized because if it is too small the liquid will freeze due to the refrigerating effect of the vaporizing gas.

If, in particularly cold weather this does happen, water trickling over the bottle from a garden hose can sometimes provide enough latent heat to vaporize the gas and allow the firing to be completed.

Because of this refrigeration effect, in practice, kilns fired on liquid petroleum gas are restricted to a maximum volume of about $0.5m^3$ (20 cu.ft) unless it is possible to comply with the regulations for the installation of a large tank.

The gas can be reticulated from the vessel at either high or low pressure.
High Pressure (HP) reticulation is anything from 35kPa (5 psig) to approximately 200 kPa (30 psig). The advantages of this system is that pipes of smaller bore can be used and the gas equipment is also smaller. It also allows a very wide range of heat inputs. On the other hand the burners can be relatively noisy.
Low Pressure (LP) systems are normally reticulated at 2.7 kPa (11" wg).



TWO BOTTLE LPG INSTALLATION

If 45kg bottles are used, a minimum of two should always be installed, one in operation and one in reserve. In the case of a four bottle installation, two should be in operation and two in reserve. If reserve bottles are not installed, the potter will almost certainly find that he runs out of gas during a firing and suffer the resulting frustration.

190kg (400 lb) storage tanks must be installed in a location sufficiently close to the kerbside to allow the road tanker to be able to refill it. The Gas Authority should be consulted; but usually if it can be positioned within 20 metres (66ft) of the kerbside it is acceptable.

The storage area must be kept clear of inflammable material and undergrowth. Bottles and tanks must be a safe distance from the kiln.

BURNER TYPES AND OPERATION

All gas flames may be characterised into two general types:–

Neat flames where the gas issues neat from the burner port and must receive all oxygen to support combustion by mixing intimately with the surrounding air. It follows that there must be a high degree of turbulence in the gas to ensure adequate intermixing with the air.

Bunsen flames have all or a greater part of the air needed for combustion (termed primary air) mixed with the gas before it issues from the burner. Additional air from the surrounding atmosphere entrained in the flame is termed secondary air.
Pottery kilns almost always utilise burners with this type of flame.

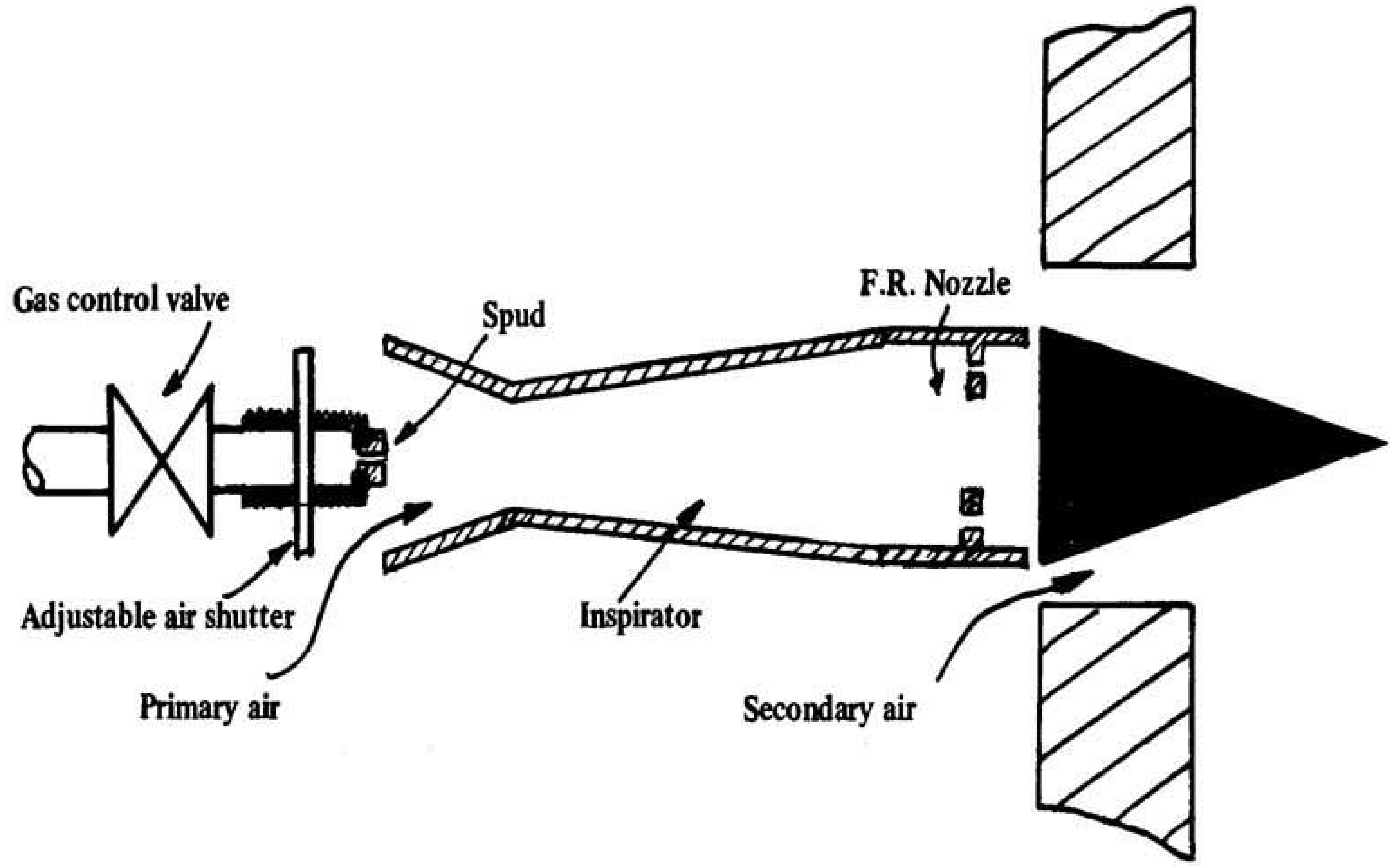
Gas burners may be divided into two general types:–

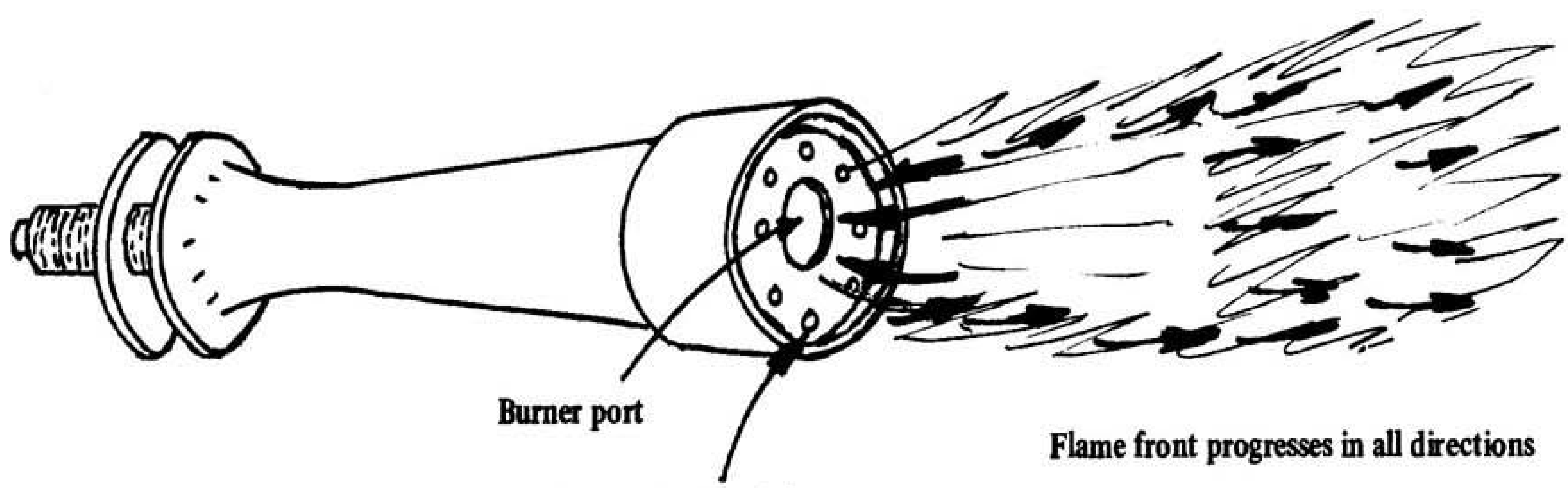
Forced draught in which all or most of the combustion air is provided by a fan or compressor. Forced draught burners can be subdivided into:

> Nozzle mix in which the gas and air are piped separately to the burner and mixed at the nozzle. This gives extremely good combustion control including an excellent turn down ratio. Pre-mix where the gas and air are mixed before entering the burner body. This gives the characteristic of exact air-gas proportioning throughout the turndown range. It is somewhat of a disadvantage in pottery kiln work because of the varying kiln atmospheres required.

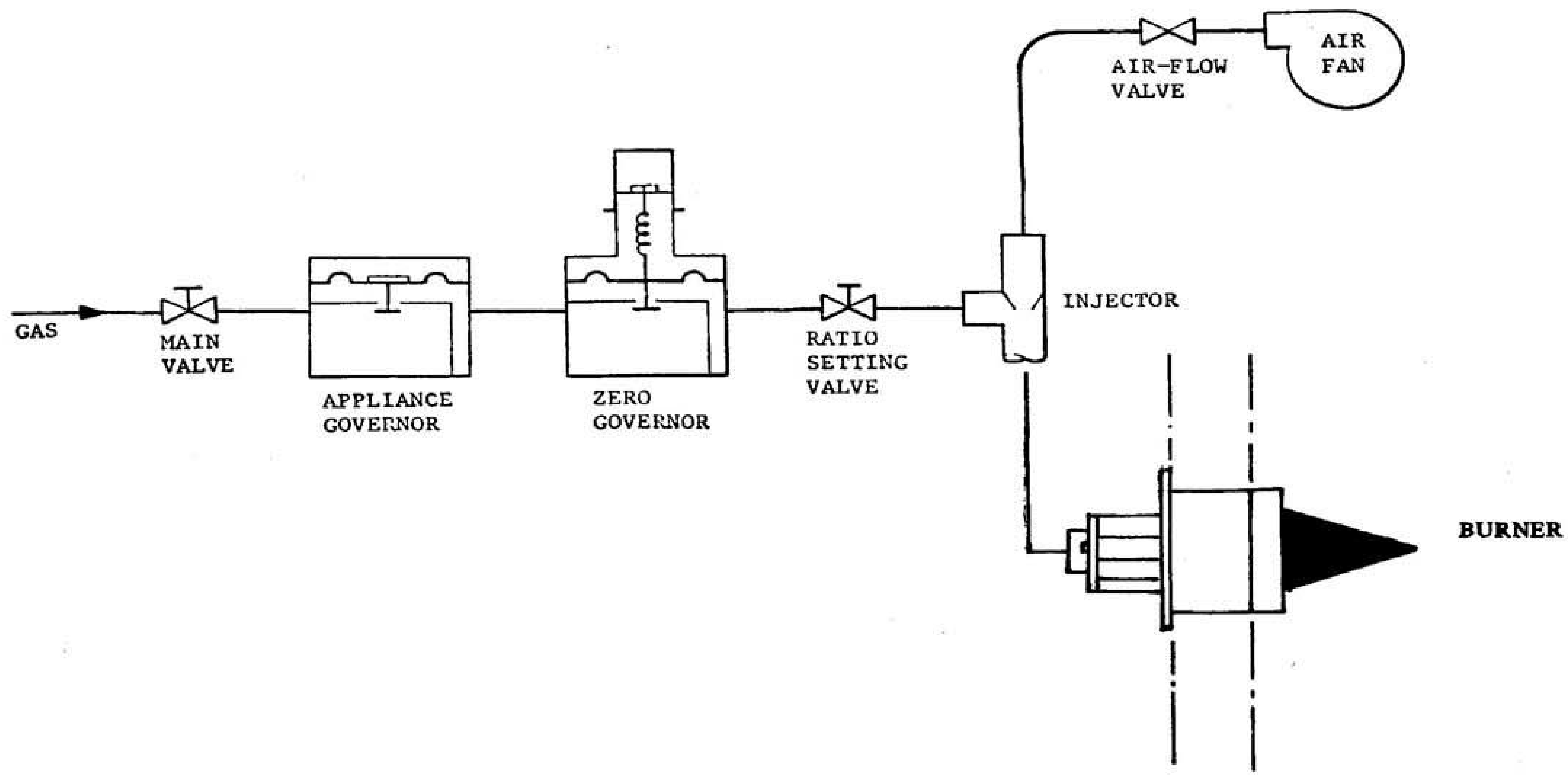
Whilst forced draught burners give a greater output for a given burner size, they are not generally used on pottery kilns because they are much more expensive to purchase and operate. They can also be comparatively noisy in operation.

