LIQUID FUEL BURNING SYSTEM FOR CERAMIC FIRING

BY

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DECLARATION

I hereby declare that this thesis has been written by me, that it is a report of my own research work, and that it has not been presented in any previous application for a higher degree. All source materials are to the best of my knowledge duly acknowledged in the references. Course work involving the subjects listed below were taken and passed as part of the pre-requisite for the thesis:

Principles and Issues in Ceramics

Advanced Studio Practice

Research Techniques

Advanced Colour and Design

Seminar in Ceramic

.....
Signature

Date 22/6/90

CERTIFICATION

This thesis entitled "Liquid Fuel Burning System for Ceramic Firing" by Yusuf Gtaru Sadiq meets the requirements governing the award of the degree of Masters of Arts (Industrial Design) of Ahmadu Bello University, Zaria. It has this day been approved for its contribution to knowledge and literary presentation.

Chairman, Supervisory Committee — 22/11/90 Date

Member, Supervisory Committee — 28/11/90 Date

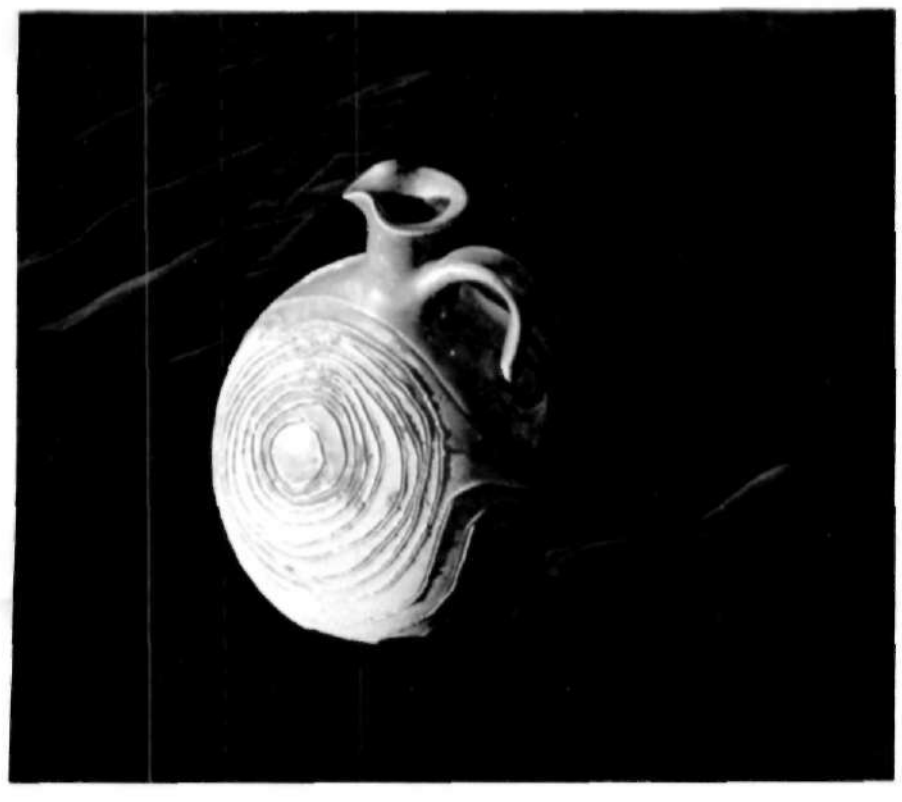
Member, Supervisory Committee — 28/11/90 Date

Head of Department — 22/11/90 Date

Dean, Postgraduate School — 4-3-91 Date

DEDICATION

This research work is dedicated to my strong, "traditional" home and every one person therein; and specially to Ibrahim my brother, for the great strength and value he reserves for the tradition and, for "education". It is also dedicated to the family lineage of OTARU.



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ABSTRACT

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This study is concerned with designing calibrating and operating a liquid fuel system for firing ceramic work as an alternative to traditional firing methods such as gas and wood firing, A "coil burner" was chosen and re-designed to eliminate prime movers such as fans, pumps and blowers. Kerosene, the fuel, was delivered by gravity feed, with a little water added to assist automization. Temperature of 1280°C and above, which are required for glazing ceramic works were achieved. The result was a more rugged fuel firing system without prime movers, a system which can be operated even in rural settings where ceramic activities need to be encouraged.

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Operational Definition of Terms

Atomization - means here, breaking of liquid fuel to a fine spray;

Bagwall - refractory partition of controlled height to deflect flame as well as prevent direct strike of flame against pots;

Clogging, Plugging - both are terms describing impedement on proper action of flow of fuel thereby obstructing combustion;

Combustion - is the burning of combustible material or fuel mixed with air in appropriate ratio.

Dense bricks - a low porosity and high density refractory bricks capable of absorving and conveying heat by convection;

Firebox - Opening at the bottom or sides of the kiln through which fuel is introduced and where combustion takes place;

Firebricks - are bricks made of fire-clay refractory that are resistant to high temperature;

Firing - refers to heat treatment process during which pots change from raw clay to ceramic products;

Kiln - in primitive usage, refers to an enclosed pit in which pots are hardened/baked by heat; and in late application, is an insulated chamber where ceramic articles are fired to high temperature;

Oxidation - in the context of firing, oxidation is the utilization of efficient combustion so that the pots are appropriately clearly manufactured;

Reduction - incomplete combustion which affects some ceramic raw materials in unique ways; some positive, some rather dull;

Ruggedized principle - refers to a simplified (otherwise) complicated system;

Underfired pots pottery lacks the anticipated level of heat.

Chapter 1

INTRODUCTION

Lately, efforts are being made by various institutions of higher learning, government and private organizations in Nigeria not only to encourage the production of tools and materials for art works but also to stimulate the growth of a basic science culture in our society (Gadzama, 1987). Workshops, exhibitions and fairs in which ceramics have been featured underscore the new interest in this area. Apparently, inadequacy of basic equipment poses a constraint on ceramic production.

As part of its own effort, the University of Maiduguri and some colleges of education jointly organised a workshop in Hong in 1988, aimed at promoting the use of local raw materials in textiles, graphics and in ceramics studies. Despite the enthusiasm generated by this workshop, it is a fact that professionals in these fields generally lack the expertise needed for fabricating or maintaining basic tools and equipment which they routinely use (Galevo, 1988). This fact (among others) is the motivation for the investigation of a burner system for liquid fuel firing for ceramic work.

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Various methods of producing durable clay articles include sun drying and firing processes using wood, gas, coal, oils and so forth. In Nigeria, the use of wood or wood-derivatives is being discouraged by the Federal Government's policy on "re-forestation" and the fight to check drought and desert encroachment (NN 7/16/87). This situation leaves gas, electricity and coal as the more appropriate sources of fuel for ceramics. The availability of gas and electricity is confined to the metropolitan areas, a factor which militates against the spread of the ceramic industry to the rural areas where it originated in Nigeria.

Besides, uneven supply and high cost of gas frequently frustrate productivity. Similarly, use of electric power has its own limitations too. By its very nature, electricity as a source of fuel for the conduct of ceramic firing is much more costly than the usual fuels. Moreso, electric kilns are only economical at high volumes of production, for example in the production of building bricks; in studio craft, production volumes are usually small. Further, electric-operated kilns, however, have to be imported with scarce foreign exchange and there is usually no local expertise to effect repairs and maintenance.

On the other hand, Nigeria is richly endowed with coal resources and this fuel is already being used in the eastern part of the country where coal is available. In the Northern part however, it is important to mention that the Dr. Ladi Kwali Pottery Center in Suleja is building a new kiln that will be coal-fired.

In view of the above, the search for alternative means for ceramic firing is still a relevant area of research in Nigeria; and, if the problem is approached in this perspective, a future of improved production scale can be envisioned. It is against this background that this study sought to design, fabricate and operate a liquid fuel device for the conduct of ceramic firing.

1.1 Statement of the Problem

"Firing" is a phenomenon synonymous with the production of nearly all ceramic works. Wood, grasses, coal, gas and at times dry animal dung and kernel shells are remarkable "epoch-making" fuels over the time. Today, inspite of increasing demand for ceramic products the use of some of these fuels especially wood-derivatives is affected by government regulations or, by reasons of labour, cost, maintenance or convinience. Faced with similar challenge,

Mossman (1982), believed that, a shift to alternative energy sources for ceramic production is a step towards self-sufficiency, decentralization and conservation of limited energy resources. "Economics" he argued, could well be an overriding factor in such "alternative" decision. Similarly, making particular reference to the Nigerian situation Ahwan (1987) implied that the problems faced by the ceramic industry is that of government's lukewarm attitude towards providing machinery and technical impetus for the industry. Such too is the experience of schools and colleges that offer ceramic courses. Really, the government's attitude should pose a challenge for innovative undertaking for an appropriate beginning to solving the problems.

The study therefore is concerned with the investigation of a liquid fuel burning system for ceramic firing.

1.2 Objectives of the Study

General Objective

The general objective of the study is to determine the possibilities of conducting ceramic firing with liquid fuel, with a view to obtaining an alternative to the usual firing methods.

Specific Objective

Specific objectives, as derived from the above general type are:

1. to design, construct and test the use of a liquid burner device;
2. to test the adequacy of such a system for both biscuit and glaze firing;
3. to caliberate the system in term of time - temperature response with respect to various operating variables; and
4. to compare fuel cost involved with gas and wood firing.

1.3 Assumptions

The study was based on the following basic assumptions:

1. that a cross-draught gas kiln can be adopted to accomodate liquid fuel firing; and
2. that the kiln atmosphere in fuel firing will produce acceptable effects on wares.

1.4 Limitations

The investigations was conducted in a kiln designed for gas firing. Adjustments were however made where applicable for maximum control.

The burner design was dictated by symplicity. The resulting burner must be one in which fuel is supplied by gravity feed and combustion air supplied by natural draught. This eliminates the need for pumps, prime movers and blowers that may not be available in rural settings or may be out of reach due to costs.

1.5 Delimitations

The coil burner system was chosen for this investigation, with a view to by-pass complications associated with using pumps or blowers as earlier stated. The study in the same vein did not pre-occupy itself with quantitative details, as they may also apply to other burning apparatuses and kilns.

1.6 Scope of the Study

The scope of the study covered reviewing of related literature, designing, fabricating and test-running of a coil burner and determining the suitability of the burner to ba gravity feed method of fuel delivery.

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1.7 Justification for the Study

The trend of ceramic production in Nigeria has come to a point where the problem of operating a ceramic workshop (among other factors), is not just the cost of fuel but availability of the fuel itself. Fuel is one very important basic consideration in starting a studio/workshop or industry-scale production. Infact, lack of fuel has restricted the ceramic industry to urban centers and prevented its expansion to the rural areas, because bottled gas is the major fuel used in existing studios and small-scale ceramic ventures in Nigeria. Coal on the other hand, has yet to be properly harnessed, while electricity is only economic in large scale production, as discussed earlier in the introduction. Above all, the cost and availability militates against the use of firewood as a fuel especially in view of government's campaign for "reforestation" - as a result of over use of wood.

Clearly, for the ceramic industry in Nigeria to expand t and move into rural areas, there is need for a fuel which is readily available even in rural areas. Such a fuel is kerosene which is being used for lighting and cooking domestically both in the cities and rural settings. This is the rationale for choosing kerosene for the investigation.

However, it might be argued that this type of investigation should be the work of engineers and technologists and by implication, that, the ceramic professionals should pre-occupy themselves with only the craft. This argument does not take into account the fact that ceramic craftsmen are daily required to

design, construct and maintain most of their major production equipment. Their success particularly in rural settings and in developing countries depends very much on being able to carry out the above functions. Also, access to technical design is blocked by both language barriers and inability to pay the cost of engineering consultancy. This is the basis of Cardew's (1969) philosophy that, ceramic craftsmen should be "technical jack of all trades". Hence there is a need for the ceramic professionals to be involved in this type of research.

