DEVELOPMENT OF A MODEL GAS KILN FOR CERAMICS PRODUCTION FROM LOCAL RESOURCES

BY

EWULE, JAMES OTEGUH

A THESIS SUBMITTED TO THE POSTGRADUATE SCHOOL AHMADU BELLO UNIVERSITY, ZARIA IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF MASTER OF ARTS IN INDUSTRIAL DESIGN

DEPARTMENT OF INDUSTRIAL DESIGN FACULTY OF ENVIRONMENTAL DESIGN AHMADU BELLO UNIVERSITY ZARIA

NOVEMBER, 1988

DECLARATION

I, EWULE, James Oteguh, solemnly declare that the contents of this thesis is the report of my study on "Development of a Model Gas Kiln Suitable for Ceramics Production From Local Resources". I collected the necessary materials, took photographs, designed and constructed the kiln also designed the burners before fabrication as stated in the thesis. I took and passed the specified courses below as a prerequisite for this thesis.

Ceramic Theory

Engineering Drawing

Research Technique

Research Media

Signature: _____

Date: 25TH NOVEMBER 1988.

CERTIFICATION

This thesis entitled "Development of a Model Gas Kiln for Ceramics Production from Local resources" found in Zaria and Kankara by Ewule, James Oteguh, meets the regulations governing the award of the degree of Master of Arts (Industrial Design) of Ahmadu Bello University, Zaria. It has this day been approved for its contributions to knowledge and literary presentation.

Dr Abashiya M. Ahuwan
Chairman, Supervisory Committee

27/III/88
Date

Dr S.A. Adetoro
Head of Department

29/12/88
Date

Dean, Postgraduate School

20-3-89
Date

DEDICATION

This thesis is dedicated to Ewule and Otelahu my late father and mother respectively.

ACKNOWLEDGEMENT

In the collection of materials, construction of the kiln, fabrication of the burners and the writing of the report of this study, I received tremendous helps from many people. All those concerned should be aware that their efforts have been highly commendable in this study.

Those that immediately come to mind to be mentioned are:

Dr Abashiya M. Ahuwan, the major Supervisor; for his fatherly advice and suggestions, tolerance through the period of supervision must not be forgotten in this acknowledgement. The spirit of leadership both as a Major Supervisor and as the Head of Ceramic Design Section, Department of Industrial Design, Ahmadu Bello University (ABU) will remain indelible.

Special thanks to Dr Rishanto the Co-ordinator, Postgraduate Studies, Department of Industrial Design, Ahmadu Bello University, Zaria, for his devoted effort and encouraging advice and support. My thanks and regards go to Dr T. Oguntona the Co-Supervisor in his support and continued faith in my ability sometimes not express in words served as pillars of strength.

For their contribution as members of Examination Committee, I am deeply grateful to: Dr S.A. Adetoro, the Head of Department of Industrial Design, Ahmadu Bello University, Zaria; Mr D.M. Clarke, Head of Glass Design Section, Department of Industrial Design (DID) Ahmadu Bello University, Zaria who untiredlessly welded the metal frame. Mr Sammy Laryea also of the same Section, I appreciate his contributions.

I am indebted to the Benue State Government for the Scholarship award which facilitates this study. Also to the Authority of Ahmadu Bello University for giving a grant with which I procured some of the items used. Dr. and Mrs. Mama of Lafia Clinic and Jacaranda Pottery, Kaduna for sparing me the use of their grinding machine throughout the period of kiln construction, I am most grateful.

The role played by David B. Kufana by typing the drafts and Hassan Latima Tula, the final scripts, the patience and care taken in everything cannot be forgotten.

Appreciation is also extended to the groups of technicians in Industrial Development Centre (IDC), Zaria, Mallam Maman; Ado; Mr. Ajao; Daniel and Cambel without which the fabrications of the burners would not have been possible.

Acknowledgement is made to Charles Counts for sparing his time to settle in Ahmadu Bello University to go through the scripts to effect necessary corrections; to numerous friends impractible to name, who in one way or the other contributed to the success of this study.

I am thankful to the members of my family, my wife Elizabeth, daughters Otelahu, Inori, Agidi, Berendina and Ogbenyi; the boy, Odo. Their continuous prayers, support and love that one day this study must be unveiled is reassuring.

Thank you all.

Ewule, James Oteguh.

ABSTRACT

Ewule, James Oteguh, Development of a Gas Kiln For Ceramics Productions From Local Resources. Master ©f Arts. Industrial Design, November, 1988. 79 pages, 4 tables, 5 figures, 16 plates and 12 appendices.

The problem with which this study is concerned is the cons-truction of a gas kiln from locally available raws materials found in Kankara, Katsina State and Zaria of Kaduna State. The problem of how to fire the kiln also arose after the pilot study as a result fabrication of suitable burners and production of kiln furniture using raw materials found locally gave an added dimension.

Being a productive development research, it was combined with descriptive research. After locating and collection of the major raw materials, Kankara clay and saw dust, a line blend was made which was tested for various properties. Some of the properties considered were drying and firing shrinkages, water absorption, apparent porosity and modulus - of - rapture tests before the production of the refractory bricks. Each of the test has bearing on each other for example, the more densely the brick is the higher the stress. The less the void the less the water absorption and less apparent porosity.

The construction of a downdraft kiln was made after consi-dering other design options. Based on the available raw materials, to obtained an efficient gas kiln which will fire to stoneware temperatures downdraft kiln was best, as compared to the updraft and crossdraft kilns. Further steps were taken to

produce burners and kiln furniture which has given the kiln a kind of self-supporting.

Established on the tests, design and construction of the gas kiln for the study, the following major findings are relevant.

1, There is sufficient clay (Kaolin, saw dust and gas for kiln construction and firing.

2. The construction of intermittent gas kiln and burners requires great care and precision for an efficient functioning of such a kiln.

3. The costs of prefabricated gas kiln are far more than the prototype built, 'Most prefabricated kilns are imported. 4. Fires to 1300°C between 7-9 hours. This is considered practical for this range of firing temperature. 5. The size of the kiln could be scaled to the design specification as desired by an individual or groups so as not to be prohibitive to build.

The general conclusion of the study is that if clay work is to mean anything to us, the knowledge of the action of fire through the use of efficient and reliable kiln should be of utmost importance to the Ceramists. The technical knowledge can be widened by changing from one method of firing to another and this is a most vital step in this process.

TABLE OF CONTENTS

PAGE

Title Page i
Declaration.. ii
Certification iii
Dedication iv
Acknowledgement v
Abstract vii
Table of Contents ix
List of Tables xi
List of Figures xii
List of Plates xiii
List of Appendices xiv
Description of Terms xv

1. INTRODUCTION AND BACKGROUND OF THE STUDY 1
   1.1 Statement of problem 5
   1.2 Objectives of the study 5
   1.3 Basic Assumption.. 5
   1.4 Delimitation 6

2. REVIEW OF RELATED LITERATURE 7
   2.1 The hearth theory 8
   2.2 The basket theory.. 9
   2.3 Traditional Pottery 10
   2.4 Development of kilns 11
   2.5 Stoneware kilns in Nigeria.. 12

3. METHODOLOGY 15
   3.1 Locating the materials 15
   3.2 Biaxial blend 16
   3.3 Drying and firing shrinkages 17
   3.4 Water absorption and apparent porosity .. 18
   3.5 The Rupture test.. 22
   3.6 Production of Insulating and dense bricks.. 24

4. KILN DESIGN AND CONSTRUCTION 26
   4.1 Basic kiln design option 26
   4.1.1 Updraft kiln 27
   4.1.2 Downdraft kiln 28
   4.1.3 Crossdraft kiln 29