Natural draught which is by far the most popular type of burner for pottery kiln work.
Essentially, it has an inspirator that mixes the gas with a proportion of the total air required for complete combustion and a nozzle which has flame retention qualities. Various types of inspirators are available; including both short and long pattern types.

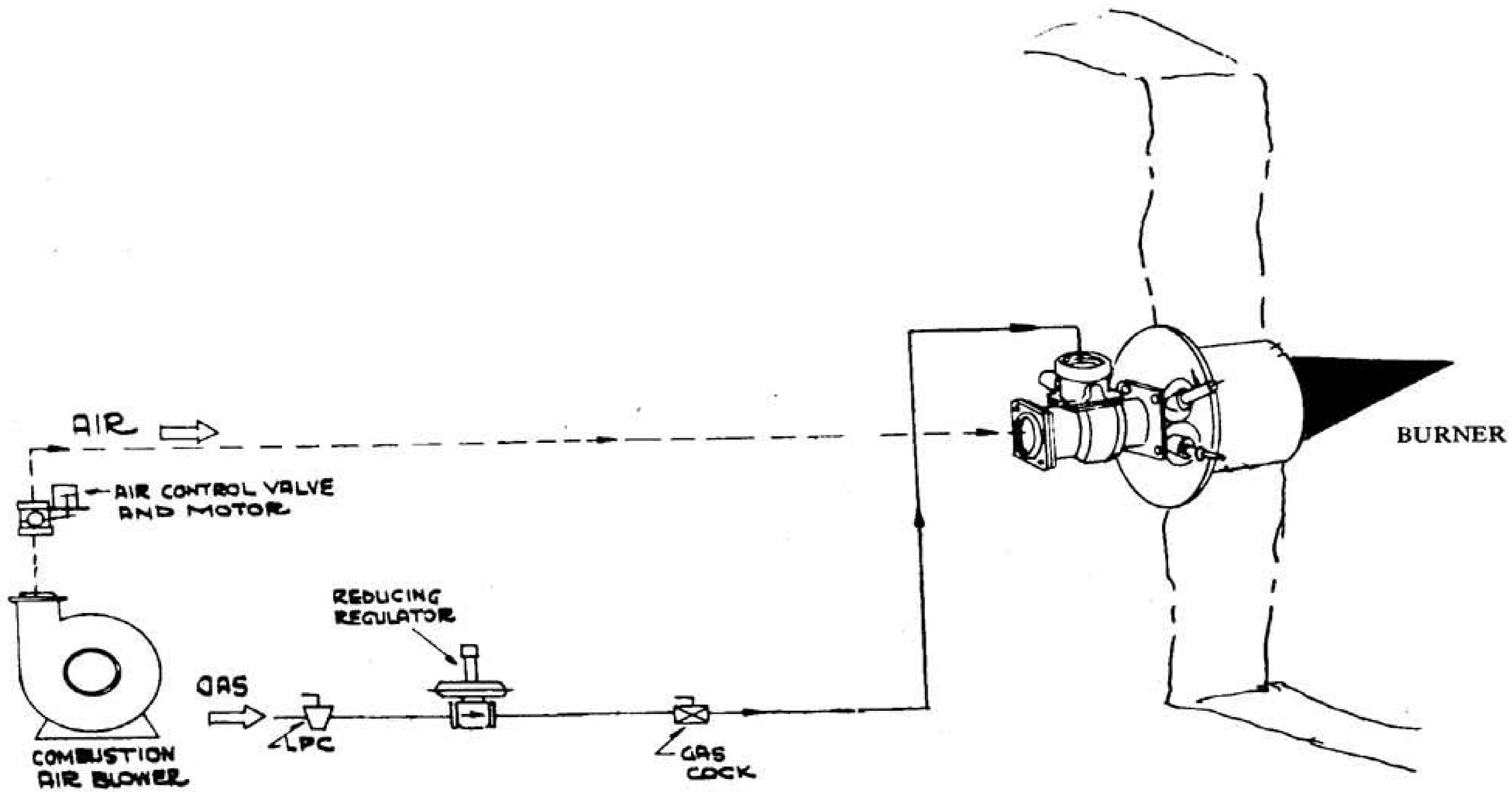




NATURAL DRAUGHT BURNER



PRE-MIX BURNER SYSTEM



NOZZLE MIX BURNER SYSTEM

However, they all work on the same principle.

The purpose of the inspirator is to induce air into its body due to the venturi effect caused by the energy of the gas stream. The amount of air mixed with the gas can be adjusted by varying the position of the air shutter. The balance of the air required for combustion, called secondary air, is obtained from openings in the kiln around the burner nozzles. The nozzle usually obtains its flame retention qualities from a ring of small holes positioned around the large centre hole. These small holes reduce the velocity of the mixture allowing it to burn immediately on the nozzle. This lends stability to the main flame. If the gas cock is closed too much, the velocity of the mixture will fall below the flame speed of the gas allowing the flame from the burner nozzle to travel back up the inspirator and burn at the inspirator jet. This must be avoided. The ratio between full flame and the lowest stable flame obtainable is called the "turn down ratio ". The turn down ratio usually obtainable is in the order of 4:1. Higher gas pressures allow higher turn down ratios.

The air shutter, in addition to this normal function of being used to adjust the air-gas ratio for stoichiometric combustion, is also used to obtain reducing atmosphere. This is achieved by closing it to limit the primary air entering the burner, resulting in a gas rich flame.

ESSENTIAL GAS TRAINS

The configuration of valves and other fittings that convey the gas from the supply pipe to the burners is known as the gas train.

All gas trains have essential elements which are incorporated to satisfy safety requirements.

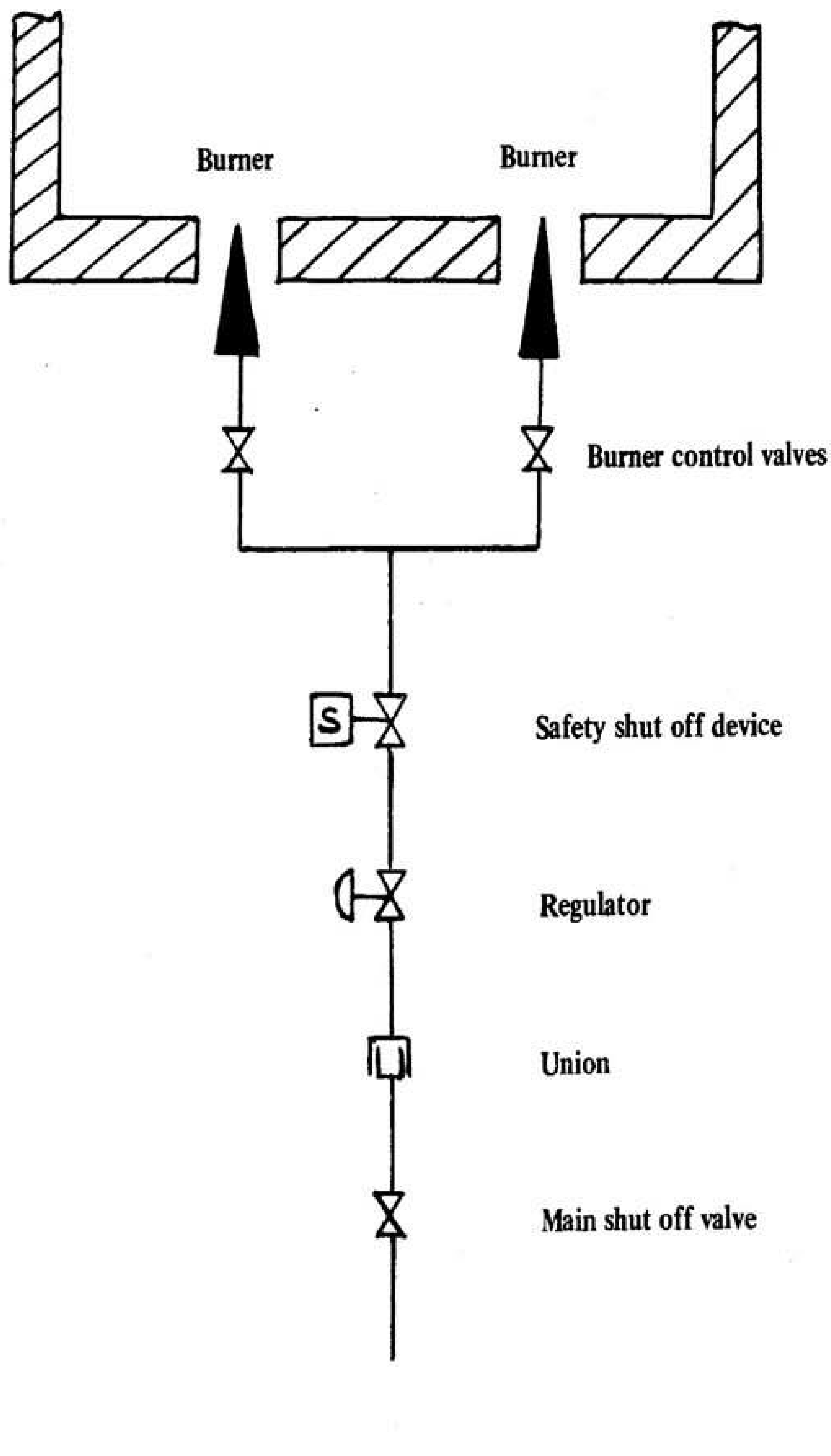
Mains gas trains must always start with a main shut off valve or cock so that the subsequent gas train may be disconnected with safety. A barrel union is the next fitting to facilitate the easy removal of the rest of the train.

A regulator or governor must follow. This automatically regulates the pressure of the gas to the burners. It irons out any pressure variations and gives a constant pressure at its outlet. In this way the burners will give constant heat output irrespective of any variation in pressure that is caused by other gas appliances on the property being turned on and off.