In line with the above, the Department of Industrial Design, Ahmadu Bello University, Zaria has recently turned its attention to design and construction of ceramic equipment. For example, a gas-fired kiln with gas burners and potter's wheel have been designed constructed and used. The need for more work in this area was lately highlighted by Ewule (1987) by his call for "a possibility of total development in ceramic". This project therefore conforms in spirit to Ewule's position. It is also in tune with the recent national emphasis on fabricating as much as possible tools and equipment for production in all sectors of our economy. Given the considerable quota the ceramic industry can contribute to the national economy by way of gainful employment of both skilled and unskilled people, steps

taken to find alternative means of increasing production constitute a viable economic policy.

To this end, it is hoped that the study will serve to stimulate students, professionals and other practicing individuals towards experimenting with the viability of some petroleum-derived oils as they exist in our refineries, as a way of diversifying sources of energy for production purposes. Similarly, it is anticipated that the study will contribute to knowledge in that it will serve as a background for involvement of the groups mentioned above.

1.8 Summary

Chapter one has introduced the study, defined the problem with which it is concerned, stated the objectives; it has also discussed its limitations, delimitations and scope, and made assumptions; the justification for the study has also been stated.

The chapter is preceeded by contextual definition of selected terms.

Chapter 2

LITERATURE REVIEW

Introduction

According to Considine's (1976) definition, a burner is a principal component of combustion; and applies to burning of fuels with air to generate heat. It is a mechanical device for preparing fuel and air under controlled atomization or vaporization for combustion, (The American Society of Heating, Refridgerating and Air Conditioning Engineers, 1976). On the other hand, oil/liquid fuel burner as it applies to the subject of this discourse, is an atomizing device designed primarily to initiate, promote and sustain combustion. An oil firing system essentially consists of the oil burner and its auxiliary equipment such as oil pump, air blower, oil tank, the oil lines and the controls.

Rhodes (1968) emphasised the need for air when he wrote that; "Anyone who tends a fire-place has learned that the secret of a lively blaze is getting the air to the fire".

This synthesis of literature includes relevant materials from books, proposals and seminar papers, journals, newspapers, professional discussions and research reports; and is used to determine the choice

of fabrication and selection of appropriate procedures for the study. The sequence of its presentation is as follows:

1. Early/ "modern" Firing sources;
2. Liquid Fuel Firing/Burner; and
3. Kiln Operation.

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2.1 Early/"Modern" Firing Sources

Up to the present time, the circumstances that led to the discovery of "red heat" (at and above 600°C) remains a subject of debate. Two rival theories - the "Basket Theory" and the "Hearth Theory" - have emerged. The former according to Counts (1960), claims that the clay-coated domestic baskets were burned by fire accidentally, producing a burnt clay. Cooper (1972), attributes the discovery of burnt clay to observing the domestic hearth used by early man for cooking and warming himself. From this discovery, primitive kilns were later developed for firing clay products using various carbonaceous materials like grass, fire wood, animal dung and such other carbonaceous fuels. The most commonly used kilns available to the early potters in many parts of the world then ([illegible]) were in the form of pit or open/bone fire.

Considerable advances were in 1900 in kiln design and construction, in the wake of the Industrial Revolution in Europe, especially in England. At this time according to Rhodes (1968) burner design was not as advanced as kiln design. Finally burner design has been perfected with the result that "tunnel" and "intermittent" kilns using both liquid fuel and gas are being used by potters of today.

Traditional Nigerian pottery and centres are also affected by this trend. High-fired pottery was first recorded in Nigeria in 1881, pioneered by one D. Roberts experimenting with indigenous ceramic oxides at Abeokuta, Ogun State. Much later, the late Michael Cardew inspired the beginning of the then Abuja Pottery Centre in 1951. This was followed by Okigwe Pottery in Imo State in 1952, to mention a few of them. Other pottery centres however sprang up around the country. About 70 percent of them going by Ewule's (1988) figures use firewood while the other 30 percent employ gas for firing. At this time, coal was being used on a small scale in Nigeria, especially in the eastern part of the country.

Norsker (1987) reported that firewood and agricultural wastes which, previously were the main fuels all over the world now represent only about 0.4

percent of the energy used in industrialized world; 25 percent in the developing countries, while the less developed regions account for 40 percent. To this end, there is no doubt that the trend of development world-wide indicates a gradual replacement of firewood with gas or fuel oil, and yet other possibilities - 'Firing With Solar Energy" (Brisson, 1981).

The implication of the above figures therefore is that both the developing and the less developed countries like Nigeria are yet to catch up with the advancements in respect of ceramic firing activity in the industrialised nations. However, besides that government policy may not favour use of firewood in many countries, liquid fuel may be much preferable where firewood and/or gas is scarce or costly.

2.2 Liquid Fuel Firing Burners

Oil does not burn as a liquid; it is oil vapour that is burned. Quick combustion requires (among other factors), quick evaporation, which is usually attained by producing a very large surface for a given quantity of oil. Maximum surface area is obtained when the oil is sub-divided into extremely small drops. This is so because for

spherical drops the surface area is proportional to the square of the diameter, whereas the volume is proportional to the cube, hence the surface area per unit volume is inversely proportional to the diameter.

Another important factor in vaporisation of oil is the temperature of the surface of the drops because temperature increases the rate of evaporation. High temperature of the surface of drop is caused by high temperature of the oil or the surrounding gas. A third factor in quick combustion is thorough mixing of oil droplets with air. Thus, the ideal fuel burner must be capable of breaking the bulk oil into fine droplets, injecting the droplets into a hot gas to increase evaporation and mixing the droplets with combustion air.

The process of producing a fine oil spray or aerosol should be called "aerosolization" but is commonly called "atomization" although the smallest drop actually contains thousands of fuel molecules; even the molecule of kerosene contains about 32 atoms. Clearly, the word atomization with its implicit connotation of reduction to the atom is a misnomer. However, this word is firmly entrenched in the literature. Atomization occurs if a fine stream of liquid flows at a high velocity through a gas.

Conversely, atomization also occurs if a gas is blown against a fine spray of liquid. The mechanics of the process is explained as shown in figure 1 below. A drop is flattened and, by the effect of surface tension, breaks into two smaller drops. The greater the relative velocity, the smaller are the resulting drops.

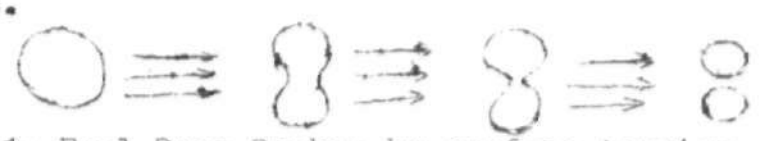


Fig. 1: Fuel Drop Broken by surface tension.

As previously stated, atomization occurs when a low-viscosity liquid and a gas penetrate each other at high relative velocity. To produce a given oil velocity requires about 700 times as much pressure as is needed to impart the same velocity to air, since oil is 700 times a dense as air. Pumping air for the purpose of generating velocity, however, requires considerably more power than is needed in pumping oil for the same purpose, because of the bigger volume of air. Unit volume of the average fuel requires 10,500 volumes of air for combustion.

In view of the above, it is usually the oil that is pumped to achieve the relative velocity.

The principal function of a burner is atomizing the liquid fuel. Atomizing burners may be classified according to the source of energy used to disintegrate the fuel into the groups:

a. pressure jets, in which pressure energy is used directly;

b. rotatory atomizers, in which centrifugal energy is imported to the fuel; and

c. blast atomizers, in which a gas is impinged on the liquid.

These atomizers differ as to the size of droplets and the shape of the combustion zone. Pressure jects give a conical spray, rotatory atomizers give a very uniform droplet size over a wide area, and blast atomizers a narrow hot and long pointed flame with a more variable droplet size than either of the other types (Williams, 1976).

In rotatory atomizers, atomization is achieved by centrifugal forces. The oil flows through a central pipe to the inner surface of a revolving hollow tappered cup. It spreads over the surface and is thrown off the periphery of the free end of lip. Because of the uniformity of the surface of the cup the thickness of the oil film and the velocity of the oil are the same over the circumference of the rim of the

cup. Good atomization is obtained and droplet size is more uniform for this type of atomizer than any other type. The cup is usually rotated by an electric motor, a turbine, driven by a proportion of the atomizing air.

In blast atomizers, atomization is produced by the shearing effect of a high-velocity stream of air or steam of oil flowing through an orifice at low pressure, for the vast majority of applications, air is the atomizing fluid at low, medium or high pressures. For the high viscosity coal-tar fuels and residual fuel oils, steam is the prefered fluid. They are further classified as either internal mixing or external mixing blast burners, according to whether the steam or air and oil impinge within the burner assembly, or the oil is released into the atomizing fluied at the burner outlet. The internal-mix burner type is the more common one and is used for all three pressure classes.

The pressure jet burner is the oldest type of atomizer and is still the most commonly used in view of its relative simplicity. Here oil is forced at high pressure through a nozzle to produce a spray of fine droplet size. Since a low viscosity value for the fuel oil favours atomization, the oil (and especially heavy oils) are pre-heated to reduce their

viscosity. The flow rate through a nozzle is proportional to the square root of the pressure. Droplet size is directly proportional to the viscosity and inversely proportional to the cube root of the pressure.

Similarly, high-pressure steam may be used as the only source of atomization in pressure jet burners and where this is the case the entire combustion air can be applied as secondary air (Krivandin and Markov, 1980); this may be done via special secondary holes created around the flame zone.

In this investigation, the pressure jet principle has been employed in designing a burner which does not require any prime movers. Pressure required to force the fuel through the nozzle was obtained by employing a gravity feed method of fuel delivery. Preheating of the fuel to reduce its viscosity was achieved by passing the fuel through pre-heating coils before the fuel exits at the nozzle. A sketch of the burner used is shown in figure 3. Importantly, the pressure jet principle was employed because it leads to "simplicity" which is the bias of this study.

2.3 Kiln Operation

Beside choosing a particular kiln option and size, a number of factors are as important in operating a kiln.

Since fuel is by far the most expensive of potter's raw materials, practical operational efficiency of the kiln must be foremost in our mind, to ensure economy of the fuel (Cardew, 1969). Kiln shape (i.e., height, length, style etc.) is a principal phenomenon around which all the other auxiliary structural features are determined. Most important among these are the Chimney dimensions; dimensions of the fireboxes; location of burners; effect of bagwalls; channelling effect of kiln shelves; and, even the thickness of the walls of kiln among other factors.

Chimney draught of a kiln is in most cases influenced by the height (more than the area) of the chimney; in every kiln this parameter has to be worked out. Generally however, many authorities believe in the rule of "3ft of chimney for every foot of downward pull,plus 1ft for every 3½ft of horizontal pull". Cardew (1969) however doubted the interpretation and this rule in any given kiln option; although he refered to Bourry as saying that the draught in any chimney of given height and diameter

reaches a maximum when the escaping gases are at 150°C stating further that it would be most ideal to go slightly higher than this temperature. All these factors depend on the chosen fuel. Wood, with its long flame in combustion, requires a taller chimney stack.

Also, the dimensions of fireboxes should relate in good proportion to the size and type of kiln, as well as fuel in use. The position of burner in the fireboxes is essentially determined in relation to its flame length and combustion intensity (liquid fuel has higher intensity burning). Similarly, this means that proper positioning of bagwall and its height would be very efficacious. Perforation are sometimes even made on the bagwall to enhance heat work within the kiln chamber.