PAGE

4.2 Points considered 29
4.3 Materials 30
4.4 Kiln Construction 30
4.4.1 Foundation 30
4.4.2 Floor 33
4.4.3 The wall.. 34
4.4.4 Door or wicket 36
4.4.5 Arch 37
4.4.6 Chimney and damper.. 40
4.5 Burners and kiln shelves 41
4.5.1 The inspirator burner 42
4.5.2 Aspirator burner 43
4.5.3 Kiln shelves 43
4.5.4 Materials 43

5. KILN OPERATION, FIRING TESTS AND RECOMMENDATIONS
5.1 Packing 46
5.2 Firing 47
5.2.1 Preheating 47
5.2.2 Full Firing 48
5.2.3 Cooling 50
5.3 First Firing 51
5.3.1 Result 51
5.4 Second Firing 53
5.4.1 Result 54
5.5 Third Firing 55
5.5.1 Result 57
5.6 Advantage of gas firing 58
5.7 Disadvantages of gas firing 59
5.8 Observations and conclusions 60
5.9 Recommendations 61

BIBLIOGRAPHY 63

LIST OF TABLES

		PAGE
1.1	Some pottery establishments in Nigeria	13
3.1	Biaxial blend or Line blend	17
3.2	Shrinkage, water absorption and apparent porosity	20
3.3	Rupture - Modulus - Test	23

LIST OF FIGURES

		PAGE
1	A sample test bar	17
2	Updraft Kiln	27
3	Down draft Kiln	28
4	The inspirator burner	42
5.	Method of arranging shelves and props ..	47

LIST OF PLATES

PAGE

1. Kiln frame showing the burners bricks in position on a concrete floor 31
2. Kiln Frame with burners blocks on the metal sheet 32
3. The floor is laid showing burners holes .. 34
4. Power grinder with a grinding disc 35
5. The door arch former in position 36
6. The door opening after the form was removed .. 37
7. Flue exit bridged over by kiln shelf and secondary air holes bridged by blocks 38
8. An arch former 38
9. An arch former in position 39
10. Chimney frame attached to the Chamber 40
11. The Chimney with the door and damper bricked 41
12. Moulded kiln shelves stacked to dry before beating .. 44
13. Checking the temparature with a pyrometer 49
14. The first firing result 53
15. The second firing result 55
16. The third firing result 58

LIST OF APPENDICES

			PAGE
Appendix	I:	Colour within a kiln during firing	66
	II:	Cost of Materials	67
	III:	Standard firebrick shapes	68
	IV:	Burner Type	69
	V:	Some of the tools used during the Kiln construction	70
	VI:	Brongniart's formula	73
	VII:	Gas Kiln Plan	74
	VIII:	Burner for gas Kiln	75
	IX:	First firing graph..	76
	X:	Second firing graph	77
	XI:	Third Firing graph..	78
	XII:	Critical Dimensions for Gas Downdraft Kiln	79

DESCRIPTION OF TERMS

Apparent porosity:	Measures the fraction of open void volume to volume of the material.
Bag wall:	A buffer wall against which the flame plays within the kiln. It serves to deflect and also to resists heat within the kiln.
Burner:	A mechanical device in which the air is combined with the gaseous fuel and ignited at the burner tip.
Ceramics:	Used in the widest application to include articles of inorganic non-metalic materials made permanent by heat.
Convection:	Hot air or gas, being lighter expands and rise, so long as there is a supply of cooler air to take its place.
Cones:	Mixtures of ceramic materials formed into triangular elongated pyramids and designed to melt and bend over at a given temperature.
Cross draft:	A kiln shape where the ware is placed between the heat source and the exhaust port. It has some of the operational characteristics of a downdraft kiln. The difference is that heat passed through the ware as in an updraft kiln.
Crystallized:	Molecules which have built up into a three diamensional repeat pattern.

Damper: A cover (brick, kiln shelf etc.) used to partially restrict the exhaust opening from the kiln. This controls the heat escaping and the fresh air entering the kiln.

Draw, Draft, Drought:
Hot exhaust gases leaving the kiln through the chimney or exhaust port.

Devitrify:
The change from a glassy to a crystaline state. Glaze may partially devitrify during a slow cooling, giving a frosty look.

Downdraft kiln:
A more complex system than the up-draft kiln in that the exhaust as well as the intake is at the bottom. This causes the heat to affect the ware on both its up-ward and down-ward paths. It requires a chimney to induce enough draft.

Firing: The process of exposing clay and glazes and controlled heat within the kiln.

Form: A term used for a 'Natural' mould or one which is used as an adjunct to the process of shaping.

Kaolin: ($Al_2O_3.2Si_2.2H_2O$) Pure clay also known as China clay. The equivalent we have here is kankara clay.

Kiln: A furnace made of refractory clay materials for firing ceramic products.

Levigation:
The separation of particles in a flowing stream (of slip) the finer ones remaining in suspension, the coarser sinking to the floor of vessel or channel.

Modulus of rupture:	The breaking point of a material under stress.
Mortar:	A mixture of fine grog with clay for kiln building.
Pottery:	Fire clay objects. The term is narrower in its application than ceramics and may be used for the less sophisticated types of earthen ware.
Psi:	Pounds per square inch. A unit of pressure.
Pyrometer:	A device for measuring high temperatures, as distinct from low temperature mercury thermometers.
Radiation:	The heat given off by a 'hot body'. In a fuel burning kiln, most of the work is done by hot gases, but radiation from the walls and from pot plays an increasing role as the peak temperature is reached levelling out the heat through the setting.
Saggars:	A clay box in which objects are enclosed to protect them from direct contact with the flames of an open kiln.
Soaking:	Maintaining ceramic articles at a pre-arranged temperature in the kiln for a considerable time.
Soldier Courses:	Bricks laid at right-angles to the wall.

Spalling: Spliting of flaking when subjected to sudden temperature changes or mechanical stresses.

Stringer courses:
Bricks laid parallel to the wall.

Ware: Pottery or porcelain in the raw bisque or glaze state.

Some sources of information are from Fournier (1977) and Pottery craft Catalogue (1984).

CHAPTER ONE

INTRODUCTION AND BACKGROUND OF THE STUDY

Nobody knows exactly when pottery or Ceramics began. Its coming certainly revolutionized the human race as a result of its wide range in practice terms and utility of its products. Some of Ceramics products include electrical insulators, electrical sockets and fuse boxes. Others are tiles, pipes, bricks for building, sanitary wares, domestic wares and spark plugs. All these are clay products made permanent by heat as defined by Haher (1975). "Ceramics" describes the whole range of articles of inorganic non-metalic materials which are made permanent by heat. Sometimes the word "pottery" is narrower in its application than ceramics.

Pottery has thousands of years of tradition in Nigeria and everyday around us pottery work is carried out. It is a wide-spread craft which meets the needs of society as cooking utensils, water storage, oil lamps and impliments of ritual and worship.

A study of ceramics will disclose ambiguities on many points, kiln design and construction being one of them. Some ambiguities result from ignorance, some results from potters forgetting what may be vital information. Until the present time, not much has been done in the area of kiln construction in the country. Most of the institutions and small enterpreneurs rely on pre-fabricated

KASHIM IBRAHIM

kilns from abroad which are hard to import. Without the knowledge of fire the potters craft would not exist thus the archeological discovery of shards would not be found. From the primitive bonfire or pit kiln to the modern kiln a long development occured which was marked at every stage by trial and error. Inspite of modern development, a degree of uncertainty still persists in some developing countries like Nigeria in the production of kilns. This resulted in the lack of engineering knowledge for technical treatment of such subjects as combustion, heat transfer and thermodynamics which would have given the researchers a scientific approach.