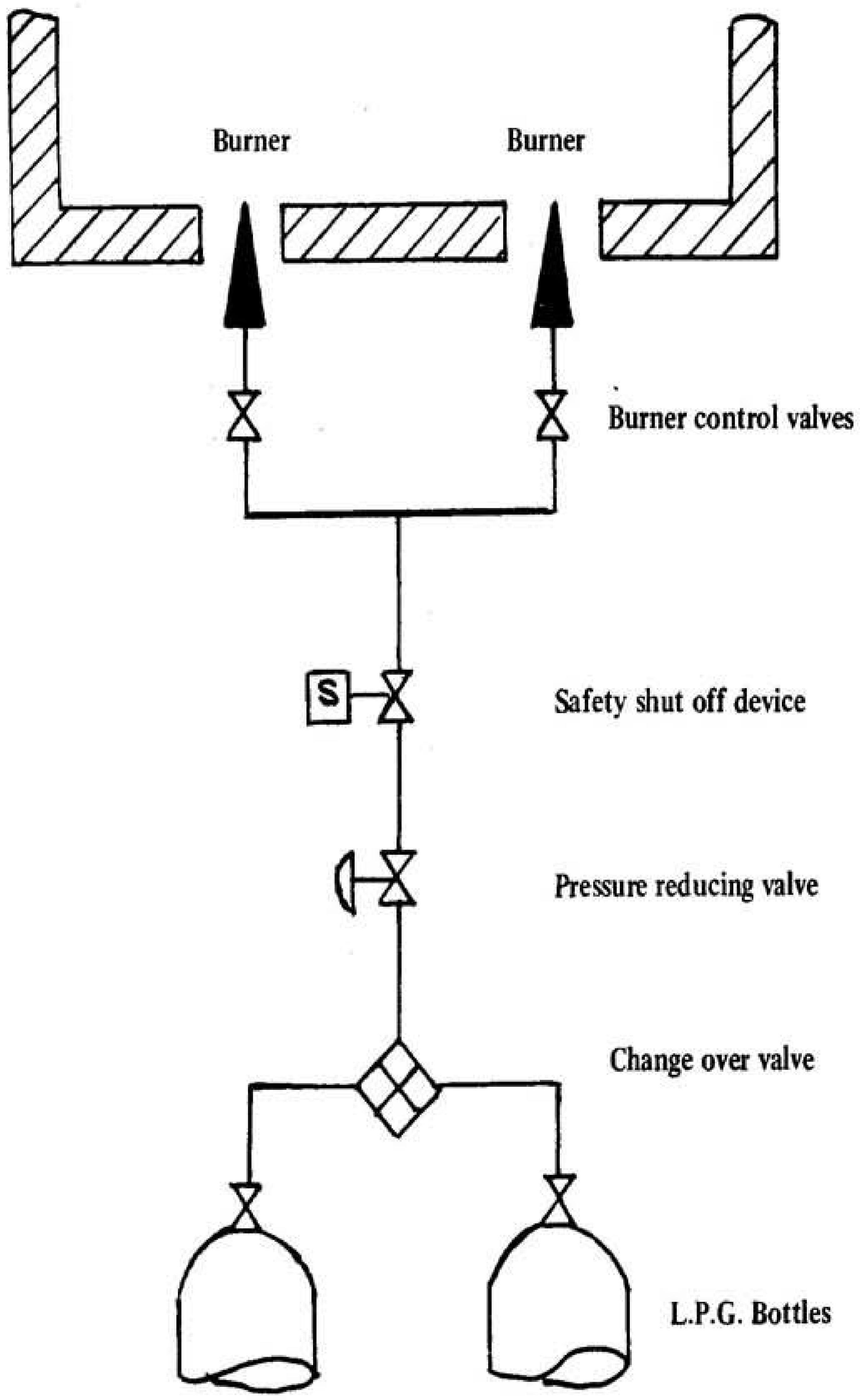
A safety shut off valve is then fitted which will automatically shut the supply off if a temporary gas failure should occur. The valve is so designed that it ensures that someone must be present to reset it manually after the gas supply is restored. Thus the uncontrolled escape of gas into the kiln is prevented. A more satisfactory alternative to this last valve is to have a thermo- magnetic flame failure valve which will shut off the gas supply should any flame failure occur.

Individual burner control valves or cocks must then be provided to control the gas at each burner.

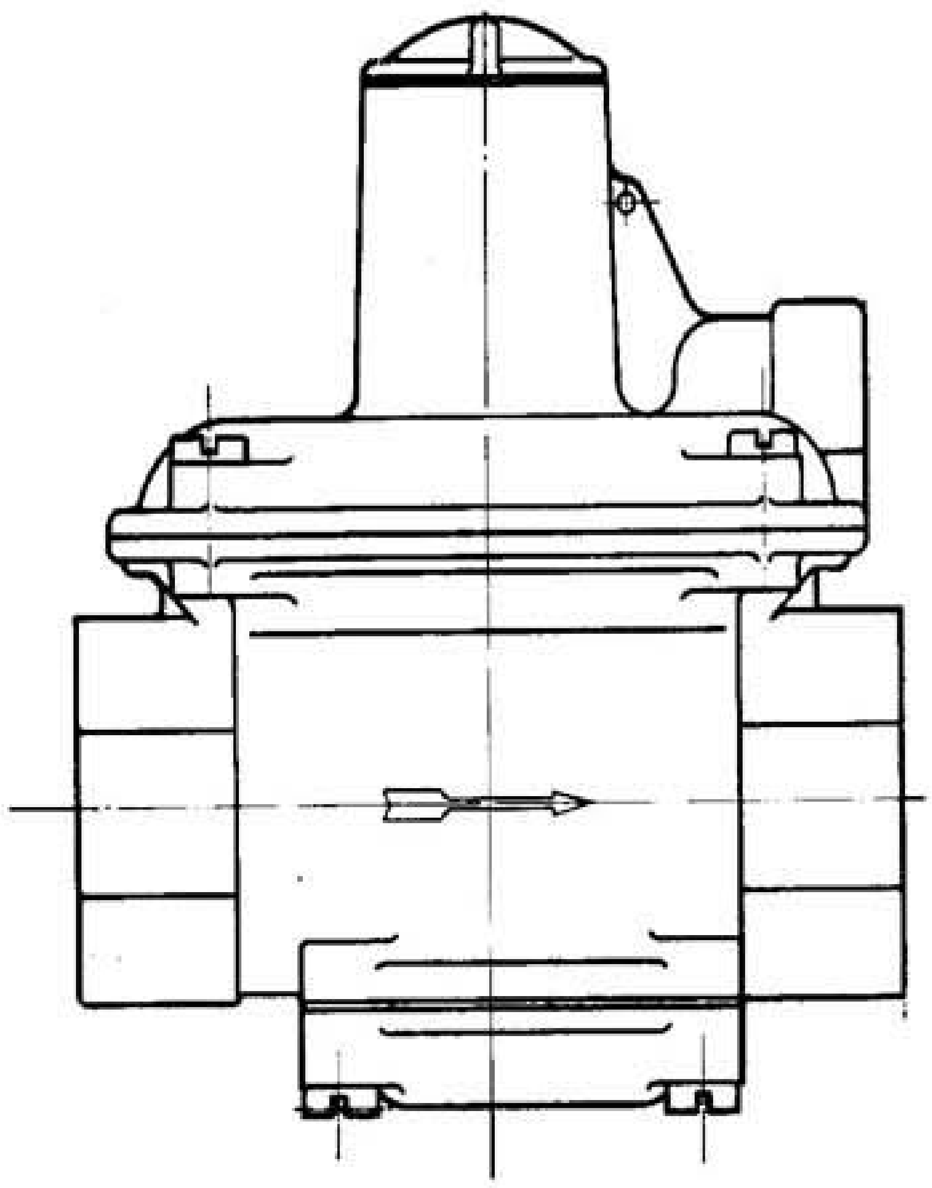
Liquid petroleum gas (LPG) trains are of much the same configuration. In the case of a gas cylinder installation, the gas train should start with either a manually or automatically operated changeover valve.