Another factors is the arch. In both arched-kilns and the non-arched types the movement of heat in the kiln chamber is, to a considerable extent affected by the roof/top construction of the kiln which in practice dictates, as previously said the direction and/or speed of heat. As a result, the arching of a kiln should be done with careful dimensions.

Kiln loading (arrangement of pots and shelves/ kiln furniture) contributes significantly to efficient firing; therefore the potter must have

enough stock of pots commensurate with the capacity of his kiln. A half-filled kiln with a lot of spaces between the "saggars" will fire badly (Cardew,1969; and Norsker, 1987). Actually, the kiln should be set with narrow passages for hot gases to travel rather than wide ones.

Finally, in several works with oil kilns Parks (1980) suggested only simple modification to switch a gas kiln to oil uses. This might include bricking up some of the gas kiln fireboxes and enlarging the boxes to accept the longer and hotter oil flame. For oil firing Parks shared certain industry recommended short fireboxes with corbelled bagwalls. The firebox should be long enough to prevent destruction and short enough to promote combustion, with optimum loading space. He further suggested a 3: 1 ratio of floor loading space to firebox as practicable.

Kiln Atmosphere

In contrast to the familiar bright and clear atmosphere in gas kilns, the peculiar oil flame is orange, long and bushy. Even at the peak of a desired temperature the kiln atmosphere in oil firing could be murky but still produce good results that is more often than not, reduction, (Parks, 1980). Practically however, the murky burning of oil can be

made very advantageous in terms of "colouring"; that is, manipulating it to vary surface treatment/ appearance such that it supplements the glazing effect. Sometimes pots are even prefered as "final" at biscuit stage especially when burnished, to enhance the subleties of heavy smoking. More importantly:

> ...no two kilns fire identically one kiln may not fire the same twice in a row; each firing varies according to how it is packed; what the weather is like outside; what burners are used, who watches the kiln, and many unrecorded naunces. This schedule is a synopsis of an oil firing when everything goes well.
> Parks,(1980)

2.4 Summary

Here, a general definition of burner has been looked at; with a brief introductory discussion on the liquid fuel burner. The literature review has also discussed, very briefly, the trend in ceramic firing as it affects Nigeria. It generally looked

at three classes of pressure atomizing devices which suggested the reason for choosing the coil burner for the study.

Finally the effect of the kiln and its features on firing operations was also briefly discussed.

Chapter 3

RESEARCH DESIGN AND PROCEDURES

Introduction

Any research study can be characterised by its type, areas of interest, data collection procedure and analysis or, by its purpose. As an adaptive re-design investigation, the study was guided by the "empirical" procedures and this consisted of trial-running/firing of the standard coil burner with modification informed by the result obtained in test-firing.

The result is a model coil burner for ceramic firing which can be constructed cheaply in a rural setting and run without the use of prime movers for either fuel delivery or air supply.

3.1 Instruments

A 10-cubic-foot gas kiln was used for the test-running of the standard coil burner to determine suitable operating variables considered in the design of the model system. The use of a gas kiln, as earlier stated under the delimitations, was suggested by the fact that only slight modification or adjustment is required to switch a gas kiln to oil firing.

The standard coil burner was obtained from Metallurgical Engineering Department, Ahmadu Bello University, Zaria originally designed to deliver fuel by a compressed air system.

A small motor-powered compressor was employed in the course of test-firing. Cones 04, 5 and 6 (as the only available cones) were used, after which hour estimation plus a "look through the spy hole" helped to determine temperature rise and end of firing.

In the design of the model coil burner, personnel and technical assistance were sought at the Metallurgical and Mechanical Engineering Department workshops.

3.2 Empirical Testing

Using the gas kiln and two burners several trial-firings were conducted by:

1. varying nozzle orifices;
2. supply of fuel through different methods; and
3. air-assisted atomization

1. Varying Nozzle Orifices

Nozzles in the range of 1 - 3mm diameter orifice were test-run, using kerosene. Those between 2 - 3mm diameter orifices were found most suitable. Smaller orifices were difficult to make and when used, fired with significantly shorter flames, giving problems of clogging and blockage by pyrolytic products of combustion. Nozzles with orifice over 3mm diameter gave poor atomization which led to bushy and soothy

flames. At some point in use also, the pulsating character demonstrated by this range of orifice frequently heated the rear line of the burner thereby encouraging the pyrolisis.

Thus, the intermediate size of 2mm diameter functioned most effeciently and was therefore choosen and used in subsequent firings.

2. Supply of Fuel Through Different Methods

A pressure container designed to deliver fuel by air pressure supplied by a compressor was first used. This was followed by use of similar container with an in-built hand pump. In either instance the smaller orifices (suitable for this delivery) conducted the firing to barely the desired biscuit temperature (900^{o}C) as a result of frequent plugging from sludge. This temperature was attained in over two and a half hours. Apart from frequent seizure in fuel supply, the use of prime movers or fans is against the bias of this investigation. Next, fuel supply by gravity feed was used. A 50-gallon domestic drum was installed at a height of 4 meters and connected to the burner by a pipe with various fittings for control. The burner had a 2mm diameter orifice nozzle. The pressure attained was sufficient to supply fuel to the burner. However, natural convection could not provide sufficient air to support complete combustion. The flame was sooty and a temperature of 920^{o}C was attained.

3. Air-Assisted Atomization

In view of the sooty flame and insufficient air for complete combustions compressed-air system was employed in order to externally aerate the fuel as it exited the nozzle. Compressed air was directed at the

atomized fuel spray at its exit, from the nozzle. Then a trial (glazing) firing was conducted. Eventually, the firing ended with the air pipe tangentially positioned to the nozzle (angle where it most favoured it). The result was a "mature" glazing (designed for 1280°C), achieved in approximately 10 hours.

Inspite of effectiveness of the external aeration, the use of prime movers as earlier stated was not desirable. Also, this jetting of the fuel spray with air improved atomization but it did not solve the problems of internal clogging of the coil at especially high temperature where they are more sensitive to pyrolysis problems. (see some of the test-firing log in appendix II).

However, this activity presupposed the "steam (oxygen) effect of water on oil". In this connection another trail-firing was started and continued for a short period of one hour. Droplets of water was introduced on the preheating nozzle and/or brick on which nozzle rested. As water steamed out around the brick and nozzle the zone of combustion became apparently further atomized.

Subsequently, water at this point was properly incorporated into the system; and, controlled burnner system was fabricated for the system.

In related studies, Parks (1980) and Norsker, (1987) reported that steam added to oil will generate extra oxygen and reduce possible carbon clinker deposits. Parks recalled the warning of his childhood: "Never throw water on an oil fire! It will only make the fire get worse". In this case the water steams, oxygenates and intensifies the fire.

3.3 Summary

Chapter three defined and identified the research design and procedures that guided the study. These included several operational tests with existing coil burner, using different sizes of nozzle orifices to ascertain the most suitable; the procedures also included fuel delivery from different methods, which altogether suggested a simple system, using coil burner composition.

Chapter 4

DESIGN AND FABRICATION OF A MODEL COIL BURNER

Having identified some design options from the experimentations in chapter three, it was then appropriate to design and construct a model coil burner, using materials such as:

	Material	Type	Quantity
1.	1.5m High-pressure pipe (10mm insidedia; 4mm outside dia.).	Mild steel	1
2.	2cm. Hexagonal pipe for nozzle (march size to pressure pipe).	Brass/Mild Steel	1
3.	Stop-cock or valve (½	Brass/Mild steel	1
4.	U-joint pipe (march size to pressure pipe)	Mild steel	1
5.	Water hose (fixable size to pipe).	Rubber	as long as desirable
6.	5cm. extra pipe (match size to pressure pipe).	Steel	1

4.1 Coiling of Burner Pipe

The burner was coiled from a 1.5m long pipe, (Fig. 2). The coiling involves heating. While it was being heated the pipe was coiled round a 2" pipe (already clamped in a vice (Fig. 3A) leaving forth about one-tenth of the length of the pipe (Fig. 3A(a) to serve as the U-joint and nozzle end; and to allow a grip of the pipe by a second person during coiling. Holding the remaining length of pipe, it was coiled in three folds. On the fourth fold the rest of the pipe was turned behind the formed coil as in Fig. 3,A(b_1). Then the remaining bit previously left before the coil was returned to remain parallel with the entire burner, Fig. 3.A(a_1) maintaining a gap, the diameter of the ring itself.

A stop-cock or valve was welded to the rear end of the burner, terminating with a piece of extra pipe as illustrated in Fig. 4. A U-joint was also welded to the nozzle holder such that the nozzle, when fixed becomes concentric to the diameter of the coil. One end of the U-joint must have been treated on the inside on which to "fit" and screw the nozzle. Between the burner line and the nozzle holder is a flame holder (optional) which enhances control of flame out of the coil. If positioning of nozzle is made concentric to the coil, a flame holder

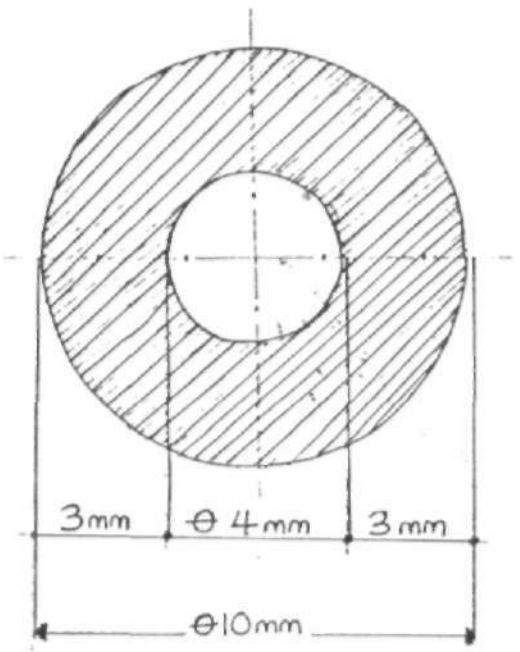
may not be very necessary; moreso, the flame holder can considerably limit circulation of primary air around the nozzle if welded too close to the nozzle.