At present, about six electric kilns including the test kilns in Ahmadu Bello University, Department of Industrial Design in Ceramics Section are almost disfunctional or completely disfunctional. It is not surprising that many of the students get scared about the whole affairs of Ceramics, although some of them sound optimistic about how to get out of the University and build a kiln of their choice and start pottery production. The kiln chamber is where works have to be fired before they become most of the honoured pots of time. Pottery and kiln building go hand in hand and contrary to some belief, it is not just a case of piling bricks together, putting in a few pots and getting a quick result.

What then is a Kiln?

Nelson (1971) in his description of kilns and its

origin states that man discovered clay at some remote time when he realised that clay would become hard and durable when baked in fire. "He did this by firing his pottery in a shallow pit on a bed of twigs with broken shards ". He "heaped up pottery to provide protection from the fuel above and to retain the heat". The description reveals that a kiln is a shallow pit with broken shards. To build such a kiln nowadays will not meet the needs of modern society in high fired ceramics products. Soldner (1966) spelt out the purposeful construction of a kiln in his definition as: "A box in which to accumulate heat". This description does not fully describe what a kiln is and what material the box is made of to accumulates heat. The definition that formed the background of most acceptable description of the kiln is the one by Coyah (1971). According to him "A kiln is a box of refractory bricks into which heat is introduced and controlled to fire the clay bodies and glazes. It is called an oven in industry and most be capable of reaching at least 600°C". This means that a cooking oven cannot be used as a kiln.

The conception of a kiln has been redefined in several different directions based on the area of one's specialization and energy source. Leach (1976) considered a kiln to be "a chamber fed with chimney draws heat and smoke". There is no doubt Leach is biased in supporting the use of wood as the source of energy. In the same vent Fournier (1977) sees the kiln as a totally enclosed refractory box

housing one or more circuits of a refractory material which is spread as evenly as possible over its inner surfaces. Fournier certainly had electricity as the source of power in his definition.

With the various definitions so far, to define what a gas kiln is will be possible. A gas kiln can be regarded as a box of refractory bricks or materials fired by fuel and air at the point of burner to fire the clay bodies and glazes.

Periodically the need to develop Nigeria's culture imcluding art and craft as well as utilizing her raw materials needed for manufacturing, comes to the forefront and occupies headlines in the national newspapers. The then Head of State, General Buhari(NNN 22 August, 1984) never said, "The days of unlimited importation of raw materials are over and industries must now find local materials". The serious lapse in our industrial policy over the years was the importation of raw materials. The present Head of State, General Ibrahim Babangida also advocates the evolution of a kind of society that has the capacity of sustaining itself materially, industrially and otherwise. This is being continued to be re-echeed by the organisation of Trade Fairs in the country in different places where emphasis is placed on Nigerian goods. The 'do-it-yourself' experiences should help students, teachers and studio potters build confidence in themselves. The present study is intended to resolve this problem.

1.1 STATEMENT OF THE PROBLEM

The problem of the study is the construction of a gas kiln and burners from locally available raw materials found in Kankara, Katsina State and Zaria of Kaduna State.

1.2 OBJECTIVES OF THE STUDY

The significance of the study is as follows:-

1. To satisfy ceramic teachers and potters curiosity that is the desire to know more about pottery craft.
2. To enable students to appreciate possibility of building their own kiln after graduation.
3. To provide plain instructions because many potters are confused by instructions from foreign manufacturers.
4. To facilitate easy introduction of pottery craft prototype idea into institutions.
5. To meet the need of abundant raw materials (gas and clay) in the country.
6. To specialize in one aspects of ceramic which cannot be regarded as luxury. It is toward such knowledge that the technological development will surface.

1.3 BASIC ASSUMPTION

For the purpose of this study, the following assumptions are made:-

1. That, there are abundant local raw materials for production of a gas kiln and burners.

2. That, the desire to increase the temperature range of firing and output of work with maximum effeciency is possible.

3. That, there is sufficient gas reserve to last over a long period of time.

4. That, apart from the aesthetic and educational satisfaction that could be derived from kiln construction it would also provide a means of livelihood to some people if pursued properly.

5. That, the method of kiln design and construction including the burners are adequate for appropriate testing.

1.4 DELIMITATION

Although the findings of this study may be used to generalized about kilns functions, construction as well as use of local primary clay, the study is concerned with the use of gas kiln with local materials found in Kankara and Zaria. The study is not intended to expand on the gas flame, strength temperature and other unknowable parameters as there are no testing equipment for standardization.

CHAPTER TWO

REVIEW OF RELATED LITERATURE

Pottery and kiln building go hand in hand and contrary to some belief, it is not just a case of piling bricks together putting in a few pots and get a quick result. Producing anything with one's hands needs thought, care and application. Any potter who intends to make a living from his craft needs a kiln which combine reliability with economy.

Pottery work today is the outcome of centuries of growth and its beginnings in Nigeria stretches back into pre-historic times, a period without written history, but potters have since learned much. Attention should be drawn that pottery clay is a unique material as it is practically indestructible after being fired to $600^{o}C$. The clay will then turn from Kaolin to Meta-Kaolin. This is the change by firing of clay into a stone like material un-affected by water and in some cases impervious of water. It is the removal of two molecules of water in the formular ($Al_2O_3.2SiO_2.2H_2O$) leaving a bonded alumino-silicate which is referred to as mata-kaolin.

Different stages of ancient cultures were often determined by means of pots and fragments of pottery found, for example the Nok and Igbo-Ukwu cultures in Nigeria. All through the story of man; fired pottery works were made by them. In each case the customs and methods of

working survived and passed on to the next generation. Thus the survival of any age might exist in the earlier age and be different to another. Now, there are many people who are the living representatives of stages of culture from the modern development down to that of "the stone age people" in the 20th century Nigeria, Dayo (1986).

Pottery is not only an ancient craft but the story of mankind from very remote times written indelibly in fired clay. Marks scratched upon a piece of pottery may be less legible than signs made from paints and ink upon paper but clay marks are more lasting. This might be perhaps why this craft in the course of time has become an instrument for artistic expression. A look at Ladi Kwali's pots depicts traditional style with stylized of decorations - lizards, birds, cameleon, turties, snakes and geometrical shapes.

Many of the historical documents in pottery emphasised the pottery wares themselves, not much is said about the origin of the kiln. One thing is clear, that pottery works were fired right from the early stages of development. The origin of pottery and firing have not been clearly determined, the two theories characterized by the heart and basket theories; were as a result of curiosity.

2.1 THE HEARTH THEORY

The hearth theory as pointed out by Rhodes (1968) stipulates that perhaps "men observed that the clay soils

benearth the camp fire become hardened by the heat". Ahuwan (1987) felt that this theory is based on the fact that early man was exposed to the harsh weather conditions, especially cold as a result was prone to warming himself up around a hearth. One can equally add that with the discovery of fire, the early man being a hunter could have observed a hardened earth where he roasted his meat. While putting off the fire, with water, he discovered the ground waterlogged.

2.2 THE BASKET THEORY

The basket theory on the other hand specified that men first began to make containers which might have been made out of grass. Since they are not water-proof they discovered they could smear clay between the ribs of their baskets to cut down on loss of liquid. Counts (1973) pointed out that "perhaps somebody tossed such a basket into the fire when too old to use and then observed that the fire charred the basket but made the clay much stronger and more water-proof". From such discoveries it would only be a small step to more controlled management of the objects made from clay. Thus a new style of container began and so did the process of firing.

One thing that is certain about the two views is that firing pottery came through domestic tragedy which has come a long way to enable early man to have much knowledge about firing techniques. It was also as a result of curiosity.