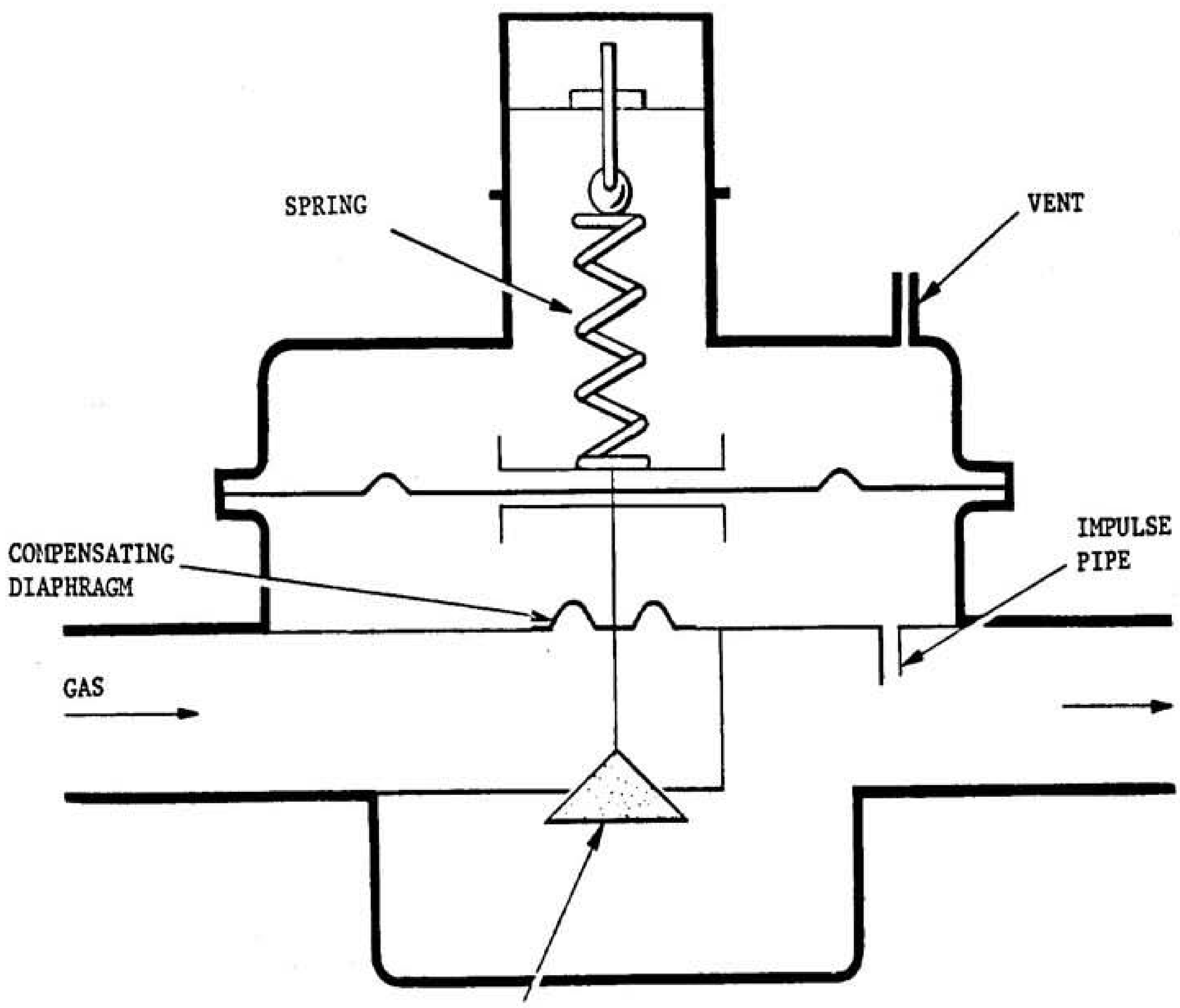


ESSENTIAL MAINS RETICULATION GAS TRAIN

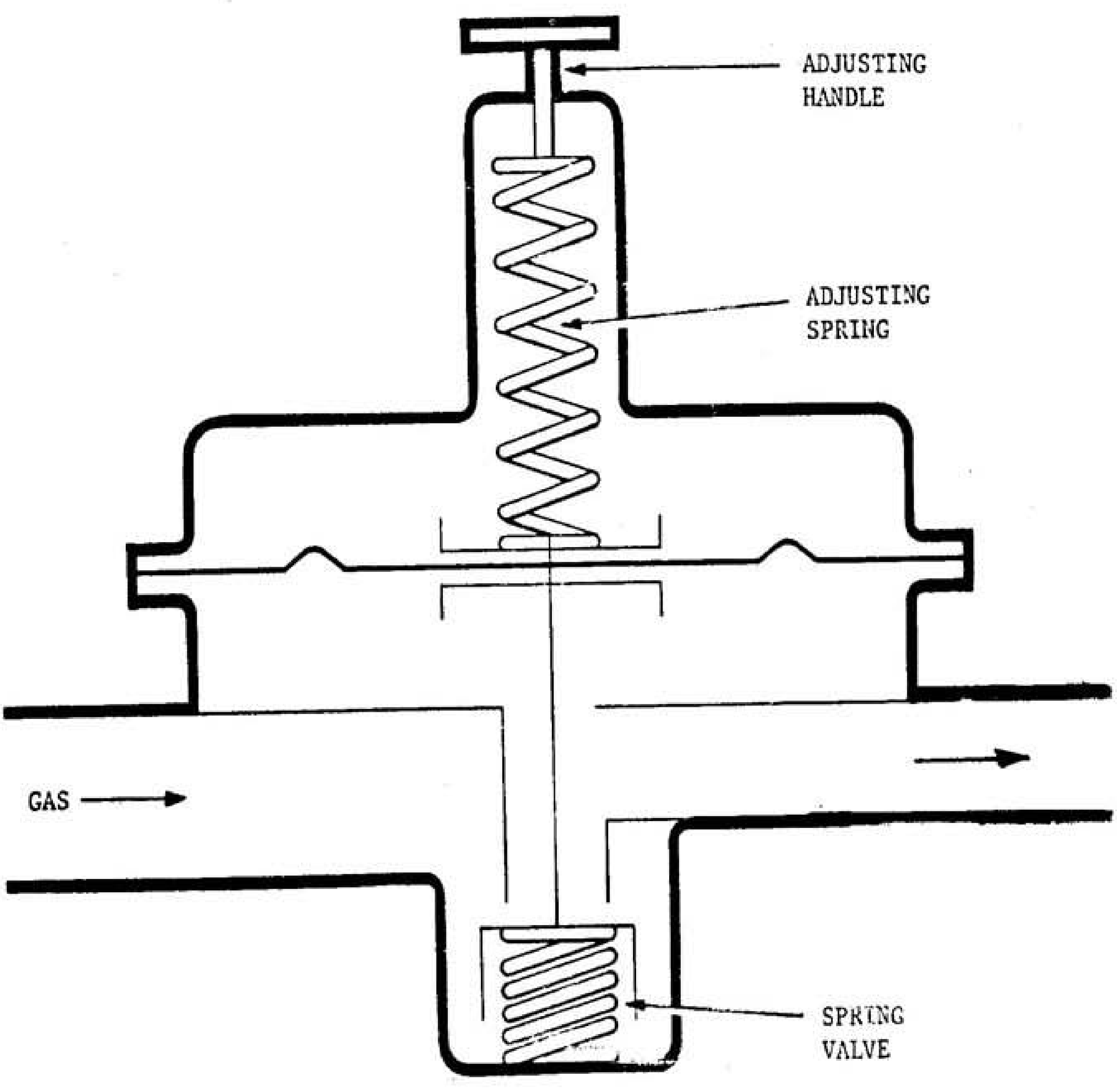


ESSENTIAL LIQUEFIED PETROLEUM GAS (L.P.G.) TRAIN

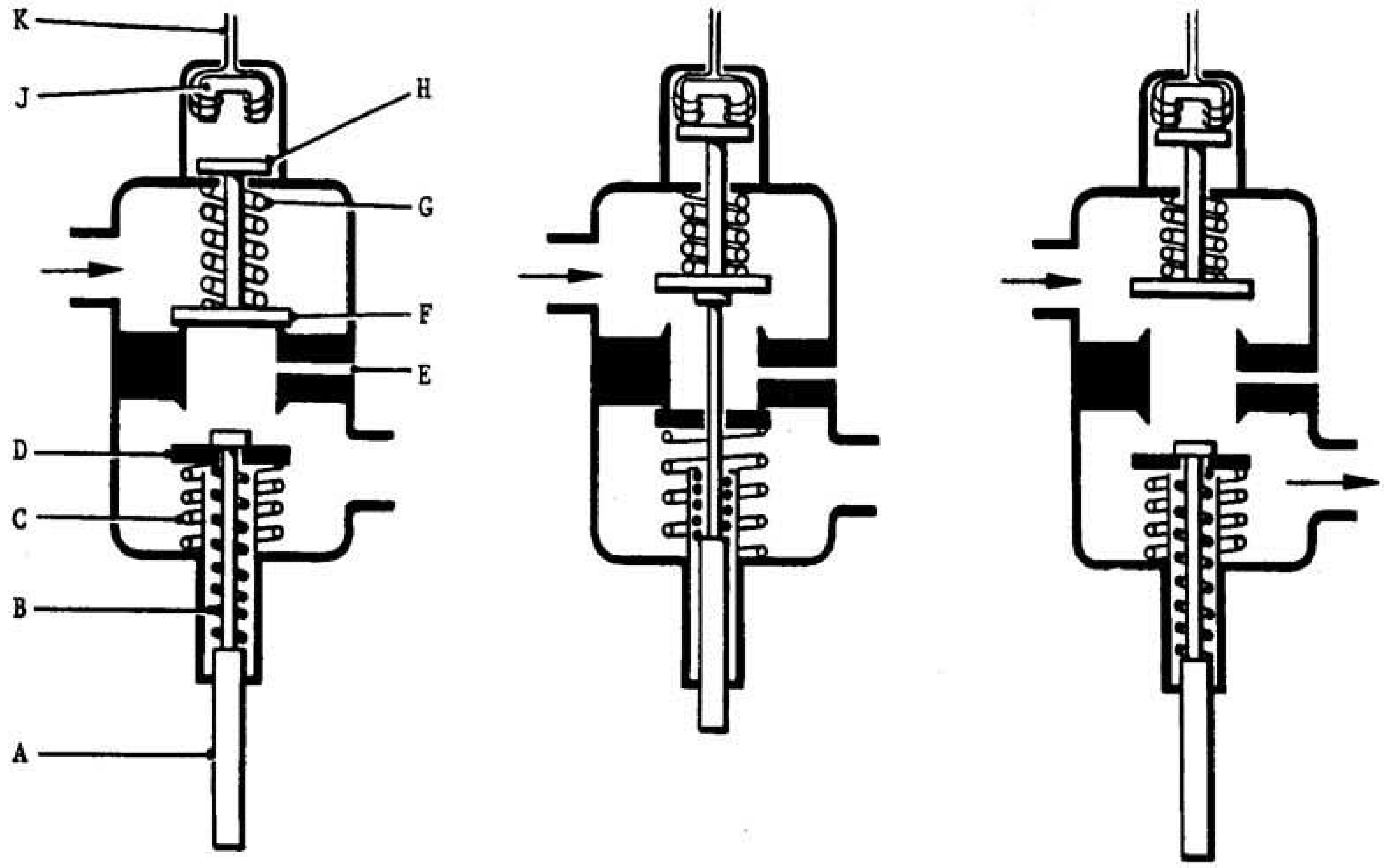




LOW PRESSURE GAS GOVERNOR OR REGULATOR

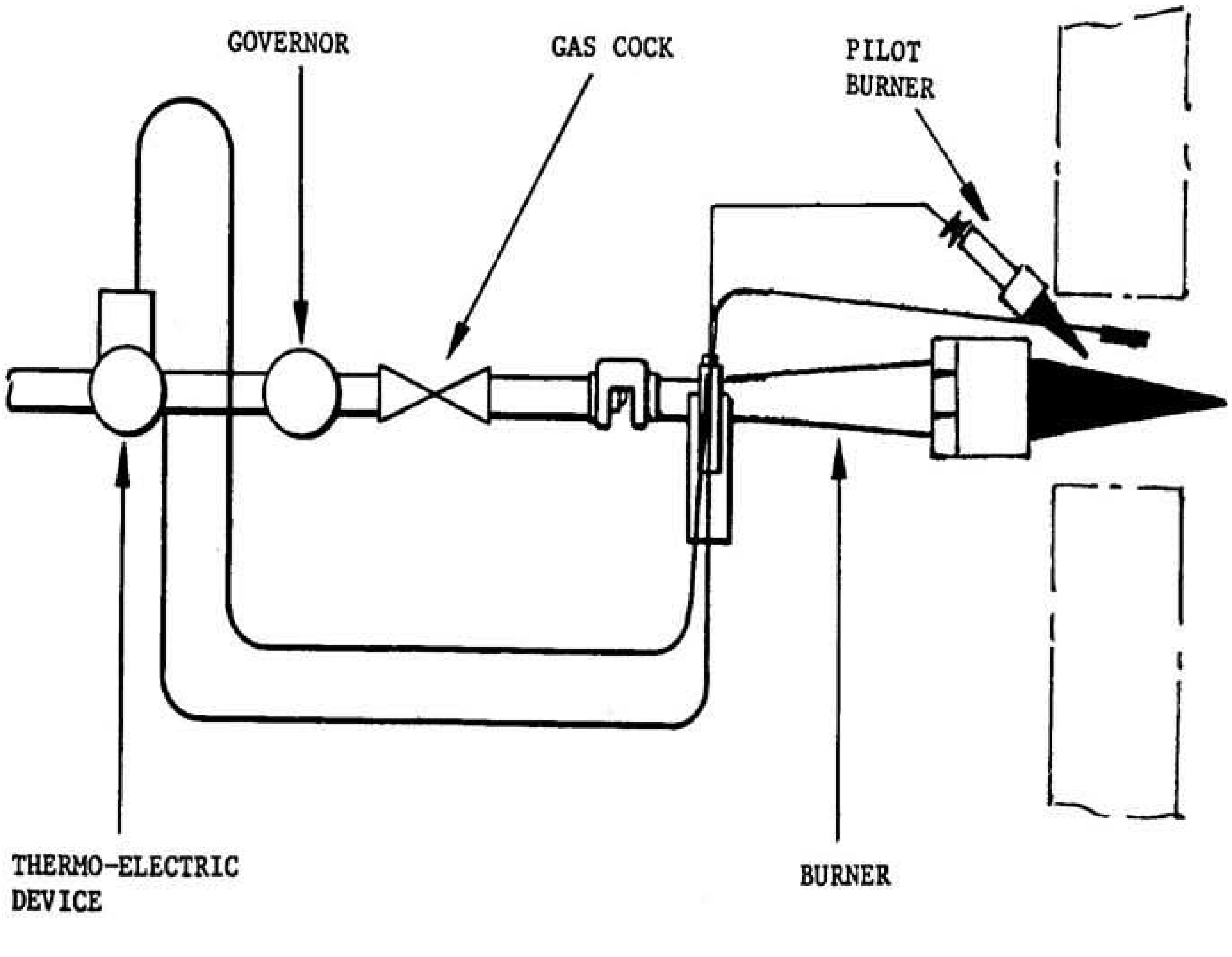


HIGH PRESSURE LPG REDUCING VALVE

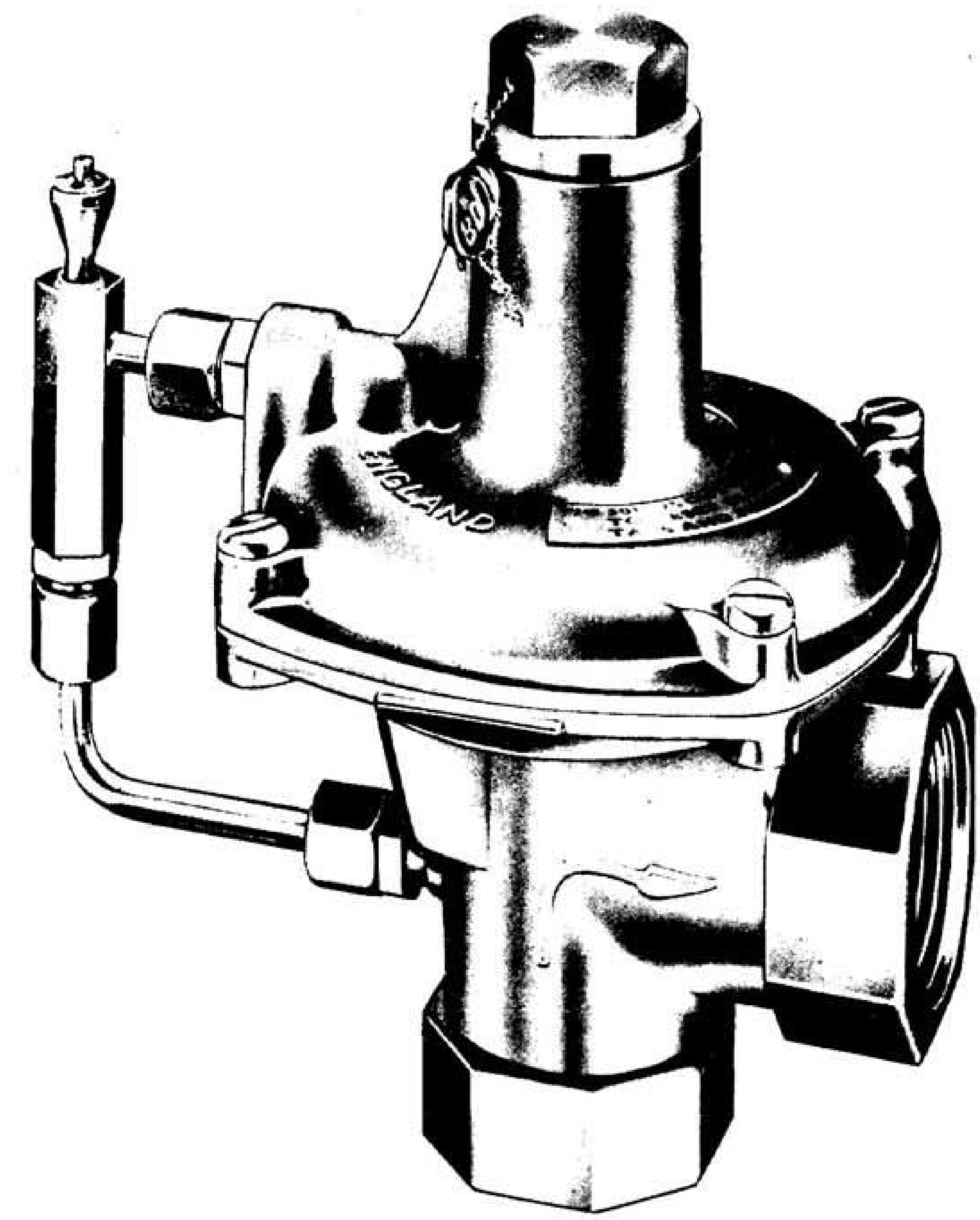


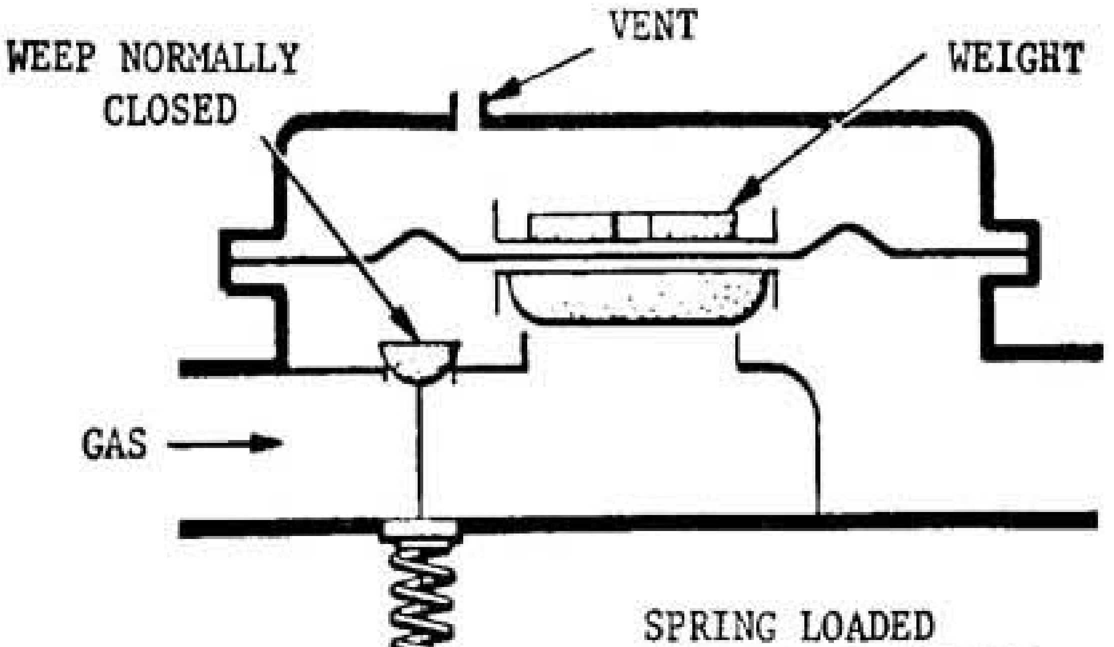
KEY

A. RESET BUTTON
B. RESET BUTTON SPRING
C. FLOW INTERRUPTER SPRING
D. FLOW INTERRUPTER VALVE
E. PILOT CONNECTION
F. MAIN VALVE
G. OPERATING SPRING
H. ARMATURE
J. MAGNET ASSEMBLY
K. THERMOCOUPLE LEAD



THERMO-MAGNETIC FLAME FAILURE VALVE





LOW PRESSURE GAS CUT OFF VALVE

The next fitting in the train is a regulator; the main function of which is to reduce the gas to the burner operating pressure and also to keep it at a constant level.
A flame failure valve is next in the train to shut the gas down automatically should flame failure occur.

Burner control valves or cocks are provided to regulate the gas to individual burners.