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DIAGRAM SHOWING DIMENSIONS OF PIPE

A



B

SECTION OF PIPE

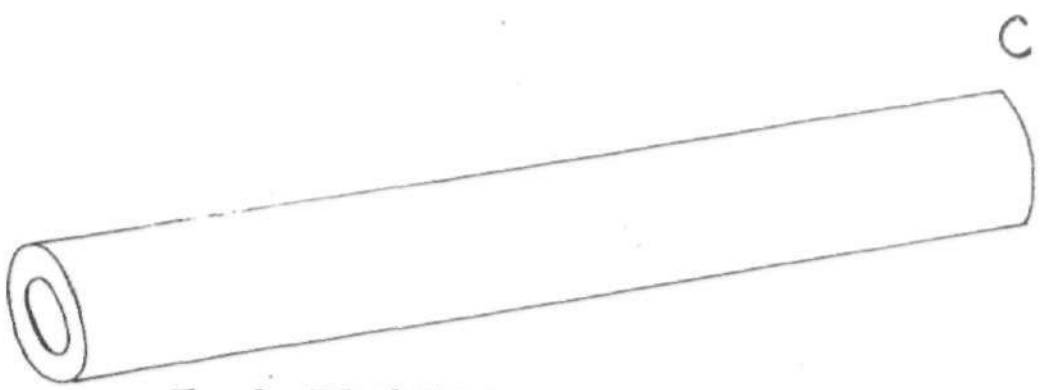
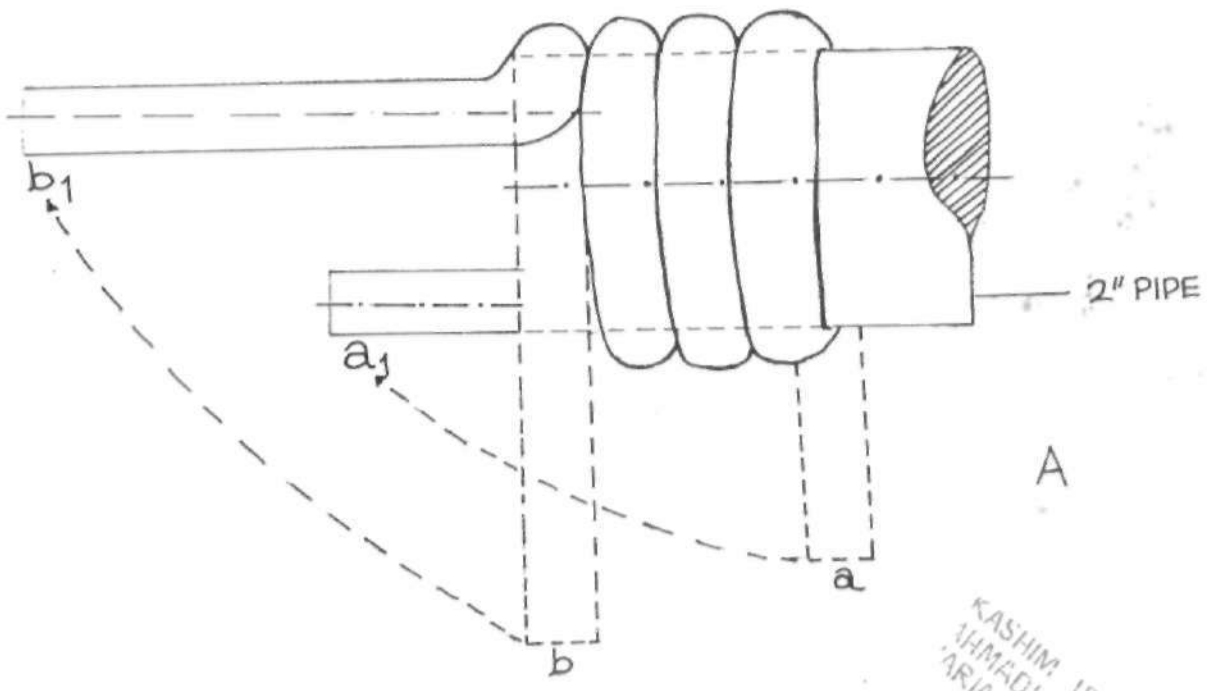
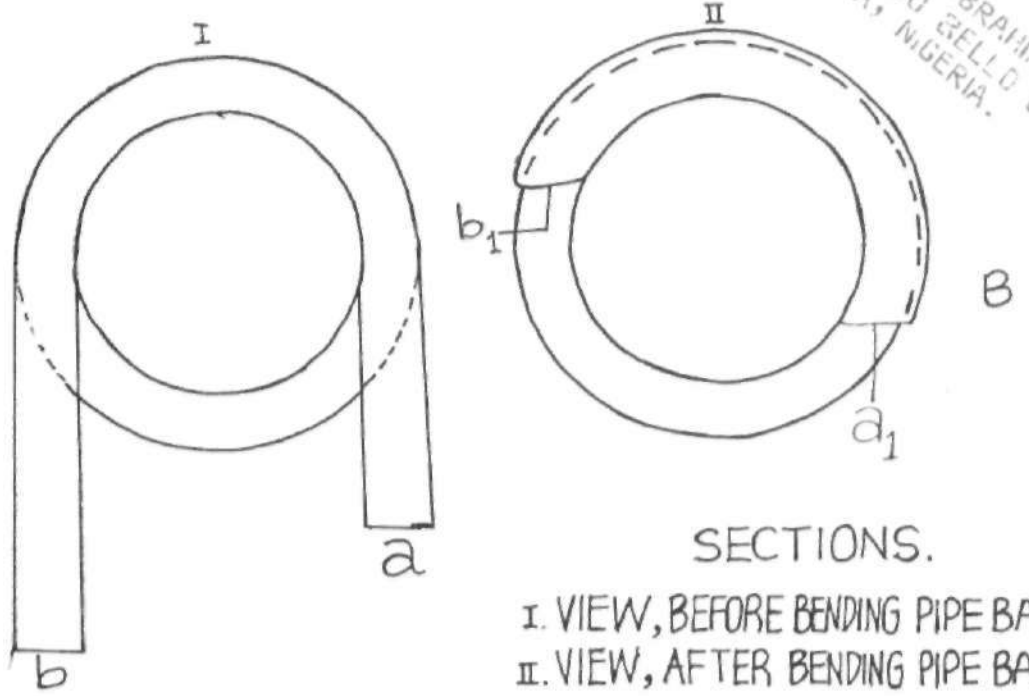


Fig 2: THREE DIMENSIONAL VIEW OF PIPE.

MAKING OF THE BURNER (Coiled Pipe)



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ARIA, NIGERIA.



SECTIONS.

I. VIEW, BEFORE BENDING PIPE BACKWARD
II. VIEW, AFTER BENDING PIPE BACKWARD

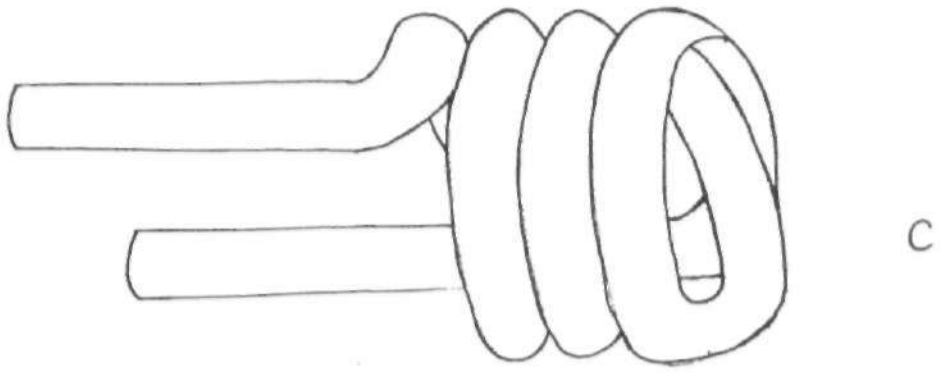
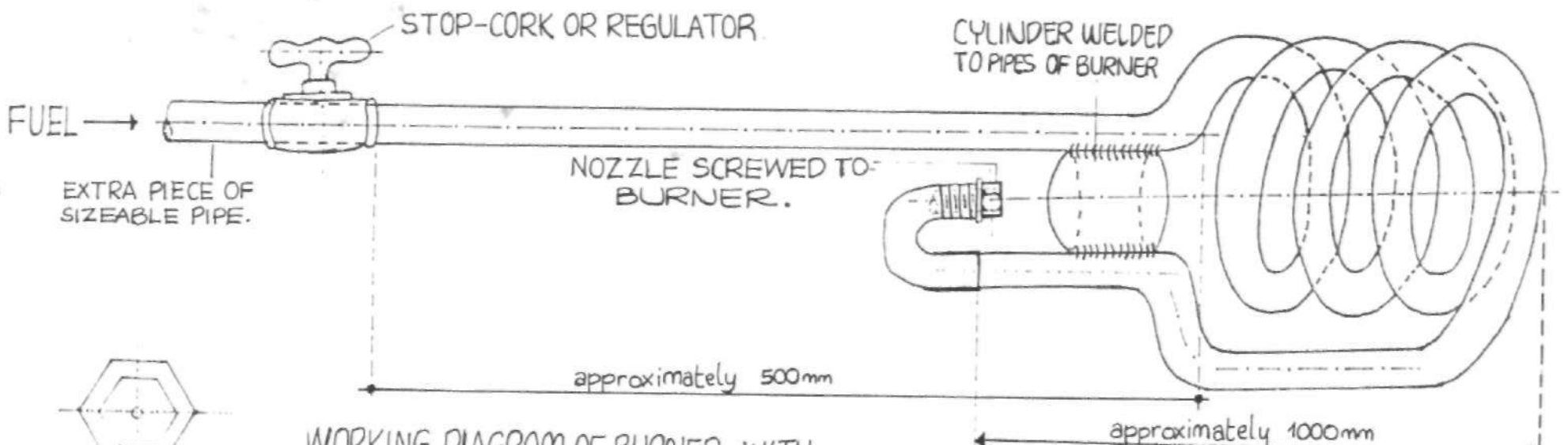


Fig. 3: THREE DIMENSIONAL VIEW OF COILED PIPE (BURNER)

BURNER WITH REGULATOR AND NOZZLE ON.



CROSS SECTION OF NOZZLE WITH FUEL OUTLET IN MIDDLE (2MM)

WORKING DIAGRAM OF BURNER WITH - REGULATOR & NOZZLE ON.

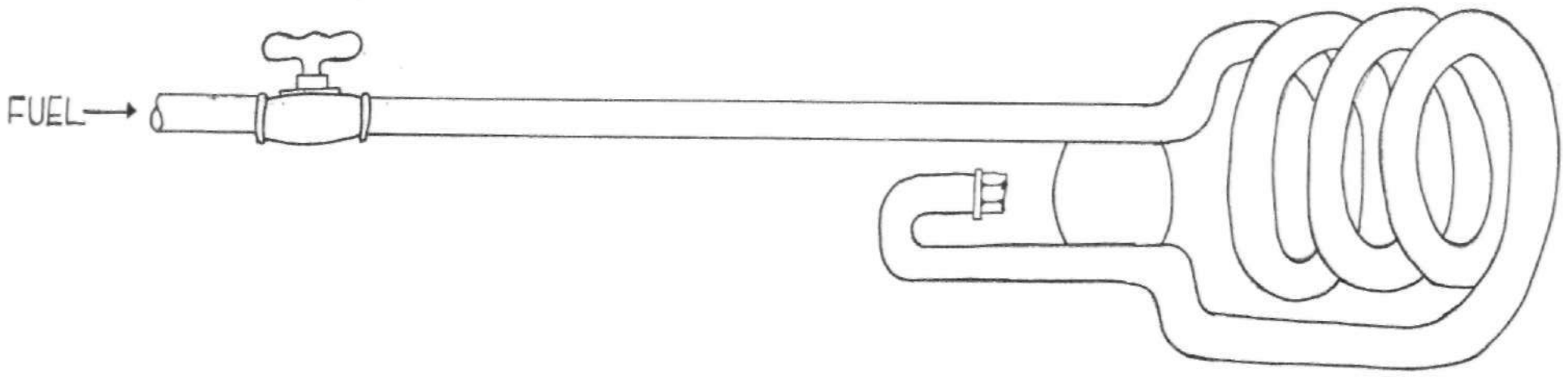


Fig. 4: FINAL THREE DIMENSIONAL VIEW OF BURNER WITH REGULATOR & NOZZLE ON.

4.2 Firing a Water and Oil Mix

Water and oil tanks were installed at slightly varied heights (Fig. 5). To obtain equal pressures of water and oil at the nozzle, the relative heights of water and oil tanks were in the ratio of 8:10. A water hose of appropriate length was fixed to the tap on the base level of the water container. The hose was connected to a T-junction unit on the end of the fuel line where water mixes with the onflowing fuel to the burner. The section of the T-junction that holds the water hose must be constructed or thinned down to almost an orifice, for effective control of the required amount of water.