2.3 TRADITIONAL POTTERY

As the knowledge of pottery making and of technique became widespread among the early potters their knowledge about firing techniques increased. Before the introduction of constructed chambersthe traditional potters were firing their pots in an open fire or pit bonfires using various fuels. Sometimes dried grasses were used, twigs of wood, bamboo and dried dung. Example of this method could still be seen in Zaria, Borno, Ilorin, Sokoto, et-cetra. The pots are fired at a temperature below 800^{o}C, if fired higher the pots will loose their ability to withstand thermal shock from being placed directly over the cooking fire. The technology of traditional potters is thus not to be regarded as backward, on the contrary they are perfectly suited for the local demands and adjusted to the local materials and fuels. Thus what has been developed from the past is the tradition of responsibility in which the traditional potters are teaching the modern ones. By the very nature of their works they are important members of their communities. Their mode of training, standing in the community and the nature and character of the works they produce are very important. They are by convention guided by the principles required by traditions and conceptions of the community not just necessarily doing their own things in their own ways as stated by Wren Denise et.al (1957).

The traditional potters in Nigeria hold the culture which aims at a finer type of pottery thus championing the craft widely practised. Their wares are used for cooking,

storage and for other domestic usage. The method of making these pots might seem simple but infact the potters follow very complex and developed procedures in order to achieve their often excellent result. stop here

2.4 DEVELOPMENT OF KILNS

Advances in kiln design and construction were made in the near East, Iraq, North Africa and Crete, infact the Egyptians were the people who constructed early known kilns. Rhodes (1968) noted that the Egyptian open-topped updrought kiln (as it is called) reaches a temperature of 900°C or even higher. Once the basic updrought kiln was perfected, little further improvement was made in kiln design in the mediterranean area, in Europe until comparatively recent times.

The Chinese, Koreans and Japanese were known to have introduced high firing kilns built with a dome somewhat similar to the Hausa 'rumbu'. The growing demand of ceramic products must have led Chinese to improve further to develop the multi-chambered kiln. Most of these early kilns utilized wood as source of energy and because of high cost of wood they are not so much in use presently.

Great advances in kiln design and construction were made in Europe during the Industrial Revolution. Improved refractories resulted in better arrangements for the circulation of heat and introduction of coke for fuel enabled the attainment of higher temperatures. On the other hand the success of the tunnel kilns came after the

development of efficient oil and gas burners. By 1900 the art of building periodic kilns was mastered except for the perfection of fuel burners and the development of improved refractories.

2.5 STONEWARE KILNS IN NIGERIA

The first known stonware kiln was built in Nigeria and indeed West Africa in 1918 by D. Roberts at Abeokuta in Ogun State. Since then, only a few other pottery studios that have been established in the fifties, the Okigwi Pottery Centre, Imo State in 1951 followed by Dr. Ladi Kwali Pottery Centre in Suleija in 1952 by Michael Cardew (formally known as Abuja Pottery Centre). Ahuwan (1987) felt that the idea of stoneware production was born out of the need to cater for the Europeans who were members of the West Africa Frontier Force (WAFF) during the First World War. The pottery studios could also be sources of gifts from the colonial masters to the traditional leaders and other people as incentive to get cheap labour force. One wonders why there was a great gap between the first pottery studio and the ones in fifties; also why there was not much impact since that time? It could be as a result of the general unrest during the first and second World Wars. Perhaps also the knowledge of the craft then was quite contrary to the native custom for pottery work to be done by men. Now the society has become more exposed to all kinds of jobs, hence the increased impact in our time of pottery manufacturing.

Apart from Jos Museum Pottery Studio established in 1963 by Michael Cardew and Kofi Athey it was within the last four years that we witnessed an increase in pottery studio establihsments. The following table is informative:

TBALE 1.1:

		Place	State	Heat Source	Year of Establishment
1.	Stoneware Pottery	Abeokuta	Ogun	Wood	1918
2.	Okigwi Pottery Centre	Okigwi	Imo	"	1951
3.	Abuja Pottery Centre	Suleija (Abuja)	Niger	"	1952
4.	Jos Museum Pottery Studio	Jos	Plateau	"	1963
5.	Niger State (Art and Culture) Pottery	Minna	Niger	"	1983
6.	Emodah Pottery	Auchi	Bendel	"	1984
7.	Jacaranda Pottery	Kaduna	Kaduna	Gas/Wood	1984
8.	Jan Pottery Studio	Kaduna	Kaduna	Gas	1985
9.	Mararaba Pottery	Mararaba-Jos Kaduna	Kaduna	Gas/Wood	1986
10.	Marhal Pottery	Bukuru	Plateau	"	1986
11.	Anthill (David) Pottery	Gboko	Benue	Wood	1987
12.	Levi Yakubu Pottery	Makurdi	Benue	Gas	1988

SOME POTTERY ESTABLISHMENTS IN NIGERIA

It is observed that five pottery establishments use gas in firing. It is worth noting that they got their gas kiln built for them as a result of the success of a gas test kiln built in 1983 in Ahmadu Bello University, Department of Industrial Design by some of the staff.

Gas kiln construction is new in Nigeria and yet to be widely introduced. The main reason is that not many people know the technicalities of kiln construction. Also the question of (burners) how to get the kiln fired is another thing. With the growing demand for ceramic products as seen from these pottery enterprises, more people and institutions have been stimulated to establish pottery studios.

CHAPTER THREE

METHODOLOGY

As a product development research in which the development of an alternative or new product is made, it is combined with a descriptive research to be able to understand the use of the product. The main material used (Kaolin) was brought to the studio for testing. It was tested for shrinkage, water absorption and apparent porosity also for modulus-of-rupture tests.

The following procedures were employed in the study which have been divided into six stages.

1. Locating the materials
2. Biaxial blend
3. Drying and firing shrinkages
4. Water absorption and apparent porosity
5. Modulus-of-rupture
6. Production of insulating and dense bricks.

3.1 LOCATING THE MATERIALS

The items listed for collection included the following:

1. Kaolin (Kankara Clay) from Kankara, Katsina State.
2. Saw dust from timber dealers, Sabon Gari, Zaria.

Clays from Kankara and Zaria have been found by Gukas (1985) Okoruwa (1986) to be refractory and could be used for porcelain and stoneware respectively. In general,

some required qualities refractory should possess according to Ahmed (1986) are:-

a) Rigidity and maintenance of size, shape and strength at the operating temperature;

b) Ability to withstand thermal shock such as is met in heating and cooling of furnaces;

c) Resistance to chemical attack by whatever gas, slag or material likely to be encountered.

These qualities are determined by the properties of the refractories. Some of the most important properties considered in this study are:

Drying and firing shrinkages

Water absorption and apparent porosity

Modulus of rupture.

The refractory body mix was with Kankara clay and saw dust. Saw dust burnt out in the kiln and left pores thereby increasing the air content causing the heat not to be conducted freely in the structure. Gilchrist (1963) pointed out that in kiln construction some degree of porosity is desirable since it is this quality that gives the kiln much of the value as heat insulation. Other combustible materials like coke, grass, paper, to mention a few, could be used also.