Many kilns are fitted with a smaller pilot burner for each main burner. This serves the dual functions of being able to cross light the main flame in the event of any flame instability and is used as a low heat input burner in the very early part of the burning cycle when temperature rise inside the kiln must be limited.

THE SUCCESSFUL AND SAFE FIRING OF GAS KILNS

Providing common sense is used in the designing, locating and operating of your kiln, it can be used with confidence. The following points should be taken into consideration.

The kiln must be placed in a location that affords adequate permanent ventilation and sufficient working space around it.

The floor must be both fire resistant and of sufficient strength to bear the weight of the kiln.

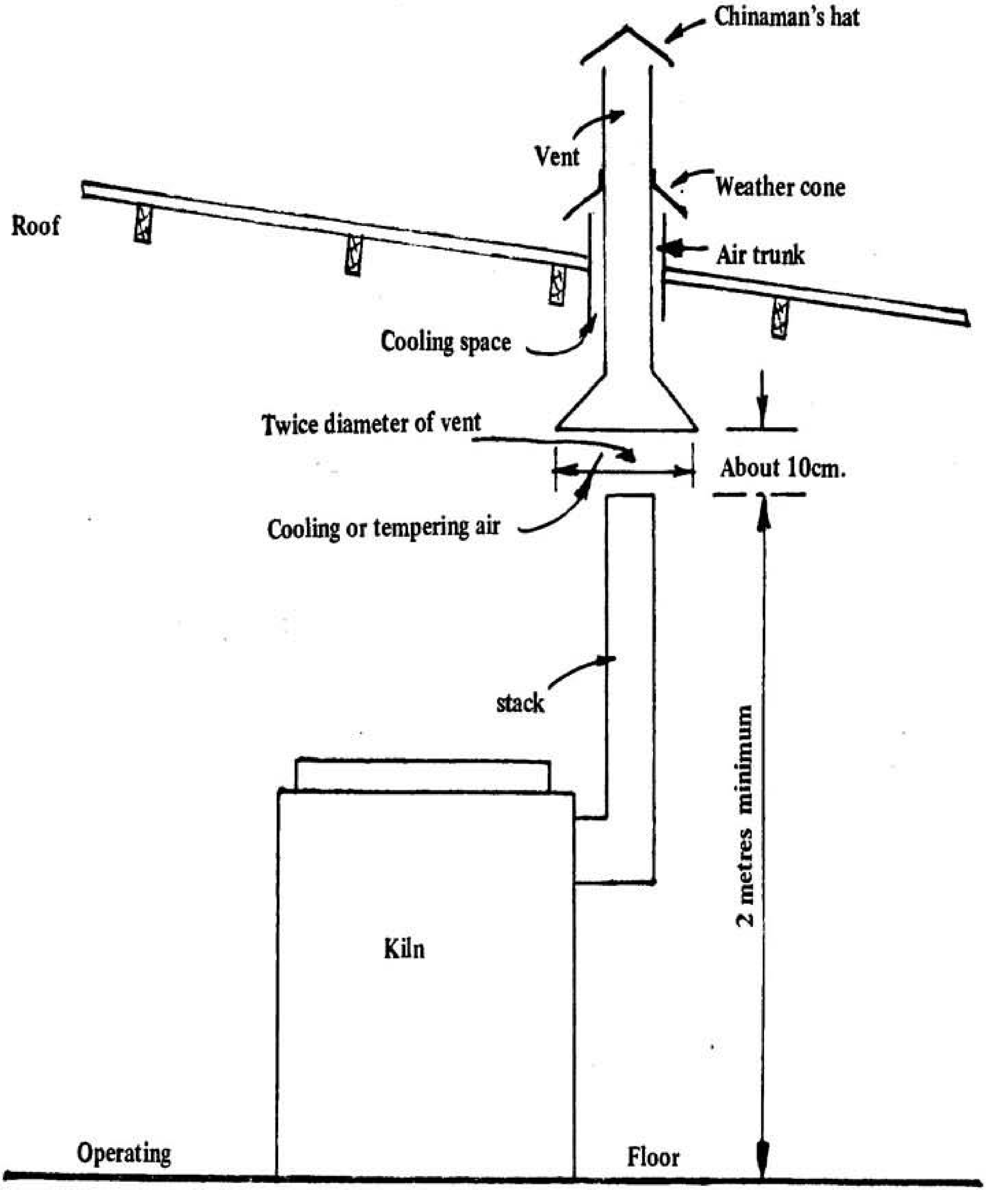
Both the walls and ceiling of any building housing a kiln must also be fire resistant.

The kiln stack must always be at least 2 metres (6'0") in height from the operating floor. In enclosed buildings a ventilator must be provided immediately above the top of the stack to conduct the flue gases outside the building. This will minimise both the risk of asphyxiation and of personal burns. This latter method also has the advantage of allowing the flue gases to be tempered by mixing with the cold air from the atmosphere.