4.2.1 Further Trial-Firing with Water and Oil

Using the model coil burner, further test-firing with water and oil mix was conducted. A successful firing was obtained and the result was a "mature" glazing (designed for 1280^{o}C) achieved in 14 hours. When subsequently two burner were used a reducing smoky kiln atmosphere, which is not acceptable, was obtained. Hence one burner was use in all subsequent firings.

Finally, firing with mixed water and oil (kerosene) now tallies with the "ruggedised" principle sought in this investigation. At this point however, other operational adjustments were made both in the kiln - [illegible] ports.

Discussion

It was found that the lower bricks on the bagwall which was struck directly by the flame have begun to melt and vapour glaze. This was due in part to the intense flame from the burner being too close to the bagwall and, because the bagwall was constructed with insulating brick. It was also suggestive that the bagwall be increased a course higher to improve heat travel.

Adjustment

1. A brick work was created at the entrance of the burner port to increase the length of the firebox
2. The insulating brick bagwall was re-constructed with dense brick. This is because dense brick transfers heat better and is more refratory. One more course was added to the previous two-course bagwall brick and, laid edge on edge.

3. The chimney suction effect was checked, the flue channel in the kiln was adjusted by raising the base shelf in the kiln from 3cm. to about 6cm.

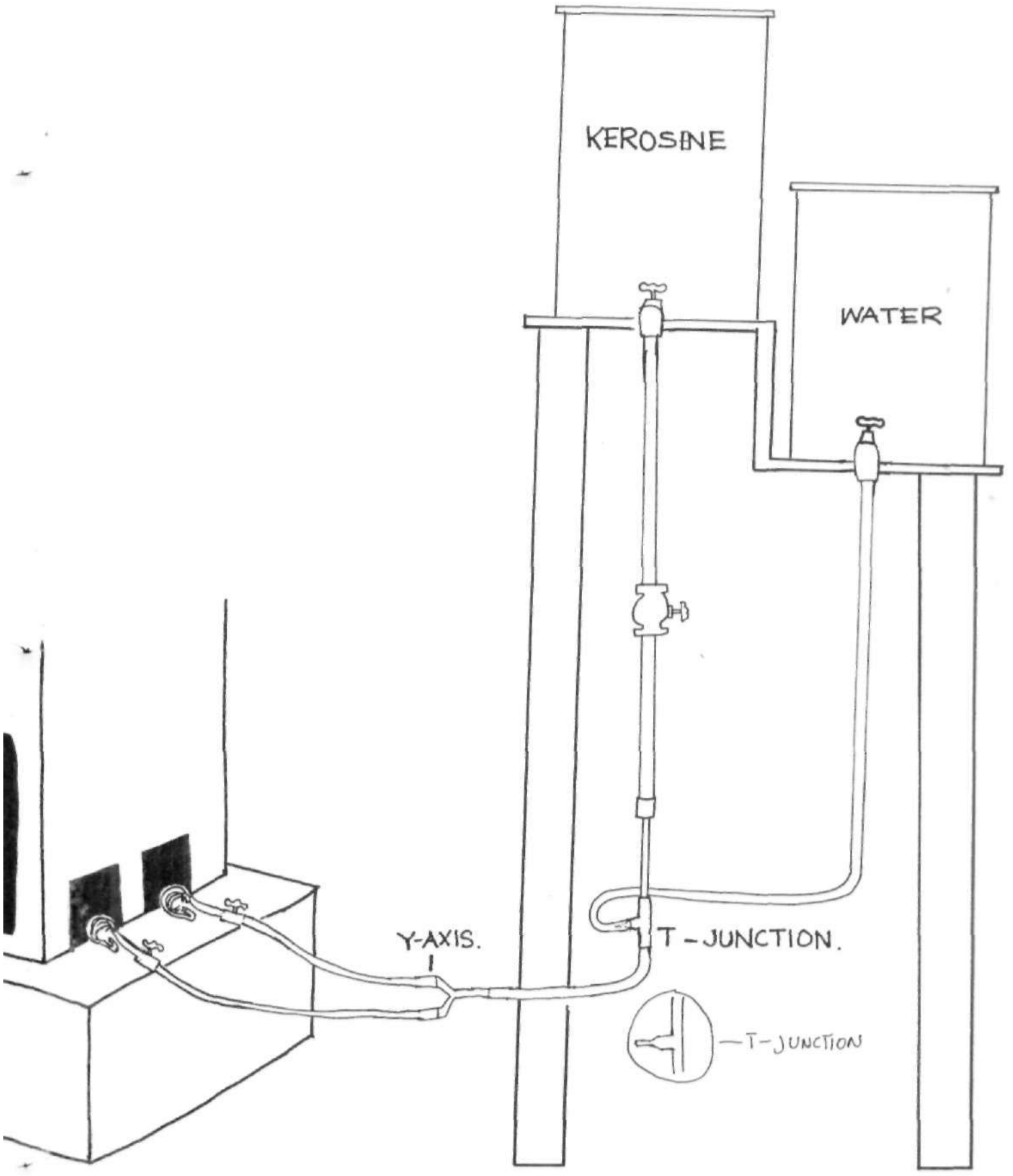
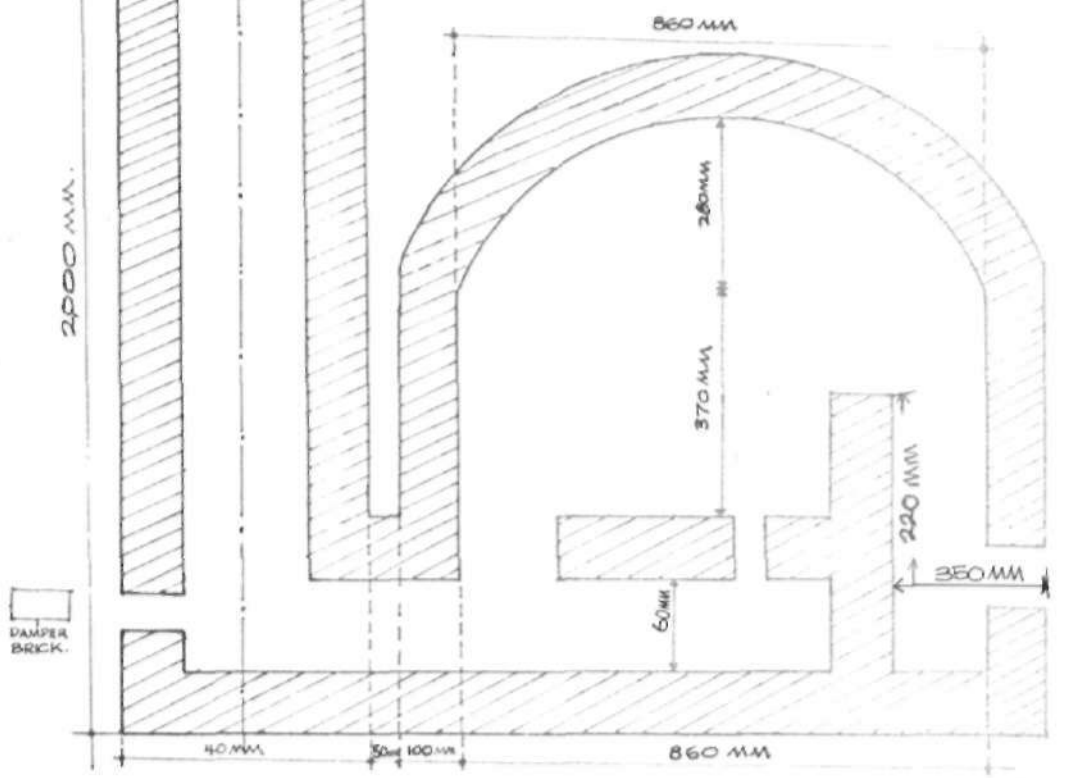
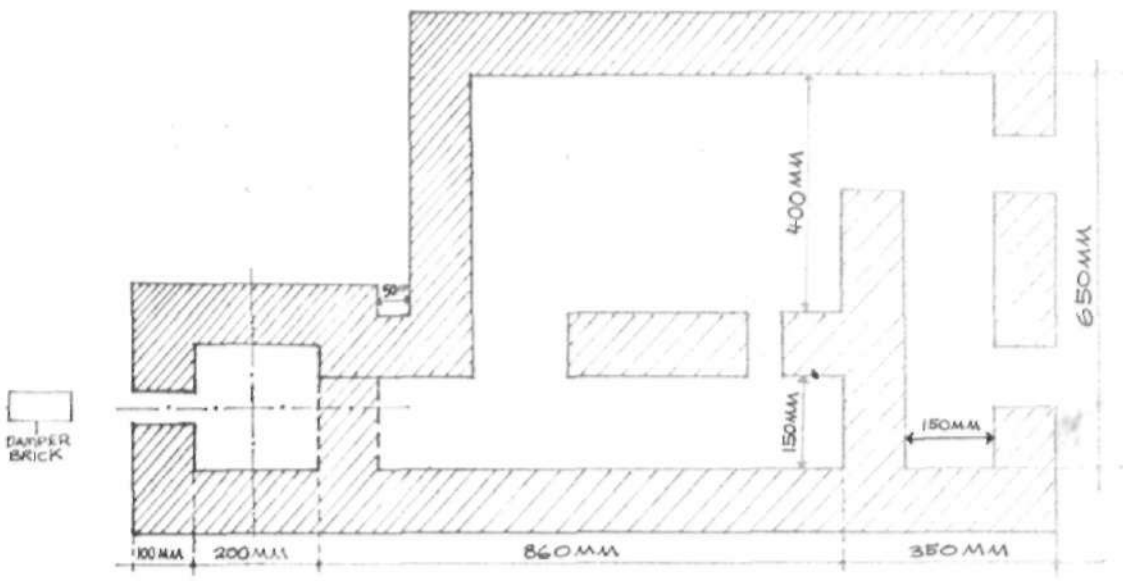


Fig. 5: DIAGRAM SHOWING TWO BURNER SYSTEM WITH Y-AXIS CONNECTED TO THE WATER/FUEL SYSTEM.

Fig. 6.
DIAGRAMS SHOWING KILN ELEVATION AND PLAN SECTIONS RESPECTIVELY, WITH RELEVANT DIMENSIONS.
(SCALE 1:10)