3.2 BIAXIAL BLEND

Several body composition of Kaolin and saw dust in the refractories area of biaxial test or line blend were made, see 3.3 below. Volumetric measurement was used in

the mixture. Okunna (1983) described the biaxial test as a method of exploring widely the mutual behaviour under heat of selected pairs of materials (in this case, clay and saw dust). The "11 blend" type was used, as given below:

TABLE 3.1

Sample Number	1	2	3	4	5	6	7	8	9	10	11
Kankara Clay	10	9	8	7	6	5	4	3	2	1	-
Saw Dust	-	1	2	3	4	5	6	7	8	9	10

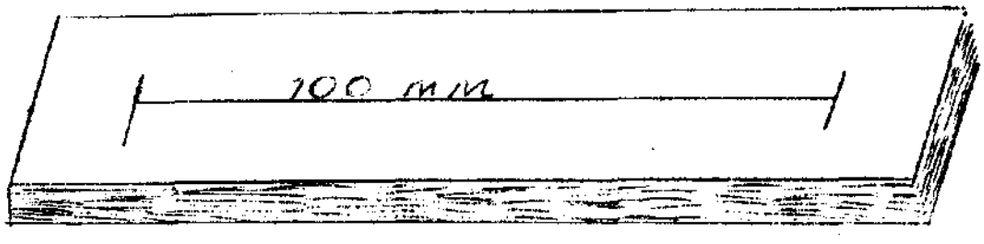
Area from which the test was taken

BIAXIAL BLEND OR LINE BLEND

From each sample, three test bars were made. A cube tile cuter was also used to cut cubes of bricks and labelled and set aside for drying before firing.

3.3 DRYING AND FIRING SHRINKAGES

A rectangular block at least weighing 100 - 200 grams and long enough to make a mark or a line of 100mm long for shrinkage mark was made still at normal throwing consistency.



A Sample Test Bar

The test bars or bricks made for line blend were tested for the following properties. The test bars were allowed to dry and measurement taken before firing. After the firing and cooling at normal rates the distance between the shrinkage marks were measured again and an over all shrinkage percent calculated.

For example:

Original distance between marks in plastic condition = 100mm

Distance between marks at dry stage = 95mm

Shrinkage 100 - 95 = 5mm in 100 = 5%

Distance between marks after firing = 92mm

Firing shrinkage = 95 - 92 = 3mm = 3%

Overall shrinkage percent = 5+3 = 8%

3.4 WATER ABSORPTION AND APPARENT POROSITY

Water absorption test expressed the weight of water absorbed by a test bar as a percentage of its dry weight. The apparent porosity expressed the volume of the unsealed pores in the piece which is expressed as a percentage of the volume of the test bar. The test blocks from the shrinkage test were weighed and immersed in water and boiled for at least two hours. They were left to cool for a night or twenty four hours, the water wiped off and weighed again. The apparent porosity was given by:

$$\frac{W - D}{D} \times \frac{100}{1} = \text{Water absorption}$$

$$\frac{W - D}{D} \times \frac{100}{1} \times \text{Bulk density of the test bar} = \text{Apparent Porosity.}$$

The bulk density of most bodies used by artist potters is

between 2.0 and 2.5. McMeekin (1967) suggested that a rough estimate of the apparent porosity could be got by doubling the water absorption. This was the method used. The results of the tests are given overleaf.

TABLE 3.2

LINE BLEND		MEASUREMENT			TOTAL	WATER ABSORPTION		WATER ABSORPTION	APPARENT POROSITY
Kaolin	Saw Dust	Wet (mm)	Dry (mm)	Fired (mm)	%	Green Weight	Dry Weight		
10	-	100	97	90	10	111	97	14	28
9	1	100	96	88	13	111	97	14	28
8	2	100	95	88	12	108	90	20	40
7	3	100	97	91	9	107	87	23	46
6	4	100	97	91	9	111	87	28	56
5	5	100	96	90	10	119	77	34	68
4	6	100	96.5	91	8	121	72	41	82
3	7	100	98	92.5	8	122	63	51	102

SHRINKAGE, WATER ABSORPTION AND APPARENT POROSITY

SHRINKAGE, WATER ABSORPTION AND APPARENT POROSITY

RESULT:

There is a notable pattern of increase in water absorption and apparent porosity in the table. With an increase in the addition of saw dust the absorption and apparent porosity increased. This is to say that the bricks not only alter in the weight per unit volume by making the refractory more or less porous but capable of reducing the heat capacity per unit volume by approximately a half. Thus tile number 1 having only kankara (10) with water absorption 14, apparent porosity 28 and tile number 5 doubling the figures. This means that tile number 5 is capable of reducing the heat capacity much more than the first tile (see table 3.2). They all have bearing on each other. McMeekin (1967) revealed that very porous bodies are nearly always soft and that they will also be low in resistance to mechanical shock easily broken. It was discovered that the last two mixture, Kaolin 3 saw dust 7 remained very soft even when fired to 1280^{o}C. The pores in the bricks were too big or form too many systems stretching continously through the whole thickness of the brick. This kind of brick could cause a good deal of heat to be transferred by radiation and conduction. The test was directly related to many other physical properties of a refractory as well as resistance to chemical attack, care was taken how much saw dust was added. The volume heat

capacity does depend on the porosity too, since the mass of material in a unit volume is decreased in proportion to the pores spaces present.

3.5 THE RUPTURE TEST

The modulus of rupture (MOR) is a measurement of the breaking strength of a refractory at room temperature. Hot modules of rupture test could not be tested although it is the measurement at high (close to operating) temperatures. Ahmed (1986) reported Chesters saying that cold strength usually has a slight bearing of strength at high temperatures.

The insulated brick, not only alter in the weight per unit volume (by making the refractory more or less porous) but the heat capacity per unit volume is reduced approximately by half. If the pores in the bricks are too big or form too many systems stretching continuously through the whole thickness of the brick a good deal of heat may be transferred by radiation and convention.

Three types of bricks were tested labelled "A", "B", and "C", in each group there were four bricks. "A" group are of arch bricks. "B" group are of insulated standard bricks. "C" group are dense bricks. Before the bricks were tested a soft board of 10mm was cut and placed on the base and above the brick for equal load distribution over the entire area. The result of the test is given overleaf.

TABLE 3.3

BRICKS SAMPLE NUMBER	WEIGHT (KG)	L	BRICKS SIZES B1	B2	B3	B4	LOAD (KN)	AVERAGE FAILURE AREA (mm^2)	LOAD (N)	STRESS (N/mm^2)	
ARCH											
A1	1.95	23.0	8.5	6.0	10	9.5	25.0	3700	25000	3.42)	Average stress 3.46(N/mm^2)
A2	1.95	22.5	8.5	6.0	10	9.5	26.0	3700	26000	3.56)	
A3	1.95	22.5	8.5	6.0	10	9.5	28.0	3700	28000	3.84)	Average weight is 1.96kg.
A4	2.00	22.8	8.5	6.5	10	9.5	22.0	3700	22000	3.01)	
STANDARD		LENGTH	BREADTH	HEIGHT							
1A	2.25	10.5	7.0	22.0			21.0	7350	21000	2.86)	Average stress= 4.28(N/mm^2)
B2	2.15	10.5	7.5	22.0			21.0	7875	58000	7.37)	
B3	2.20	11.0	7.5	23.0			21.0	8250	21000	2.55)	Average weight= 2.20kg.
B4	2.20	10.5	7.0	22.0			32.0	7350	32000	4.35)	
DENSE											
C1	2.35	12.0	8.0	24.0			30	9600	30000	3.13)	Average stress= 5.54 (N/mm^2)
C2	2.50	11.5	7.5	24.0			53	8625	53000	6.14)	
C3	2.45	11.5	7.5	24.0			61	8625	61000	7.07)	Average weight= 2.45kg.
C4	2.50	11.5	7.5	23.5			50	8625	50000	5.80)	

KEY: L = Length in centimetres (cm)
B = Breadth in cm.

RUPTURE MODULUS TEST

TESTED BY THE CIVIL ENGINEERING DEPARTMENT, A.B.U., ZARIA (1987).