Great care must be taken in the use of dampers. Generally gas authorities require that all dampers be fitted with an interlock that will shut off the gas burners when the damper is closed beyond a predetermined point. This interlock can only be dispensed with on approval from your Gas Authority.

When operating the kiln, care must be taken to prevent burns to the person. Special care must be taken to avoid burns to the eyes when viewing the inside of the kiln through the spy holes. Loose clothing should be avoided and industrial gloves should be worn when handling hot parts. Remember, above all, safety first and successful firing can follow.

The first requisite for a successful firing is to have the kiln set or stacked correctly. It is not a complex procedure. If a few rules are observed it is possible to stack the pots one on top of another without breakages occurring. Larger pots should be placed at the bottom to support the smaller ones. The weight or shape of a pot should not be a burden on the one below and the pots should be evenly distributed.



INDOOR KILN LAYOUT

Particular care must be taken to allow for shrinkage. A pot will shrink progressively as it dries. It will then expand a little as it is being heated in the kiln and then will shrink even further towards the end of the bisque firing. Be careful if placing one pot inside another as it may be impossible to withdraw the inner one due to the contraction of the outer pot after it has been fired. It is best to place the flattish pieces of ware on the floor of the kiln. Two of three pots can with care be stacked inside each other providing the weight is taken on their bases. Naturally the heavier pots should not be placed on lighter and more delicate ones. If possible stack pots of simular height at the same level so as to make the best use of the available space. Props should be long enough to clear the tallest pot in each layer. If possible props of each layer should be directly under each other so that the weight is eventually transferred to the kiln floor.

Make sure that there is plenty of room for air movement between the shelves and the kiln walls. Something like 50mm(2") should be allowed.

Segar cones,if used, must be fixed in their sockets, tipped slightly so that as they melt they will bend in the same direction and not interfere with each other. They must be arranged when packing the kiln so that they are visible from the spy hole; this can be checked by putting a piece of burning paper in the kiln and shutting the door.

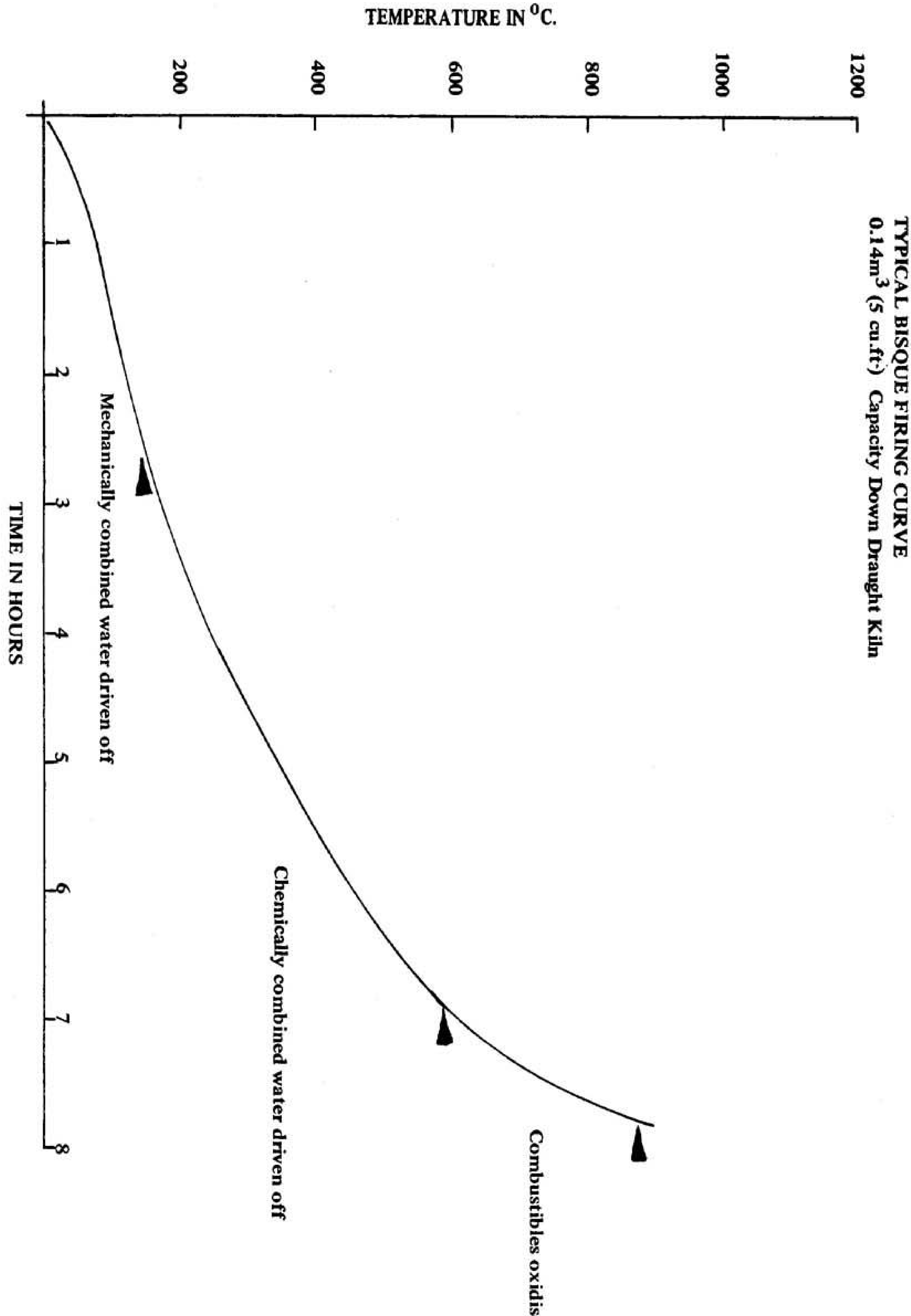
Before attempting to light a kiln it is essential to ensure that the damper is fully open. If this is not done there is a grave risk of an explosion occurring when an attempt is made to light the burners.

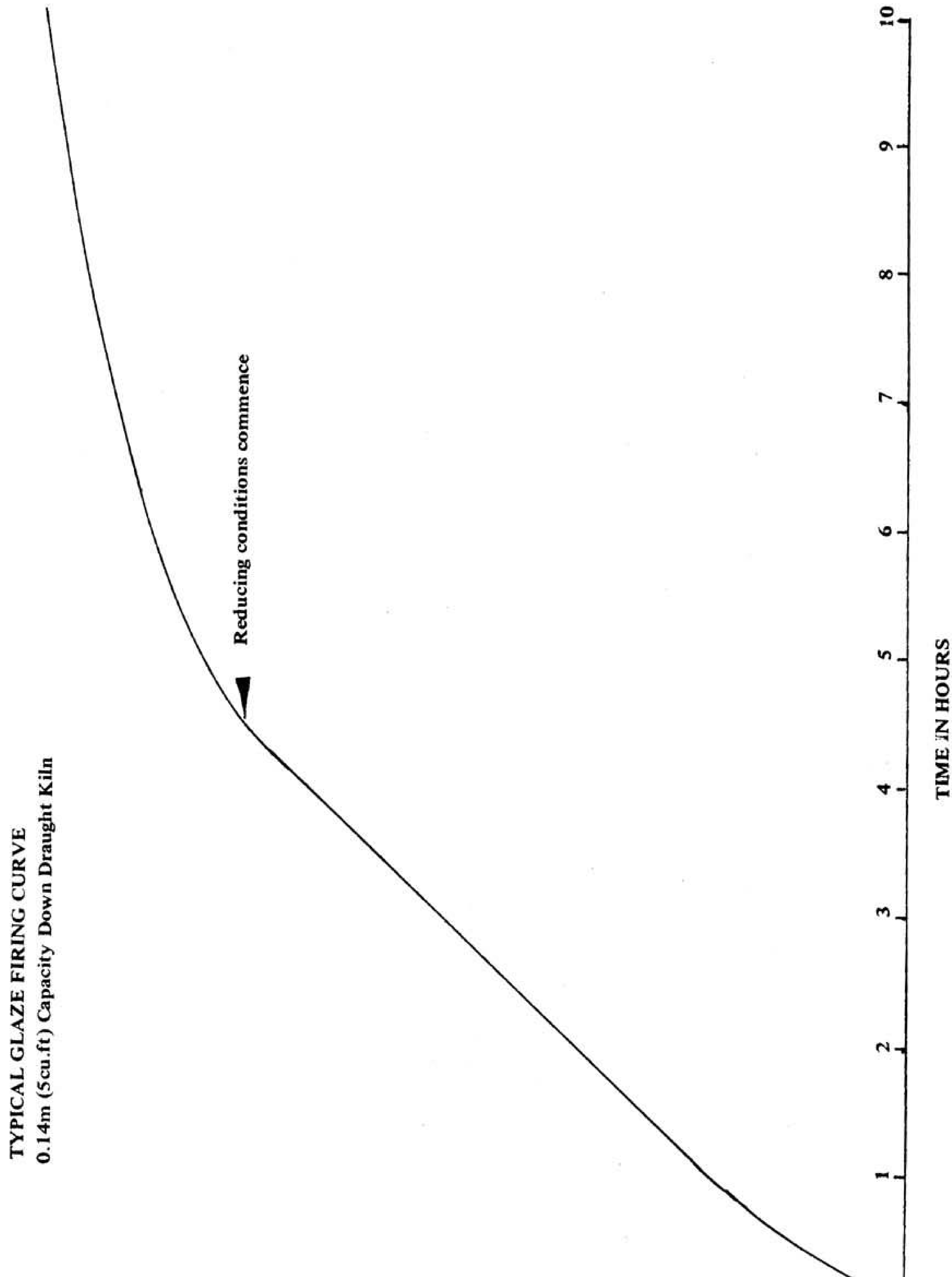
The main gas shut off valve should be opened and the safety shut off valve if fitted, set in the open position.

Always place the lighting torch against the burner before attempting to open the burner control valve. This ensures that no raw gas enters the kiln.

The secret of successful firing of pottery ware may be summed up in two words – go slowly. This is especially true during the very early part of the burn when the moisture has to be completely removed from the ware leaving it absolutely dry.

Heat alone cannot dry the pieces of ware. The ware is actually dried by the moisture being gradually absorbed in the air and the flue gases as they flow through the kiln. The heat merely raises the temperature of the air, which in turn lowers its relative humidity and allows it to absorb a greater weight of moisture than it would at ambient temperatures. Heat therefore only speeds up the drying process and allows the air currents passing through the kiln to carry the mechanically combined water away more quickly.


TYPICAL BISQUE FIRING CURVE
0.14m³ (5 cu.ft.) Capacity Down Draught Kiln
TEMPERATURE IN °C.
200
400
600
800
1000
1200
TIME IN HOURS
1
2
3
4
5
6
7
8
Mechanically combined water driven off
Chemically combined water driven off
Combustibles oxidised


TYPICAL GLAZE FIRING CURVE
0.14m (5cu.ft) Capacity Down Draught Kiln
Reducing conditions commence
TEMPERATURE IN °C.
200
400
600
800
1000
1200
TIME IN HOURS
1
2
3
4
5
6
7
8
9
10

Pottery is usually fired twice. The first firing turns earthenware clay into what is called "bisque" or "biscuit", which is hard, dry and porous.