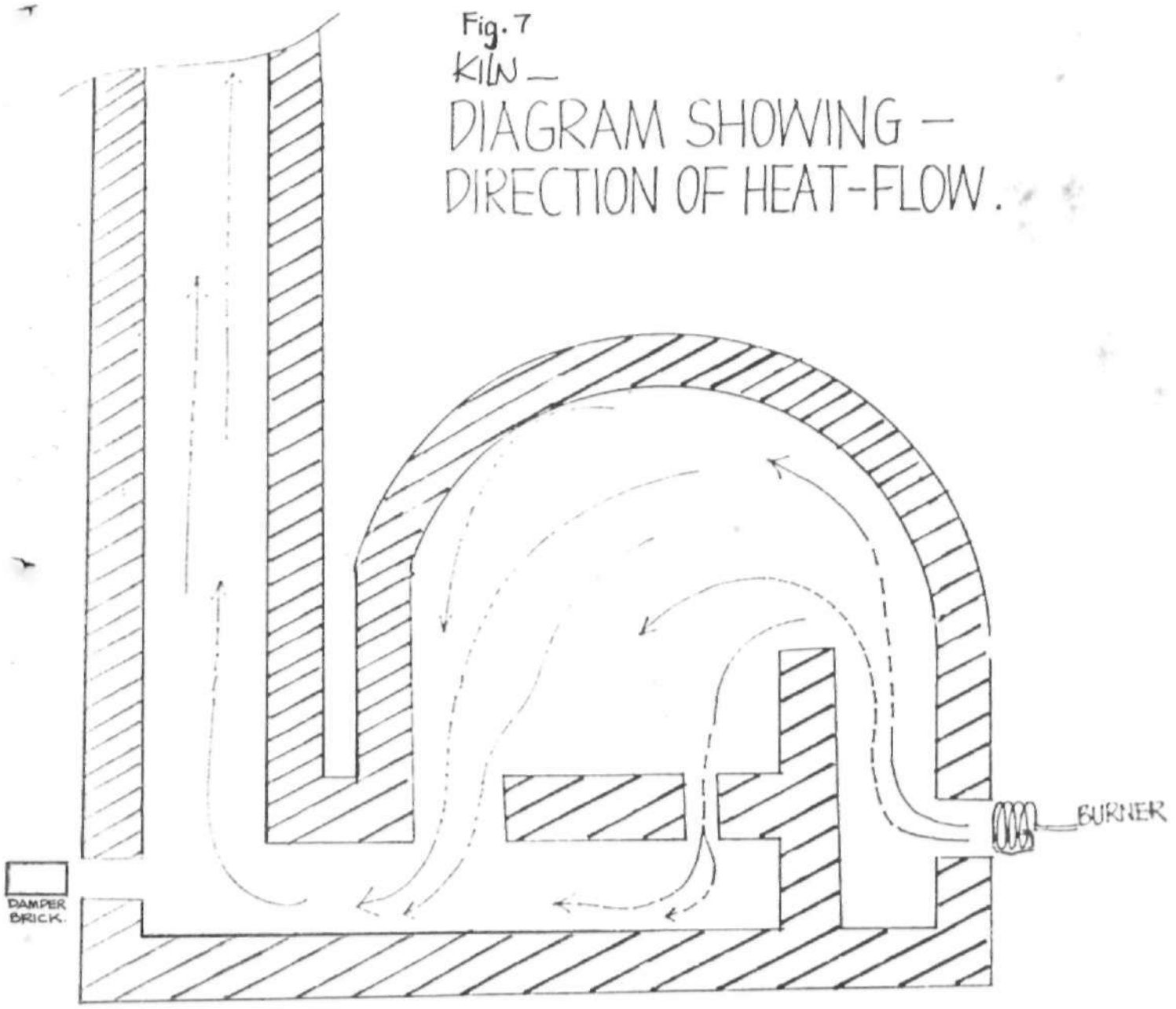


SECTION: ELEVATION



SECTION: PLAN.

Fig. 7
KILN —
DIAGRAM SHOWING —
DIRECTION OF HEAT-FLOW.



4.3 Subsequent Production Firing

To start, it was better to put a second burner on a stand-by should clogging or blockage of the one in use occur. Also, since two burners produce a reducing kiln atmosphere, one of the fireboxes was controlled rather to serve as secondary air source. The design of the burner component as shown in (Fig.5) is such that the Y-axis can be detached for one burner to be fixed to the T-junction directly.

However, further production firings were conducted in the usual operational mode: igniting; pre-heating; full starting; stopping and colling and cleaning of the burner.

Igniting:

Starting the firing was preceeded by first pre-heating the coil for five minutes or more by burning a piece of rag, dry grasses or other such carbonaceous matters in the coil space or flame holder. When fuel is introduced into the preheating coil thereafter, it vaporises and swirls through the burner orifice in the form of gas, igniting at the orifice.

Preheating

During preheating, fuel supply is adjusted to a minimum (about the level turned on for ignition) ensuring that the flame was not so dense as to excessively smoke up the kiln chamber. Preheating was continued for over an hour during which the moisture contents of the pots would have escaped. At preheating, the damper was allowed a maximum opening to ensure good escape of the moisture.

Full Firing

At the end of preheating the firing was fully continued with more intense heat by increasing fuel supply to a maximum. This is better done watchfully as turning the valve abruptly fully on would result in pulsation and hence smoke and reduction in temperature. Water was also introduced at this point for the commencement of full firing. The damper brick was now pushed in for consistent chimney draught.

Stopping and Cooling

When the operational temperature was reached, the firing was stopped by shutting off fuel supply. The burner unit was then detached with the residual fuel drained into container for recycling. The burner port must be "clamped" as soon as possible.

Cleaning of the Burner:

After the burner has been drained of residual oil, it was safer to further pour fresh oil into it to remove any likely dirt and blow with mouth while the control valve was fully turned open.

However, when the burner became seriously blocked in operation, this was undone by supplying excess water to flush the burner coil; and if the blockage persisted a compressor or any pressure pump was employed to unplug it. It is important to note here that the major cause of plugging in the coil is over heating if the burner is put too far into the hot zone of the firebox.

4.3.1 First Firing

The first firing took 13 hours consuming about 20 gallons of kerosens. After preheating, steam was introduced by turning on the previously closed water tap, water would flow down to a T-junction where it makes contact with the onflowing fuel, to the preheating burner coil, and, to serve as steam. (See firing log in appendix IV).



Plate I: First Firing Result

Discussion

The 13-hour firing duration is relatively too long and needed to be cut down. It was observed also that the kiln was too densely packed resulting in poor circulation of hot gases and in underfiring of some of the pots on the down shelves. As a result, the loading of the kiln was checked in the second firing.

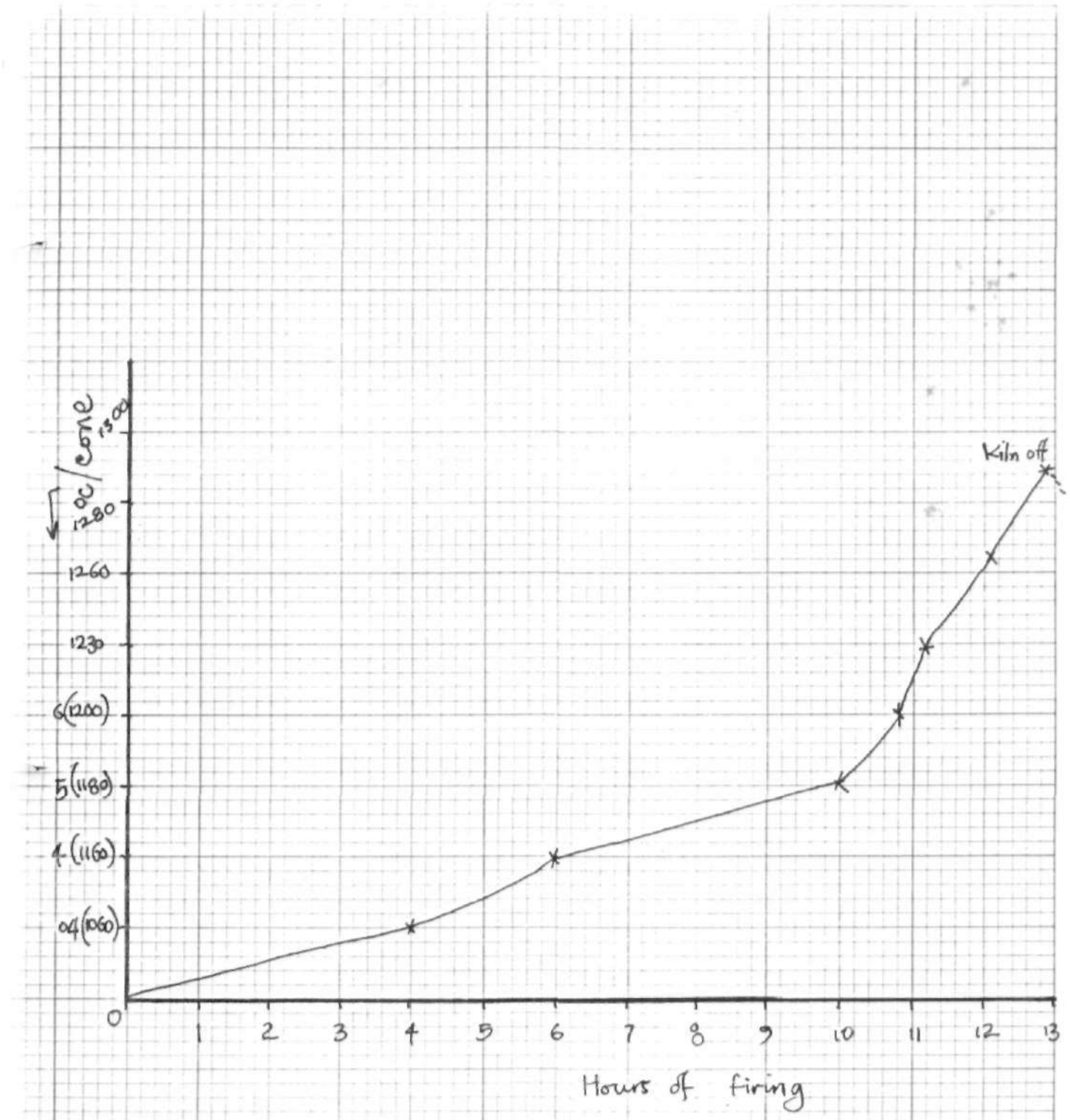


Fig. 8: 1ST FIRING CURVE WITH MAJOR CONE/TEMPERATURE CHANGE.

4.3.2 Second Firing

This was preheated in the same way as above, after which steam was introduced to continue a full firing. With a better packing of the kiln than in the first firing, the second operation fired in ten hours.



Plate II: Second Firing Result

Discussion

The kiln was fired with comparatively clear atmosphere. As a result, the pots were neither reduced nor oxidized. The firing therefore became normal.

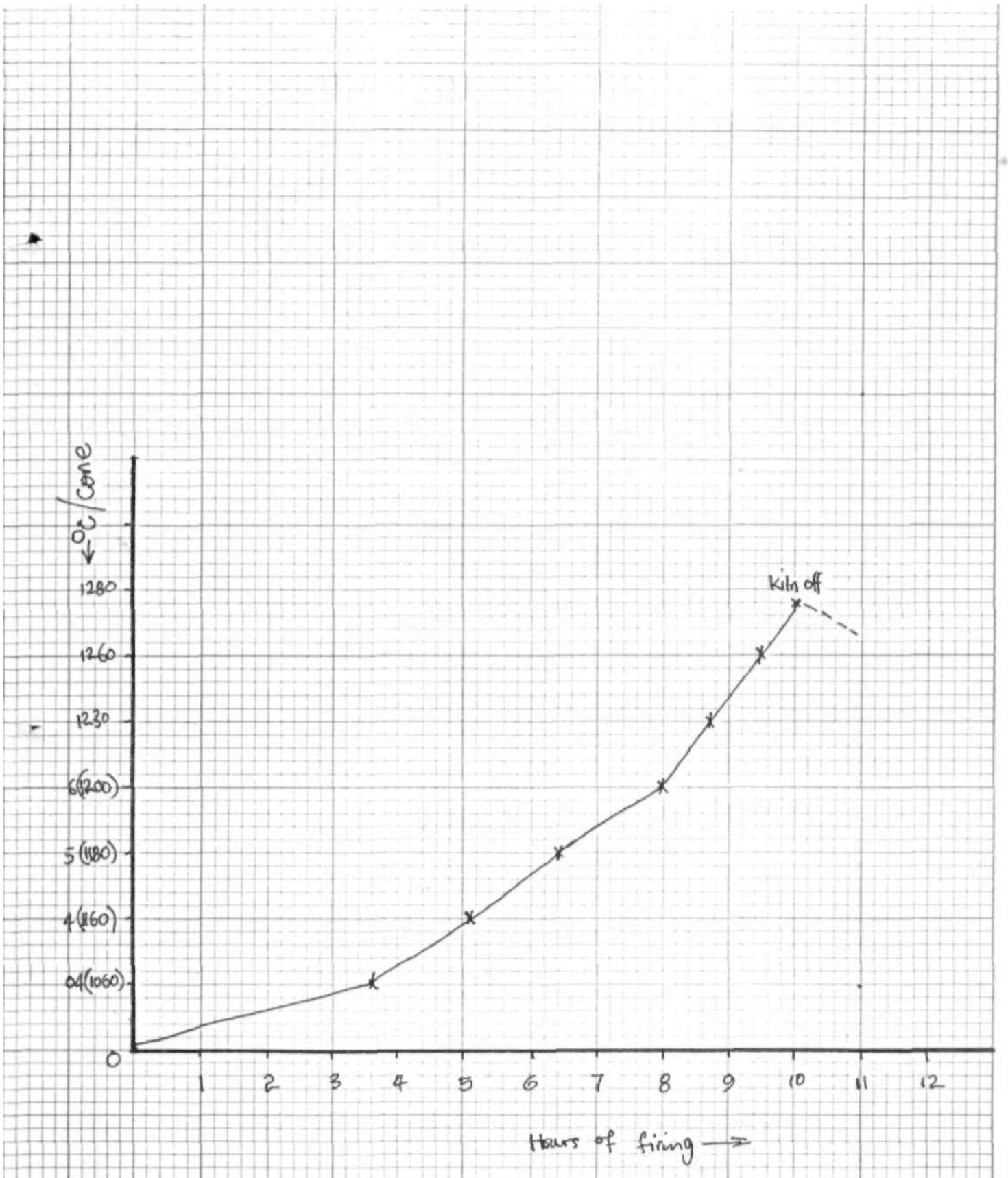


Fig. 9: 2ND FIRING CURVE WITH MAJOR CONE/TEMPERATURE CHANGE.