RESUIT:

As noted earlier in the shrinkage and porosity tests, the various tests have bearing on each other. It was noted that the more densely the refractory brick is, the higher the stress. This is because there is less void in the brick. The sample bricks in group "A" and "B" are of the same mixture and yet the average stress for "B" blocks are the same. The sizes of the bricks could be taken into account here. The bigger the size of the block the higher the stress.

3.6 PRODUCTION OF INSULATING AND DENSE BRICKS

Two brick moulds were made for standard and arch brick having the following sizes:-

Standard straight brick: 24cm x 8.5cm x 11cm
The sizes of the standard brick is: 23 x 7.5 x 10cm, hence provision for shrinkage was made with additional centimetre.

Arch brick: 23cm x 8.5cm x 6cm x 10cm x 9.5cm, or
25cm x 12.5 x 7cm x 5cm.

The range of the insulated brick (Volumetric mixture of Kaolin 5, saw dust 5) determined from the previous tests (Table 3.1) was used in producing the required bricks. In chosing the mixture it was considered that if there was excess saw dust in the blend as in sample numbers 8, 9 and 10 the bricks would shrink considerably at high temperatures. They will devitrify and crystalized to mullite and cristobalite and render

the brick very brittle. On the other hand if little saw dust was added as in sample numbers 2, 3 and 4 the bricks would have been dense thereby causing the heat conducted freely.

The bricks were made by hand using the slopped method, Cardew (1969). The clay is watered, heaped up and left to soak for about three days to enable water penetrate into the clay particles. It was trodden by foot to the right consistency.

To produce the brick, the frame was dipped into the water and immediately laid on the ground. It was filled with the slop and levelled off by hand or with a flat stick. The frame was then lifted off leaving the brick on the ground to be lifted up on its side when the surface stiffened to be dried before firing.

The bricks were fired to 1280^{o}C, although some authors suggested that bricks should be fired above operating temperature to avoid further shrinkages. The operational temperature is 1280^{o}C which is the maximum range of stoneware temperature.

CHAPTER FOUR

KILN DESIGN AND CONSTRUCTION

This chapter is concerned chiefly with the design, building of gas kiln for stoneware temperature. Intermittent electric kilns and wood kilns are omitted. From the pilot study carried out, it was discovered that the most economical fuel at moment in the country is gas. It is almost impossible to produce electric kilns in the country because of non availability of kiln elements except if they are imported. Results of the highest qualities rarely come from electric kiln and attempts to alter the basic limitation of atmosphere by introducing agents to promote reduction of the oxygen during firing cycle are inconsistent and disappointing as well as expensive. Thus to settle for the very extensive range of effects can be achieved in reduction firing, gas kiln was the choice.

The kiln design and construction is discussed under the following principle areas:-

1. Basic kiln design option
2. Points considered
3. Materials
4. Kiln construction
5. Burners and kiln shelves.

4.1 BASIC KILN DESIGN OPTION

There are three basic kiln design options:

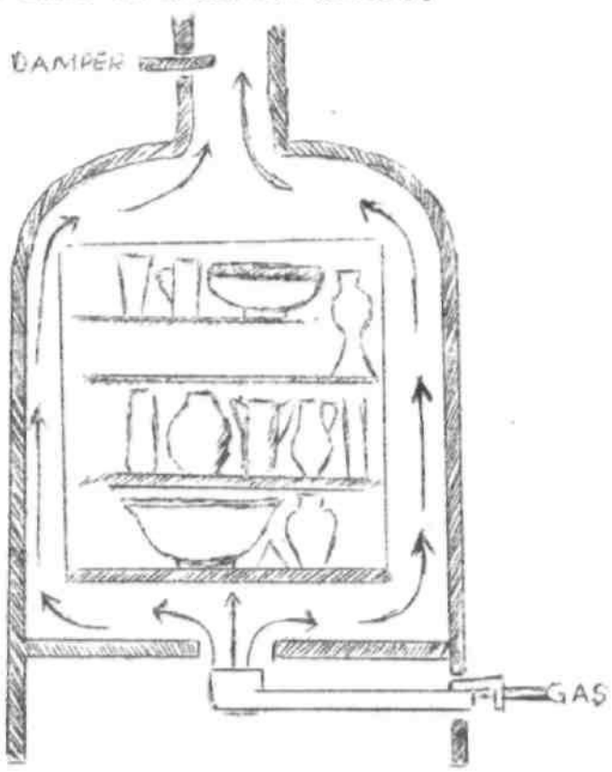
1. Updraft kiln

2. Downdraft kiln

3. Crossdraft kiln.

4.1.1 UPDRAFT KILN

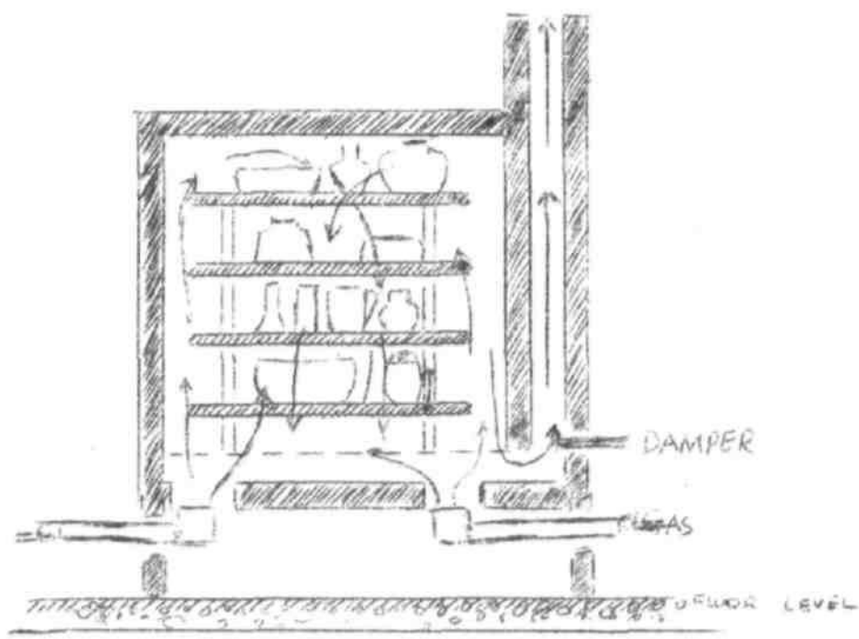
Ritchie (1975) describes an updraft kiln as one "that introduces heat at the bottom and exhausts at the top". This kind of kiln does not require a kind of chimney to induce a draft. The flame and heat travel in but one direction: the flame enters at the bottom and exits at the top. Rhodes (1968) warns that this type of design tends to have cool spots either toward the top or the middle of the setting. He went on to say, "the difficulty of achieving perfectly even heating, however, makes the updraft kiln a less than perfect solution". Despite this the virtues of the design are its ease of building and the large amount of usuable space per cubic inch of kiln structure.



UPDRAFT KILN DIAGRAM

4.1.2 DOWNDRAFT KILN

"The downdraft kiln has burners located on the bottom front, back or side of the kiln", Brodie (1982). Ritchie (1975) sees it as a more complex system of kiln than the updraft kiln in that the exhaust as well as the intake is at the bottom. This causes the heat to affect the ware on both its upward and downward paths. The flame and the heat stay in the kiln for a longer time and more of the heat can be utilized before it exits from the kiln. This type of kiln requires a chimney to induce enough draft. Nelson (1971) pointed out that downdraft kiln provides a more even heat distribution and has come to be the standard design used by most potters. Brodie (1982) confirms this statement by saying that "it is the most efficient, traditional system, easy to fire and gives more consistent results". This is the type of kiln adapted in this study.