Great care must be taken. Although the pot is apparently bone dry when it goes into the kiln, there is still a quantity of both mechanically and chemically combined water which has to be driven off. This first stage, variously known as steaming, preheating or smoking, must be taken very slowly to prevent shattering due to uneven shrinkage. At about 150° centigrade all of the free water has evaporated. Chemically combined water is driven off as the heat increases and at 600° centigrade most of this water has been turned into steam. Care must be taken to make sure that heating proceeds slowly from 450° centigrade to 600° centigrade so that the steam can escape. The thicker the clay, the slower the heating rate. If the heating is too rapid and the steam cannot escape quickly enough, it will build up a pressure and burst, and shatter the pot.

At this stage the clay has decreased in weight.

After 600°C. heat may be applied more rapidly to 900°C. when the sulphur compounds and carbon are fired out. Vitrification takes place as the firing rate is increased but the temperature at which this starts varies considerably with different bodies. It is generally regarded as commencing from the point at which most fusible ingredients begin to melt. With earthenware this will generally occur between 1040°C and 1140°C. Terracottas commence vitrification at lower temperatures, usually between 900°C and 1040°C. In stoneware bodies the point is reached somewhere between 1200°C and 1400°C.

It is usual to only light one burner initially so that the heat input can be kept low. Additional burners can be lit as required.

Only experience with a particular kiln can ensure that the correct air/gas ratio is achieved. If too much secondary air is allowed to enter the kiln, the temperature rise will be retarded and gas will be wasted.

Bisque firing requires an oxidizing atmosphere in the early stages to provide oxygen to burn out the carbonaceous material in the ware followed by a period of neutral atmosphere which is obtained by firing the burners under stoichiometric conditions.

Air which enters the burners and mixes with the gas before combustion, is called primary air. Air that enters through the burner ports, not through the burner itself, and adds oxygen to the flame is called secondary air. It is pulled or sucked into the kiln by the pull of the draught. The sign of a clear oxidizing fire is a clear atmosphere in the kiln, everything being sharply visible. There will be a total lack of visible flame at the damper or coming from the spy holes. The flame at the burners should be burning with a predominantly blue colour, with little yellow flames appearing. If the kiln appears to be oxidizing, yet no temperature gain is noted, it is probable that too much air is being admitted.

The most critical period in a bisque firing is immediately after lighting up of the kiln when it is quite easy to shatter the pots within the first few minutes. This can happen if the pots are too damp or the temperature of the kiln is raised too quickly.

Great care must be taken to ensure that the ware is as dry as atmosphere conditions will permit. A check can be made by holding each piece against the cheek to feel if any dampness is present.

A considerable degree of patience is required to ensure that the kiln temperature is kept quite low during this steaming or drying stage of the burn. The temptation to push the kiln along must be resisted until the potter is sure that all the mechanically combined water has been removed.

As the temperature rises, the organic material in the clay breaks down and when the kiln begins to show the threshold of colour physical change takes place in the silica; which is the main constituant of all clay. This is also a critical point in the burn as it is at this temperature during the cooling cycle.

The normal signs of too fast a rate of either heating or cooling through the silica change point, are cracks penetrating into the body of the piece. If the edges of such cracks are rounded, giving indications of the sharp corners having flowed, it shows that it was on the upward rise of the temperature that the damage was done. Conversely, sharp-edged cracks give notice that the cooling rate was too rapid.

As the interior of the kiln glows a bright cherry red the critical period will have passed and any damage which has not already been done will not be so likely to occur until the heat is turned off. The rate of heating can now be increased. The interior of the kiln will turn orange and begin to fade off to a yellow. The burn can finish after the pre-determined temperature is reached.

At the completion of the burn, the burners are first shut off, then the damper closed fully. The burner ports should then be closed off to allow the kiln temperature to fall gradually.

It is important that just as much care is taken when cooling the kiln. It must cool down quite slowly. If the kiln is opened up too soon the potter is likely to hear the pings and chimes as cherished pieces of ware crack and fall to pieces due to the uneven cooling as the cold air rushes into the kiln. Leave all kilns at least 24 hours before opening up.

Glaze firing is similar in principle to bisque firing, but there is no longer any necessity, as far as pots are concerned, to heat the kiln slowly at first.

Much more care must be taken with packing for a glaze firing, and there should be a gap the width of a finger between the pots so that they can touch neither each other nor the sides of the kiln. The pots however, need to soak at temperature.

Glaze firing involves a reducing atmosphere being provided towards the end of firing. This is to allow the unburned carbon from the gas to be absorbed by the glaze.

It is seldom that a heavy reducing atmosphere is ever needed to produce good glaze ware.

To obtain a reducing atmosphere it will be necessary to reduce the supply of combustion air to the kiln. Either the primary air or the secondary air supply may be diminished, or both may be cut back until the flames begin to burn with a yellow color. The damper should be closed somewhat until a slight back pressure developes in the kiln. This will be evident by some flame at the spy hole. Flame may also be observed at the damper.

Since reduction involves unburned gas inside the kiln, too much reduction is obviously a waste of fuel. Heavy reduction will usually halt the advance of temperature or even cause a loss of temperature. If the temperature in the kiln is not advancing, admitting more air at the primary or secondary sources of air will sometimes bring about a satisfactory rate of climb.

As a general rule it will be found that a neutral to very light reducing kiln atmosphere is all that in fact is needed to produce good glaze colour and texture. Some experimentation will be requireed with a new kiln to determine what is required to produce satisfactory glaze conditions. Once this is arrived at, the firing pattern can be recorded and a programme produced for use in future firings.

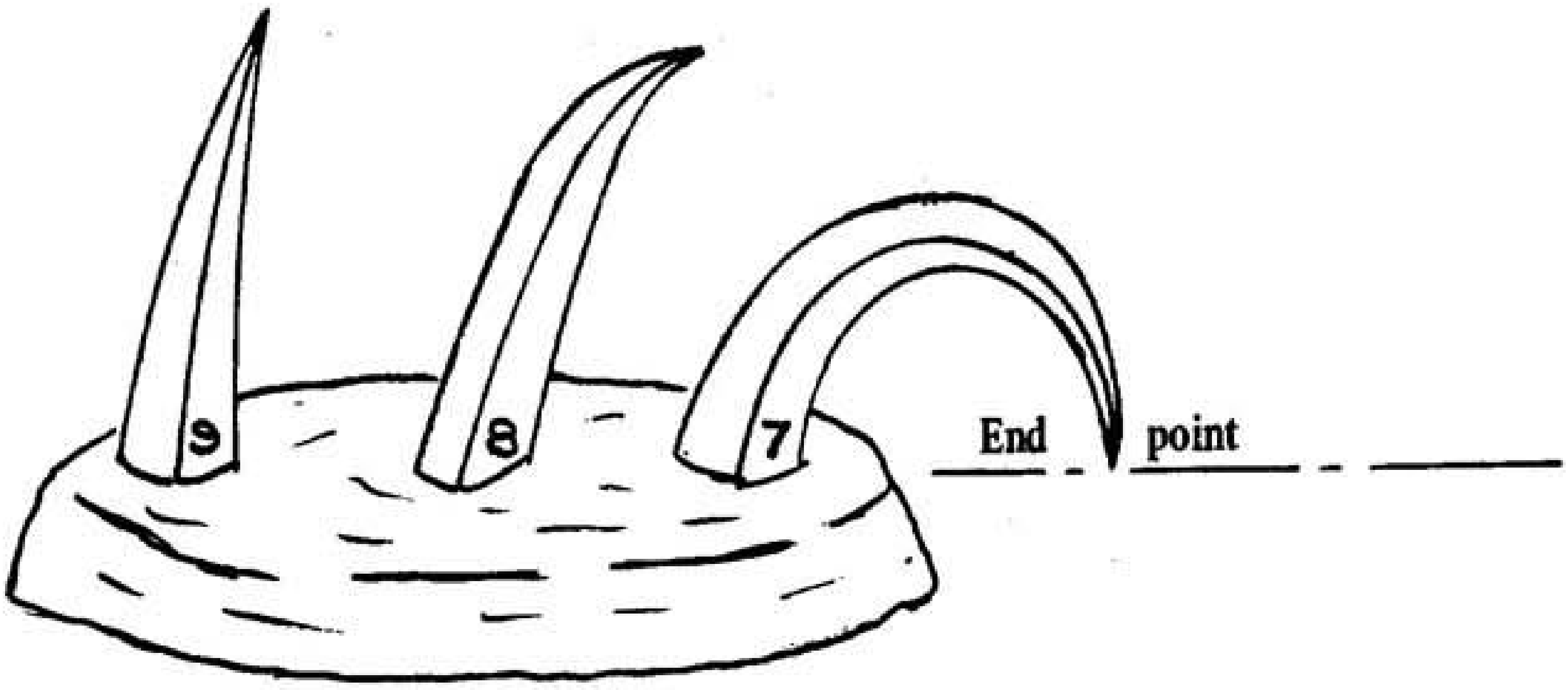
Just as much time must be taken to cool the kiln after a glaze firing as is taken with a bisque firing.

Whilst poor stacking of the kiln causes most of the damage likely to occur in glaze firing, cracking of glaze is also another common difficulty. Fine cracks may appear in the glaze after firing. It is often caused by the firing temperature of the biscuit being too low, and it can sometimes be rectified by just refiring the pot at a higher temperature. Otherwise it is caused by the glaze contracting more than the body; this can sometimes be put right by adding flint to the glaze mixture.

MEASURING THE TEMPERATURE

The measurement of kiln temperature is of all importance to the potter and usually one or more of four methods are used.

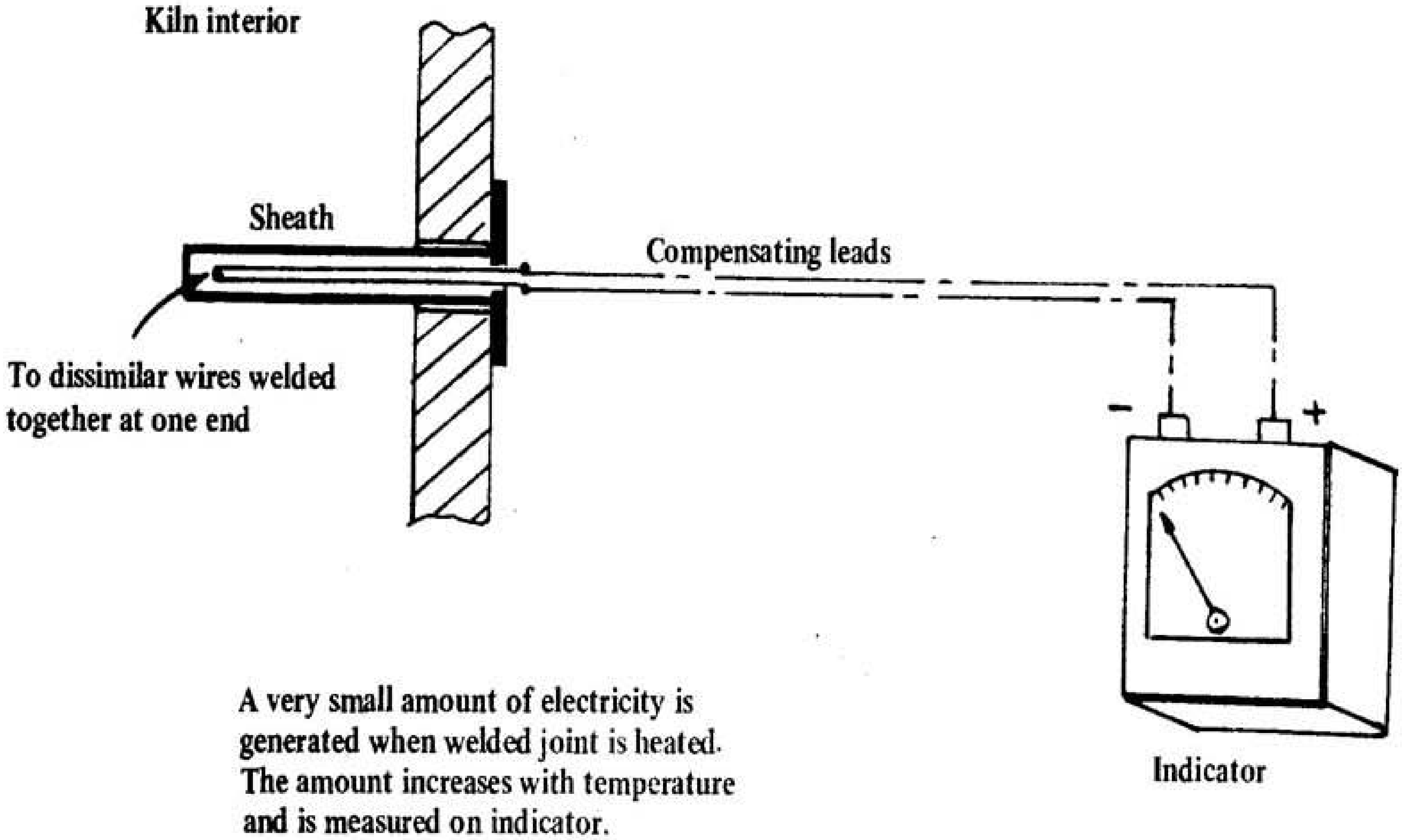
The potter can look through the spy hole and assess the colour of the interior of the kiln. This facility in judgement is much to be envied and really only comes with long years of experience. As a guide to this method the following table may be useful:



Cones should be set in a piece of clay at an angle of approximately 8°from the vertical.

CONE NO.	END POINT	CONE NO.	END POINT
012	840°C.	1	1125°
011	875	2	1135
010	890	3	1145
09	930	4	1165
08	945	5	1180
07	975	6	1190
06	1005	7	1210
05	1030	8	1225
04	1050	9	1250
03	1080	10	1260
02	1095	11	1285
01	1110	12	1310
		13	1350
		14	1390

SEGAR CONES



PYROMETER AND THERMOCOUPLE

COLOUR SCALE FOR TEMPERATURES

COLOUR	DEGREES CENTIGRADE
Threshold of visible red	475
Lowest visible red to dark red	475–650
Dark red to cherry red	650–750
Cherry red to bright cherry red	750–815
Bright cherry red to orange	815–900
Orange to yellow	900–1090
Yellow to light yellow	1090–1315
Light yellow to white	1315–1540
White to dazzling white	1540 and higher

Segar cones may be purchased from most stockists of ceramic supplies. They are small clay pyramids designed to melt at predetermined temperatures. A number is cast into the side of each cone indicating the temperature that it will bend to its "end point". Usually three different cones are placed, at an angle from the vertical, in a lump of clay and placed in a convenient position in the kiln. The temperature at any one time can be estimated by looking through the sight hole and observing which cones have started to bend and melt. At any one time the kiln temperature will be higher than the bent cone but lower than the ones still standing.

An easier and more accurate method of measuring kiln temperature is by using a pyrometer and thermocouple. This is a device that generates an extremely small electric current when the end of the thermocouple is heated. The current energizes the pyrometer which is a voltmeter calibrated to read temperature. It is one of the best methods of measuring kiln temperatures but reasonably costly to buy. It should be remembered that it is a somewhat delicate instrument and needs to be treated with care.

The fourth method of measuring kiln temperatures is with an optical pyrometer. This type of pyrometer compares the colour of pieces of ware observed through the sight hole against the colour of a filament of a light globe inside the instrument. The intensity of light globe can be varied to match the colour of the ware inside the kiln being measured. The temperature can then be read off the calibrated scale. The instrument is extremely accurate but some skill is required to be able to use if effectively. They are quite expensive and hardly warranted by the average potter.

OWNING AND OPERATING COSTS

The first question to be answered is whether to build or to buy. It is usually considerably cheaper to build a kiln than to buy one.

In addition to the purchase price of the kiln, there must be added additional charges such as freight and often crane hire to lift what is probably a heavy kiln into its final position.

When planning to build a kiln rather than buy one, the potter is strongly advised to make out a detailed bill of materials and carefully price each item to arrive at a final cost.

Whether the kiln is purchased or built a further sum must be added to cover the gas reticulation pipework.

The decision whether to use reticulated gas or LPG, when living in a reticulated gas area may depend on the projected frequency of firing. The additional cost of the reticulated gas pipework should be compared with the undoubted additional cost of LPG and an evaluation made.

The operating cost will depend largely on both the type and size of the kiln. An estimate of operating costs can only be reached by actual previous kiln firing experience, or discussions with other experienced potters. Your Gas Authority can usually also assist in making an evaluation of the operating costs.

SOME QUESTIONS TO BE ANSWERED

The prospective kiln owner should do a great amount of reading, talking, listening and above all thinking before deciding on a kiln and its location. Once built, there is an awful amount of time, effort and money involved in moving or modifying it.

It is a good idea to sit down and write down the answers to the following questions, before making that final decision:

1 Kind of ware to be fired. If large and heavy sculptures or pots are to be fired, for instance a car kiln might be almost a necessity.

2. Size of kiln desired. In general, it is good to have a kiln which is ample in size for all foreseeable needs. But if the kiln is too big, the time lapses between firings may be too great. Remember you have to make enough ware to fill it. Also if the kiln is to be fired on LPG there are definite limitations to size.

3. Where to locate the kiln, both from the point of view of safety and of minimising installation costs.

4. Size of the space available. The kiln should be in an area which allows some work space in front, and plenty of room to walk around it to get at the burners and operate the damper There should be ample height above and good ventilation if it is inside a room or shed.

5. Temperature and atmosphere desired. Versatility is desirable and if a kiln will do both high and low temperature work and will oxidize or reduce, so much the better.

6. Availability of a chimney of the possibility of building one.

7. Permanence. If it is known that the kiln will be used for only a short time, a different kind of structure may be indicated than if the kiln is intended to be permanent.

8. Type of kiln; updraught, downdraught catenary arch, raku etc.

9. Cost to build or buy the kiln. Skills and help needed if the decision is made to build it.

10. Availability of gas. A decision must be made to use mains gas or LPG, depending on the local conditions.

11. Fire regulations or zoning laws in effect at the kiln location.

12. Cost of the installation of the gas firing equipment.

13. Price of gas and cost per burn.

Once a kiln is built the only thing left to do is to fill it fire it and to suffer the agonies and ecstasies of opening it up and removing your first pots.

GLOSSARY OF TERMS

AIR-FUEL RATIO	The relation between the air supply flow rate to the fuel supply flow rate.
AIR SHUTTER	The disc on an inspirator that is used to control primary air to the burner.
BUTTERFLY DAMPER	A damper that consists of a disc in the kiln stack and can be rotated about its diameter as an axis. This type of damper is not permitted.
BRITISH THERMAL UNIT (BTU)	The amount of heat required to raise one pound of fresh water through $1^{o}F$.
BURNER PORT	The orifice in the burner nozzle which the gas or air/gas mix issues and from which the flame commences.
CALORIFIC VALUE	The measure of quantity of heat released by burning a fuel. Expressed in megajoules (BTU).
CARBON DIOXIDE (CO_2)	An inert non–toxic gas which forms part of the flue gases.
CARBON MONOXIDE (CO)	An inflamable toxic gas which can be formed through in–complete combustion.
COMBUSTION PRODUCTS	Matter resulting from combustion, such as flue gases, water vapor, and ash.
CONDUCTION	The transfer of heat through a material by passing it from molecule to molecule.
CONVECTION	Transfer of heat by moving masses of matter. Convection currents are set up in a fluid by mechanical agitation or because of differences in density at different temperatures.
DEFICIENCY OF AIR	A supply of air which is inadequate for complete com–bustion of fuel. This is the same as an excess of fuel.
EFFICIENCY (COMBUSTION)	The percentage of heat input that is realized as useful out-put by changing the green ware into fired ware. It is usually only a very small amount in the case of pottery kilns.

EXCESS AIR	The air provided to a burner in excess of that required for complete combustion.
FLAME BLOW OFF	The phenomenon which occurs when a flame moves away from the burner. This happens if the air/gas velocity is greater than the flame speed. This often results in the flame becoming unstable and extinguishing.
FLAME RETENTION NOZZLE	Often known as F.R. Nozzle. A burner nozzle incorporating a series of small holes around the periphery to give flame retention.
FLAME SPEED	The speed at which a flame progresses into an air/gas mixture relative to the speed of the mixture.
FLASH BACK	The condition that can occur in an inspirated burner when the velocity of the air/gas mixture is so low that the flame travels back along the inspirator to the gas orifice. The gas then burns as a neat flame off the end of the orifice.
FLUE GASES	The gases that are exhausted from a fuel burning device, such as a kiln. Under stoichiometric firing they will consist of:– Nitrogen Carbon Dioxide Water Vapour
GAS GRAVITY	The ratio of the weight of a given volume of a gas to the weight of an equal volume of dry air under the same conditions of temperature and pressure. Also called specific gravity.
HIGH FIRE	A relative term meaning that the input rate to a burner or combustion chamber is at or near maximum.
IGNITION	The act of starting combustion.
IGNITION TEMPERATURE	The lowest temperature at which combustion can start.
INCOMPLETE COMBUSTION	Combustion in which fuel is only partially burned, and is capable of being further burned under proper conditions.

LEAN MIXTURE	An air-fuel mixture in which an excess of air is supplied in proportion to the amount of fuel.
LOW FIRE	A relative term meaning that the input rate to a burner or combustion chamber is at or near the minimum.
MANOMETER	A glass U tube partially filled with water and used to measure gas pressure. One end is connected to the gas system to be measured whilst the other end is open to atmosphere 27" water column equals 1 psi or 7 kPa.
MANUAL VALVE	A hand operated valve.
ORIFICE	Usually refers to the hole in an inspirator spud from which the gas issues.
OXIDIZING ATMOSPHERE	The condition in a combustion chamber existing when excess air is present.
PERFECT COMBUSTION	The combining of the chemically correct proportions of fuel and air in combustion so that the fuel and oxygen are both totally consumed.
PILOT	A small gas burner used to light a main burner.
PLATE DAMPER	A damper consisting of a sliding plate that is usually in–stalled in the base of the stack.
PRESSURE POINT	A small fitting installed in a gas system from which pressures may be measured.
PRIMARY AIR	The porportion of the air needed for combustion which enters the kiln through the burner nozzle; usually via the inspirator tube.
PROPANE	The most common liquefied petroleum gas (LPG). There is also another one known as butane which is sometimes used in industry. It is not normally used by potters.
RADIATION	A mode of heat transfer in which the heat travels very rapidly in straight lines without heating the intervening space.

REDUCING ATMOSPHERE	A kiln atmosphere which is gas rich. It may be produced by supplying inadequate air to the burners, thus intentionally making the combustion incomplete.
REFRACTORIES	Highly heat resistant ceramic materials used to line kilns.
REGULATOR	A device which gives a constant gas pressure on the down-stream side whilst the upstream side may vary. It also reduces the pressure of the gas. Also known as a governor.
SECONDARY AIR	The additional air needed for combustion that enters the kiln through the air register.
SPUD	The small plug in an inspirator in which is drilled the gas orifice.
STOICHIOMETRIC COMBUSTION	The perfect state of combustion when air and gas are in exact proportions.
TURN DOWN	The ratio between maximum and input fuel rates.