4.3.3 Third Firing

The third firing was stopped before completion became of profuse leaks and dissengagement of hose couplings in the fuel supply line. Before the interruption however, the rate of kiln temperature rise was slow but, favoured some of the low glaze pots at cone 6 (1200°C).



Plate III: Third Firing Result

Discussion

Worn-out clips were replaced to make hose/pipe couplings firmer.

The mature (low/graze) pots removed replaced with fresh pots for the fourth firing. Examination of kiln performance showed that increasing the height of the bagwall was counter productive. This essentially suggests that the original 2-course bagwell of the kiln is appropriate.

4.3.4 Fourth Firing

The fourth firing was completed in over 10 hours with 18 gallons of kerosene.



Plate IV: *Fourth Firing Result*

Discussion

The atmosphere during the firing was much like that in the second firing, bright and clear; except for the down portion of the kiln which fired (rather ~~comparatively~~) slowly as the lower placed cones five (5) and six (6) bent down one hour later than the same cones at the top had bent. This was, similarly, due to faults in kiln loading. As a result two or three pieces from the down shelves were underfired.

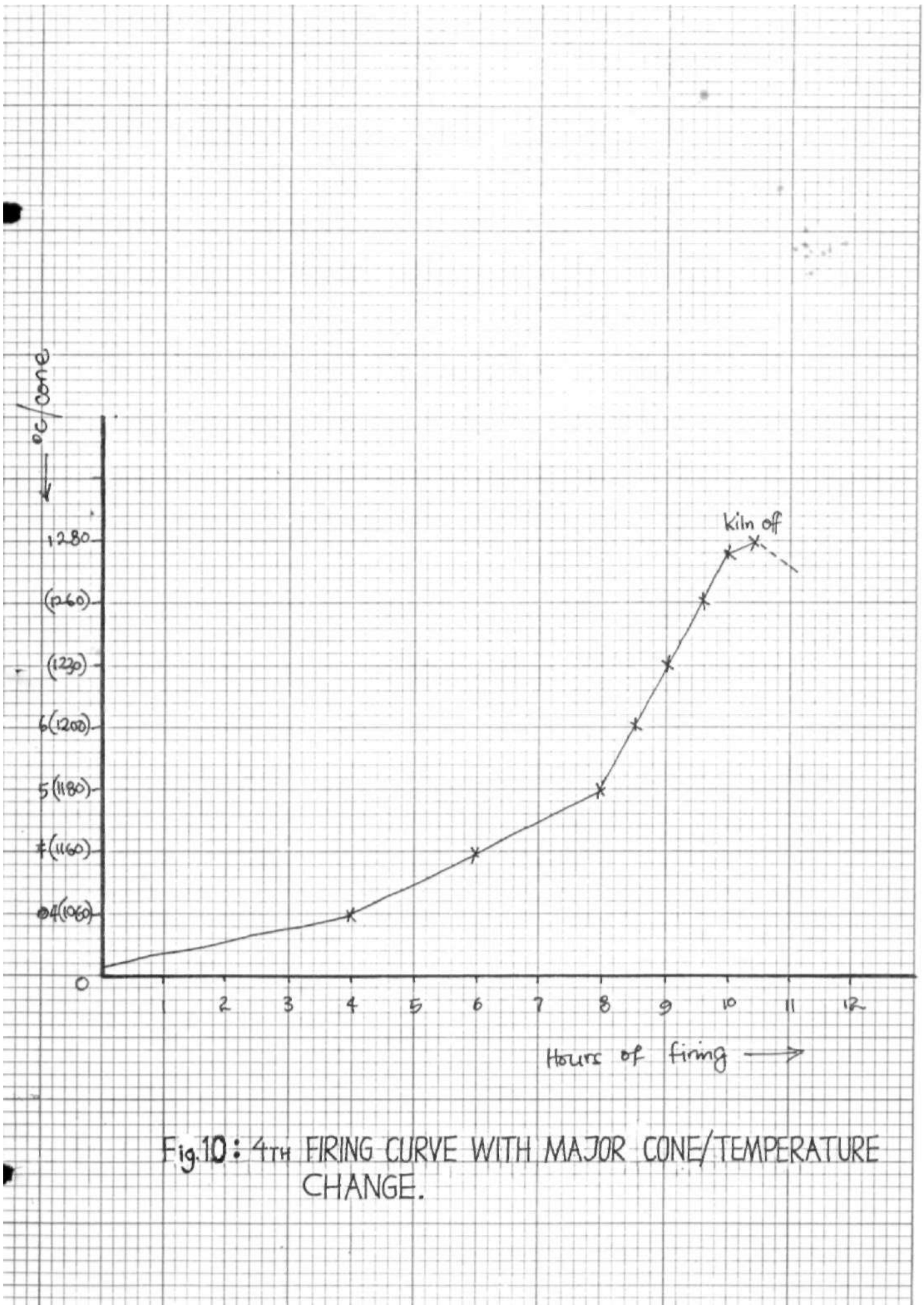


Fig.10 : 4TH FIRING CURVE WITH MAJOR CONE/TEMPERATURE CHANGE.

4.4 Cost Analysis of Kerosene, Gas and Firewood

Although the actual prices of kerosene, gas and firewood vary with time their relative cost should remain fairly constant.

4.4.1 Operational Cost Estimate of Kerosene Gas and Firewood

The present price of the above fuels are used to obtain a rough estimated firing cost of each, using a 10-cubic-foot kiln of the size used in this investigation is as seen below:

	Price Per Gallon/ Cylinder	Quantity per Firing	Cost per-firing
Kerosene	₦2.50/gallon	16 gallons	₦40
Gas	₦60.00-₦80.00/50kg cylinder	1 50kg Cylinder	₦60-80
Firewood	₦1.00- ₦1.50/kg	about 20kg	₦20-30

The fuels, in terms of operational costs suggests firewood as the least expensive. Its continued use, however, runs against government legislation in Nigeria. Although it is noteworthy that, smaller kiln of this size consumes significantly larger quantity of firewood than bigger ones new "fast-firing" wood kilns have been designed in the United States and Britain (Olsen, 1983), which requires commensurably less wood consumption. Therefore the above price cannot be a "hard and fast" costing.

Gas firing is the most costly. Gas supply is very erratic on the Nigerian market leading to wild price fluctuations. Hence gas firing introduces an unpredictable cost element into production costing. Furthermore, it requires special machine-fabricated nozzles, which have to be imported in its burners.

On the other hand, operational cost of firing kerosene is comparatively cheap (as this applies to similar grade oils like diesel, drain oils etc.) Kerosene is the most common petroleum product which is already being used for domestic cooking and heating. It is also available in both urban and rural setting in Nigeria. Finally the burner nozzles can be fabricated locally, yielding a locally produceable burner.

4.4.2 Initial Capital Cost Estimate of Kerosene, Gas and Firewood

The initial capital/infrastructural investment in each firing option must also be considered. Wood-operated kilns have the least initial investment costs, which comprise of the cost of storage for fire wood. Gas firing requires having in stock cylinders of gas with each empty cylinder costing about one thousand naira (₦1000); including a gas guage also costing about one thousand naira (₦1000). Furthermore, the nozzle

for burners have to be imported and cost on the average one hundred naira (₦100). Kerosene firing requires a small domestic drum, costing one hundred naira (₦100) to store kerosene. and a locally fabricated burner, which can be fabricated for three hundred and fifty naira (₦350) per burner; plus the oil lines and controls estimated at two hundred and fifty naira (₦250). On the average one needs half as many fuel burners as gas burners. Hence the ratio of fixed capital cost for gas and fuel firing is about 6:1.

Finally, firing with kerosene delivered in the form of the "ruggedised" coil burner system in this discourse make significant cost difference nothwithstanding its dirt, attention and early smoke burning (although a phenomenon with nearly all oil-operated systems). Hence the kerosene firing option has the following distinct advantages over the gas system:

1. Kerosene is more readily available than gas; hence its price is more stable;
2. Kerosene is easier to store; gas storage requires expensive cylinders and guages.
3. Kerosene is safer; gas leakage can cause explosions.
4. The kerosene burner can be fabricated locally whereas gas burners contain import items.

4.5 Advantages and Disadvantages of Liquid Fuel Firing

The main advantages of liquid fuel firing over other fuel firing include:-

1. A high combustion intensity
2. A high combustion efficiency in that a limited unreacted (unburnt) fuel as much as possible, leaves the combustion chamber.
3. Compared to solid fuels, deposition of soot on the combustion chamber walls is minimal in liquid fuel operations.
4. The higher calorific value of oil fuels enables much greater furnace heat output from a given weight and/or volume of fuel.
5. Solid fuels are susceptible to spontaneous combustion and deterioration during storage. For example, oils can be stored more securely than coal and they are easily handled and moved about the firing premises.
6. Gaseous fuel firing requires special safety precautions to prevent explosion which occurs if any line of burner slightly leaks or opens.
7. Liquid fuel operation attracts less cost compared to most other fuel types except wood.
8. Possibilities of achieving and experimenting with different stone ware surface effects are available in oil firing compared to gas.

4.5.2 Disadvantages

1. There is the early smoky burning which makes its operation very messy and which perhaps explains its non-popularity.

2. Liquid oil burning requires more attention especially, given its "early smoke" and tendency to plug.

3. It is more prone to producing a reducing atmosphere than gas firing.

4. Liquid fuel operations constitute limitations on kiln options; this is directly applicable to the "nuggedised result" in this investigation.

Chapter 5

IMPLICATION, CONCLUSION AND RECOMMENDATION

5.1 Implication

It is evident that the coil burner even when operated with prime movers is not very viable because of the frequent problem of "plugging" which actually negates its cheapness.

Except where burner and/or kiln is taken into design consideration, crossdraught/downdraught and catenary arch kilns seem most suitable for oil burner construction.

The empirical procedures employed in this study justifies that a coil burner operated with oil mixed with a little water works, with the water serving dual efficacy of atomizing fuel flow in the coil and, to a considerable extent preventing clogging. However, it is imperative that the fuel be properly filtered before entering the burner; the water should not be dirty either.