DOWN-DRAFT KILN DIAGRAM

4.1.3 CROSSDRAFT KILN

Ritchie (ibid) explains this kind of kiln as a kiln shape, where the ware is placed between the heat source and the exhaust port. It has some of the operational characteristics of a downdraft kiln. The difference is that heat passed through the ware as in an updraft kiln.

From the three basic kiln design option, it would be declared that kiln designed for stoneware temperatures and above, should either be a downdraft or a crossdraft kiln. Some level of temperature could be attained in updraft kilns but not very much. Some of the advantages downdraft or crossdraft kiln have over the updraft are, better fuel economy and more even temperature in the kiln chamber.

4.2 POINTS CONSIDERED

Before the kiln was built the question of size was determined. A kiln that would hold enough wares which would be built at a reasonable cost. The choice of a modest kiln size with 15 to 20 cubic feet (0.28 - 0.37m) of stacking space was desired. The numbers of shelves in the plan and their dimensions also were envisaged with burners port space. The choice of a modest kiln will enable it to be fired more often at the same time one will grasp the effects of glazes and clay bodies on each other. See page 79 for critical specific design options.

The fuel to be used was determined by what is available. At moment a gas kiln is more feasible in the country because gas will soon be the most common fuel

in use and easily available. The problem of burners was equally considered.

4.3 MATERIALS

Insulating refractory bricks (volumetric mixture of Kaolin 5, saw dust 5) was used including other materials listed below:

		Quantity
1.	Stadnard bricks 24cm x 11cm x 8.5cm	920
2.	Arch Bricks 24cm x 11cm x 6cm x 5cm	100
3.	Dense bricks 24cm x 11cm x 8.5cm	40
4.	Angle iron 4 cm x 59cm	6
5.	Metal sheet 0.2cm thick, 134cm x 246cm	1
6.	Ply wood 0.6cm thick, 120cm x 240cm	1
7.	Burners big 7.5cm tip	2
	small 5cm tip	2
8.	Rubber hose (gas) 10 metres long	10 metres
9.	Connectors	9
10.	Clips	20
11.	Plank (hard wood) 5cm x 31cm x 360cm	1
12.	Nails (1kg weight) 2.5cm long	1 packet
13.	Pressure guage regulator	1
14.	Cement	4 bags

4.4 KILN CONSTRUCTION

4.4.1 FOUNDATION

A suitable floor of 18cm of concrete on a well-bedded hard-core base was built. This was to prevent the weight from setting unevenly, to hold the walls erect and, when located outside, to keep rain water from running under the kiln. The floor concrete was made from the

mixture of gravel, sand and cement with ratio 4:2:1 respectively. The ground on which the concrete floor made was watered and rammed with a heavy metal. It was possible to reinforce with steel embedded in the lower half. It pays to have the best foundations possible so that no subsequent shift can take place. The cement paved area was cured by keeping it damp for about a week.



KILN FRAME SHOWING THE BURNERS BRICKS IN POSITION ON A CONCRETE FLOOR.

The froth angles iron were cut with a hack-saw and assembled by welding before being painted to prevent rust. The legs for the kiln, 39cm above the concrete foundation; were provided by the extensions of the corner angle-iron uprights, steadied with cross-stays.



KILN FRAME WITH BURNERS BLOCKS ON THE METAL SHEET

Cladding metal sheet for the base was cut and placed in position. Fournier (1977) suggested an alternative to the metal sheet which is asbestos. Asbestos is most suitable when constructing an electric kiln as electric

current will not pass through it - it is a bad conductor of electricity.

Before the actual construction began, the floor was mock up by placing the shelves, wall thickness marked, burners positions demarcated and cut out. Also, the clay mortar (a mixture of Kaolin and saw dust, half half respectively) was used for binding the bricks together as well as for levelling irregular bricks. The mortar mixture was left in the bin for at least three days. In this case it was desirable to use more than one container for the mixture for continuity. The best dipping consistency of the mortar was obtained when the slop was thick enough to float a brick half way submerged in the slop. Rhodes (1968) felt that the purpose of mortar was not to stick the bricks together but rather to level them up and to provide a solid bed for each brick. The mortar serves to fill the cracks and makes for a more air-tight structure.

The mortar was applied by dipping the brick into it and by application with hand or trowel. In order to tap the brick in position Rhodes suggested that the bricks be dampened to prevent quick sucking of mortar which would be too stiff.

4.4.2 FLOOR

The floor was built first of all with single course of bricks. The bricks were laid length wise following the flue direction leaving the burners blocks in position. The second layer was not laid at this time because of the inconviniences this would cause in clearing the

droppings from the walls and roof. For maximum strength, bricks were laid in stringer courses. Stringer course are bricks laid parallel to the wall.



THE FLOOR IS LAID SHOWING BURNERS HOLES.

4.4.3 THE WALL

Just like the floor the bricks were laid in stringer courses and tied together every fourth row by a soldier course. Soldier courses are bricks laid at right angles to the wall. The bricks were staggered so that no joint leads directly to the outside. In the case of soldier course, however, this was not possible since the course is the same width as the wall thickness. The bricks used for this course were ensured to be of good quality with straight edges. Rhodes pointed out that the

important thing in building a brick wall is to keep the structure level and plumb. In order to achieve this, each brick was carefully placed and moved, or tapped with the hammer or trowel until it lined up perfectly with the rest of the structure (see appendix). When half bricks were needed, carborundum discs with a power grinder was used.



A
POWER GRINDER WITH GRINDING DISC.

This saved a lot of time from manual method. In this method, the brick was scored all round, including the four corners, placed on a bed of sand to help prevent splitting, then cut across the scored line with a brick chisel. For best results, the bricks were cut while resting on a base of sand. Rough edges were then ground up on a cement slab.

4.4.4 DOOR OR WICKET

The door, or wicket as it is called was not built in the walls supporting the crown. A separate arch was built for the door using the same method for the crown.



THE DOOR ARCH FORMER IN POSITION



THE DOOR OPENING AFTER THE FORM WAS REMOVED.

For convenience, a slamming door instead of a clamping one would have been built as this will save labour. For the purpose of the study it was felt the bricking method would be enough. The door is expected to be bricked in before each firing. The opening was plumbed with the sides parallel and squared with each other. In this area the bricks were tied more often with stringer and soldier courses. The bricks for bricking the door for firing could be of generous size for ease of loading but the standard type were selected for usage.

4.4.5 ARCH

Small arches, flue exits for example, were bridged over by blocks or pieces of kiln shelf. The main arch was not quite such a simple job.

Flue exit bridged over by kiln shelf and secondary air holes bridged by blocks.



A former was constructed to hold the arch in the correct position on the walls during construction. It was made of wood with three templates for the inside arch shape. They were joined together with 2.5cm x 1.25cm/2" x 0.5" batens. It is also quite possible to use hard-board or thin plywood over the frame. With the batens nailed tightly together it was not necessary to use any other thing.



AN ARCH FORMER

The former was placed in between walls with brick supports underneath. Having done this, the laying up of the arch was done the same way as the walls, starting from the two sides working toward the centre. The joints were broken and the centre course of wedges fitted tightly. The centre course was tapped down into place with a brick hammer and wooden block. When this was completed, the arch was left for a week to dry. The drying period would normally depend on the weather before the former is withdrawn.



An arch former in position.

The arch was built to spring from the feather-edge brick. Feather-edge bricks were made from the regular standard bricks by cutting them diagonally from one corner to the opposite side length wise. The purpose of this was to transfer the weight of the arch to the steel frame.