It is also implied that two burners of this type would fire dense in the size of kiln used. This number of burners will perhaps be just suitable for about twice the size of the kiln. "When firing with

gas, the old kiln rule was that the more burners you stuck in, the more likely the kiln was to heat evenly. Firing with oil, multiple burners are redundant", Parks (1980).

5.2 Conclusions

Based on the findings of the study, conclusions were drawn that:

1. inspite of the adaptable result, the behaviour of fuel and water system implies that an instrumented component will function more efficiently.

2. having chosen high temperature to fire, it is concluded that the system fires well to biscuit temperature (900°C and above); and lends its suitability to conducting burnt brick firing for building purposes. Low glazing temperatures (1000°C - 1200°C) as well as stoneware temperatures (1280°C and above) are also within its potential.

3. firing time is reasonable

4. surface character produced on the fired pots in oil firing is the same as that obtained in gas firing, if an oxidizing atmosphere is maintained.

5. firing with kerosene on coil burner attracts only modest cost in terms of the fuel, storage, burner construction and operation as compared to gas and firewood.

6. finally, it is practicable that the coil burner system will conduct other heavier oils like diesel, drain oil and so forth, when appropriately preheated (as implied by literature investigation) to reduce viscosity.

5.3 Recommendations

The following general recommendations have been warranted by the findings of the study:

1. Following the ideas of Parks (1980) who called for exchange of ideas among potters in order to realize the potential of "waste oil", it is recommended that design systems capable of conducting other oil products besides kerosene should be encouraged. In this way the Nigerian potter may find alternative fuels to gas.

2. Also, it issuggested that technicalities inherent in constructing oil burning devices and/or adaptability of kilns to them be purposefully simplified and taught in ceramic

training classes particularly, now, that the Federal Military Government is campaigning for utilization of available human and natural resources in terms of "basic technology".

3. Similarly, in her experimentation with solar energy for ceramic firing, Brisson (1981) has stated that attention must be given to new method of energy while the modern technology is still utilized. In this vein it is further thought worth while that authorities in ceramic and other related areas should create opportunities for inter-disciplinary exchange of ideas for this helped this research work grow into a co-ordinated direction. Brisson further stressed that, "To meet today's and tomorrow's energy needs, many diverse avenues of research must be considered for possible development; this will require an open mind toward unconventional and innovative approaches to the problem".

4. Above all, given the emerging enthusiasm about operating an unfamiliar system of firing as this, students' firing choices can be broadened if further encouraged. By the same token, the ceramic programme of Ahmadu Bello University, Zaria, would add another achievement to her

already impressive record. This new research will inspire other institutions. Also, it further broadens the technical and economic possibilities available to ceramic studios/workshops.

5.3.1 Recommendation for Further Research Work

This research work is, at this stage, essentially experimental. Therefore it is further emphasized that more work should be directed at instrumenting the system so as to optimize its efficiency and temperature potential, especially under reduced operating/ finishing time. Altogether, more research is required in terms of making kilns most adaptable to oil burning systems.

REFERENCES

A. BOOKS

Adetoro, S. A. (1985). Research Techniques. Ahmadu Bello University, Zaria, pp. 1-64.

Borgs, W.K. and Gall, M.D. (1979). Educational Research. Longman, New York, pp. 177, 179.

Brodie, R. C. (1982). The Energy Efficient Potter. Waston Guptill Publications, New York, p.146.

Brouwer, L.E.J. (1966). Petrolem Handbook: Sheel International Petroleum Company Limited, London, pp. 144-149.

Cardew, M. (1969). Pioneer Pottery. St. Martin's Press, New York, pp. 93-96; 170-200.

Cooper, E. (1972). A History of Pottery. Longman Group Limited, London, pp. 13-15.

Counts, C. (1973). Pottery Workshop. Macmillan Publishing Co. Inc., New York, pp. 69-100.

Harvey, R. and Kold, S. and J. (1975). Building Pottery Equipment. Watson-Guptill Publications, New York, pp. 144-145.

Krivandin, V. A. and Markov, B.L. (1980). Metallurgical Furnaces. Mir Publishers, Moscow, p. 286.

Norsker, H. (1987). The Self-Reliant Potter: Refractories and Kilns. Friedr. Vieweg and Sohn, Brauschweigh/Wiesbaden, pp. 82-90.

Olsen, F. L. (1983). The Kiln Book: Materials, Specifications and Combustion. Adams and Charles Black, London, pp. 173-174.

Parks, D. (1980). A Potter's Guide to Raw Glazing and Oil Firing. Charles Scriber's Sons, New York, pp. 66-70.

Rhodes, D. (1957). Clay and Glazes for the Potter: GreenBerg, New York, p.57.

Rhodes, D. (1968). Kilns: Design, Construction and Operation: Pitman Publishing Company, Johannesburg, South Africa, pp. 60-82.

Williams, A. (1976). Combustion Spray of Liquid Fuels. Elek Science, London, pp. 165-167.

B. JOURNALS:

Brisson, H. E. (1981). Firing With Solar Energy. The National Council on Education for Ceramic Arts 2(1): 24-27.

Yule, A. J. and Bolado, R. (1984). Fuel Spray Burning Regime and Initial Conditions. The Journal of Combustion Institute, Elsarvier Science,Publishing Co., Inc., New York, 55:1-2.

C. UNPUBLISHED MATERIALS:

Ahuwan, A. M. (1987). "The Importance of Ceramics in National Development; the Nigerian Experience". Lecture delivered on the Occassion of the Annual Conference of Ceramic Association of Nigeria, Northern Zone at the Industrial Development Centre, Zaria.

a) Ewule, J. O. (1987). "Development of a Model Gas Kiln for Ceramic Production". Seminar Paper, Dept. of Industrial Design,,A.B.U., Zaria, pp. 1-10.

b) Ewule, J. O. (1987). "Development of a Model Gas Kiln for Ceramic Production". M.A. Thesis, Dept. of Industrial Design, A.B.U., Zaria.

Gadzama, N. J. (1987). "Appropriate Technology: A Factor in the Industrial Development of Nigeria". Paper Presented at the Borno State National Orientation Course Lecturers and Language Studies for the 1986/87 Batch of N.Y.S.C.

Na-Allah, S. (1980). "Gwary Pottery and the Pottery Training Centre, Abuja", Ph.D. Thesis, Teachers' College, Columbia University, p. 107.

D. NEWSPAPERS:

"The Launching of the 7th Yearly National Tree Planting Campaign in Sokoto State by President Ibrahim Babangida, New Nigerian Newspapers, 16th July, 1987.

E. ENCYCLOPEDIA:

Considine, D. M. (1976). Van Nostrand's Scientific Encyclopedia. Van Nostrand Rheinhold Company, New York, p. 268.

Appendix I

COLOUR WITHIN A KILN DURING FIRING.

Temperature (°C)	Colour	Fired Ware
500	dull Red	
750	red	enamels
1,000	brightred	bisquit and earthenware
1,100	orange red	glaze
1,150	bright red	high bisquit
1,200	white orange white	stoneware: bone China bisquite.
1,350	blue white	porcelain

David Hamitton (1974).

Pottery and Ceramics, the Themes and Hudson Manual, London.

Appendix II

TEST-FIRING LOG 1

15/4/90 Time	Function	Remarks
1.00p.m.	preheating (one burner)	low pressure; dense flame and smoky chimney;
2.00p.m.	2nd burner introduced	improved flame; same chimney;
3.45p.m.	full firing (air-assisted); damper closed	clear chimney kiln atmosphere picking red heat
6.30p.m.	"	red, bushy atmosphere
7.00 p.m.	as a result of bushy burning one burner removed	cone 4 (top) starting to bend; 04 (below) still erect; chimney draught high
7.45p.m.	One burner still going	topcone, 4 (1160°C) down flat
9.30p.m.	"	down cone, 04 (1060°C) also down flat (irregular timing with above)
11.00 p.m.	2nd burner introduced again; removed soon after	before removal of 2nd burner, bushy burning atmosphere in kiln and out of chimney reappeared

15/4/90	Function	Remarks
2.00 a.m.	one burner functioning better	cones 5 (top) and 6 (below) are only slightly titled; same atmosphere as above
3.30 a.m.	- do -	cone 5 (1180°C) way down.
3.45 a.m.	"	cone 6 (1200°C) going down
4.45 a.m.	"	cone 6 half way there
5.15 a.m.	"	cone 6 down
5.25 a.m.	"	cone 6 down flat
6.05a.m.	"	about an hour after cone 6, kiln put off, ending with strong blue-white but steady flame

TEST-FIRING LOG 2

18/4/90 Time	Function	Remarks
4.10 p.m.	preheating (one burner - air assisted operation	dull flame, now readily smoky chimney
5.00 p.m.	2nd burner introduced	stronger flames chimney now smoky
6.09 p.m.	firebox bricked out, burners repositioned with motor-powered compressor introduced	chimney less smoky
8.08p.m.	above depreciated after 2 hrs. and discontinued	sudden bushy/dense burning had already began
8.10p.m.	one burner discontinued;	kiln atmosphere clear and glowing orange
8.15 p.m.	one burner operating	cone 4 (1060°C) down
9.33p.m.	- do -	cone 4 (1060°C)
11.20 p.m.	- do -	cones 6 (top) and 5 (below) still standing

18/4/90 Time	Function	Remarks
11.20p.m.	lone burner operating	cones 6 (top) and 5 (down) still standing.
11.27p.m.	- do -	atmósphere bright yellow, cone 6 bending-top wares showing shine down, otherwise.
11.20p.m.	"	"
1.15a.m.	"	cone 6, ¾ way down.
1.40a.m.	"	flame pulsates at short intervals, burner pipe gets very hot; thus the bricking the firebox removed.
2.00a.m.	"	above changes dissapear, draught in chimney goes higher to about half the height of the chimney.
2.15a.m.	"	cone 6 (top down; 5 (down) still same.
2.40a.m.	"	cone 6 gone flat, 5 same as above; chimney draught good.

18/4/90 Time	Function	Remarks.
4.15a.m.	lone burner operating	after cone 6 near 2 hours earlier cone 5 stand still erect; firing however is discontinued; with cone 5 down pots may have been underfied.

Appendix IV

KEROSENE/WATER OPERATION - FIRST FIRING.

10/5/90 Time	Function	Remarks
1.45p.m.	preheating	starting well
2.48p.m.	full firing, with introduction of steam	starting well
5.00p.m.	2nd burner tried on	starting well.
5.10p.m.	introduction of burner introduces smoke then removed.	cloudy atmosphere + chimney; reduction in temperature.
6.30 - 7.00p.m.	the one burner siezes but ~~flushed~~ flushed with excess water allowed; hence function restored	clear chimney restored too.
7.30p.m.	- do -	clear chimney restored too.
8.15p.m.	"	cone 04 down; chimney as above.
10.53	"	cone 6 begins to tilt; bright yellow atmosphere, hot chimney and improved draught.

Appendix V

KEROSENE/WATER OPERATION - THIRD FIRING

26/5/90 Time	Function	Remarks
2.00 p.m.	preheading	smoky
3.00 p.m.	full firing; steam introduced	less smoky
4.30 p.m.	fuel addition (one jerry can); full firing continued	less smoky
6.00 p.m.	- do -	good draught up the chimney
6.30 p.m.	- do -	"
6.49 a.m.	spy-hole opened bright atmosphere	flame most steady clear chimney and higher draught
7.00 p.m.	- do -	.. do ..
9.00 p.m.	.. do -	cone 6 going down
11.30p.m.	exhaustion of fuel;function discontinued	atmosphere very bright; and may have fired some of the lower-glaze pots

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