CHIMNEY FRAME ATTACHED TO THE CHAMBER

4.4.6 CHIMNEY AND DAMPER

The chimney of about 92cm above the top level of the kiln was built to increase the draft. Rhodes (1986) suggested that the chimney cross section be at least equal to that of the flue. And that each of the horizontal flue must be compensated by 2 additional feet of chimney. The kiln was built with one flue opening.



THE CHIMNEY WITH THE DOOR AND DAMPER BRICKED.

A damper made of brick large enough to cover the flue opening was fixed at the base of the chimney. The damper is use to cut out the pull of the chimney, thus helping a reduction atmosphere in the kiln. This also prevents excess cold air being drawn into the chamber through the burners mouth both during and after firing, when a slow cooling down is required.

4.5 BURNERS AND KILN SHELVES

The diffused type of flames used formally in firing tended to form carbon deposits on surfaces which came in contact with them. The effective temperatures were relatively low. The clear premixed (air and gas) flames give much more intense combustion and a higher effective temperatures and are free from soothing troubles by the

use of burners. Gas burners are used for cooking and other domestic gas-fires.

As a result of the explosive nature of gas and the need to handle it the right way and in conjunction with correct control equipment not many people would like to make their own burners. Safety is important.

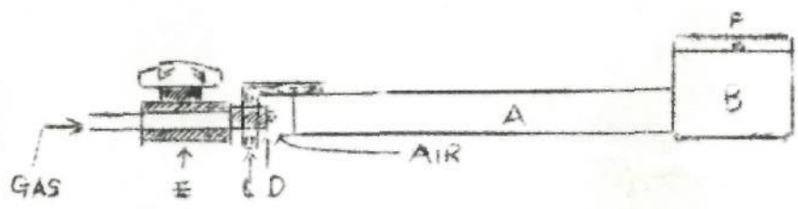
Gas burners are of two types:

1. Inspirator burners
2. Aspirator burners.

4.5.1 THE INSPIRATOR BURNER

Also referred to as an atmosphere or venturi burner, This induces air into the burner, mixes it in the burner tube and flame at the tip. Rhodes (1985) distinguished such burner as having a cast iron tube into which the gas is introduced through a small orifice. The flow of the gas is controlled by a valve. When gas enters the tube, it entrains it through the openings.

It is the version of this burner that was adapted for the kiln construction patterned by Fordham Thermal systems, England and modified as seen below.



A is a 2.5cm pipe attached to B 8cm pipe sealed at one end with metal disc, at the other end F with a refractory material. A 5cm angle iron cut and fitted in with 1.5cm

hole drilled in it to hold the reducing fittings at C.D is the orifice from where gas jets out before mixing with air into A pipe. The gas is controlled at E and air controlled through the gap between the angle iron and the pipe tip. The cup shape in the burner B head is enlarged. This enabled the velocity of the air/gas mixture at the burner to match the natural flame speed. The burning take place at F which is the refractory material at the tip. This burner needs secondary air to complete fuel cumbustion in firing chamber.

4.5.2 ASPIRATOR BURNER

This type is also referred to as a forced air burner or forced-draft. This type relies on a blower. It utilizes electric blower to create a draft for a short lean flame. Forced draft is not necessary if the correct balance between air intake and size and height of flue is obtained. See appendix for burner types.

4.5.3 KILN SHELVES

4.5.4 MATERIALS

1.	High fired grog made from kaolin	70%
2.	Levigated kaolin	15%
3.	Levigated secondary clay	15%

Levigation of clay involved soaking of clay with plenty water and allowed to soak for about four hours or more. The clay stirred thoroughly and allowed to settle for 2-4 minutes. The surface water which contains clay, discharged into a second container leaving the

denser materials which is silica in the base. The process was repeated once or twice before the clay slip poured into the plaster mold for drying. When the measurements of the materials were required immediately, Brongniat's Formula (see appendix) was used. This formula was used to find the dry weight of the suspended solids in a slip without the trouble of drying it.

The grog was first spread out in the concrete, the mixed levigated clays discharged into the grog and mixed thoroughly with a shovel. The material was covered with plastic paper and left for about three days for edging to become to a workable condition.

The moulding was done by laying a plastic paper around the edges of the moulding frame on a board so that the materials would not stick to the mould to ease removal. The material was beaten hard into the mould and smoothen, levelled up, the mould pulled off. The shelf was then put on its side with plastic paper to stiffen up.



MOULDED KILN SHELVES STACKED TO DRY BEFORE BEATING

When the shelf dried that it would not receive a depression when pressed with hand, it was then put back into the mould for actual beating. The beating was done with a heavy piece of metal after which the frame was unbolted and the shelf left on its edge for complete drying. They were fired to 1280% before being used for packing.

CHAPTER FIVE

KILN OPERATION, FIRING TESTS AND RECOMMENDATIONS

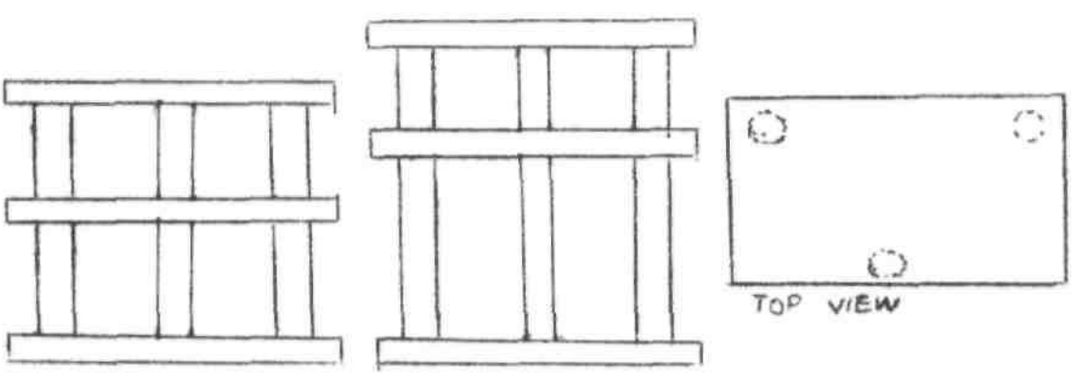
In the bonfire firing, the wares are piled together in a closely packed mass taking particular cognizance of how the pieces fit together. With the introduction of glaze firing, arrangements have been devised to keep the pots from sticking together. In some cases saggars are used for protection holding wares in the kiln. They protect the ware from direct contact with the flame and hot gases from the fire but consume a great deal of space inside the kiln.

Shelves and props are the most efficient furniture for setting the kiln. Rhodes (1986) recommends the size of shelf as 31cm x 62cm and 4cm thick made from fire clay and refractory grog. The shelves made were given a coating of kiln wash to prevent any glaze that would drip onto the shelf from sticking permanently. The props were made from cutting the standard brick lengthwise to get the longer props and from the width the shorter ones and levelled up into various sizes.

5.1 PACKING

Packing in the gas kiln is open which is to say that there is no need for saggars. Care was taken when packing the pots. If they were packed touching each other as in biscuit firing, the melting glaze would stick to each other. A gap of about 1cm between every pot was left to prevent any danger. The shelves were supported

on three props, set out in a triangle and each set of props holding a shelf was directly in line with the ones underneath. More than one tier of shelves were used hence the shelves in one column were staggered higher or lower than the other one. This was to allow heat flow easily through the kiln and not be shut off by shelves lying at same level right the way through the kiln. Where the arrangement seemed wobbly, they were steadied, using pellets of moist refractory clay.



METHOD OF ARRANGING SHELVES AND PROPS

5.2 FIRING

The firing was divided into three phases:

1. Preheating
2. Full Firing
3. Cooling

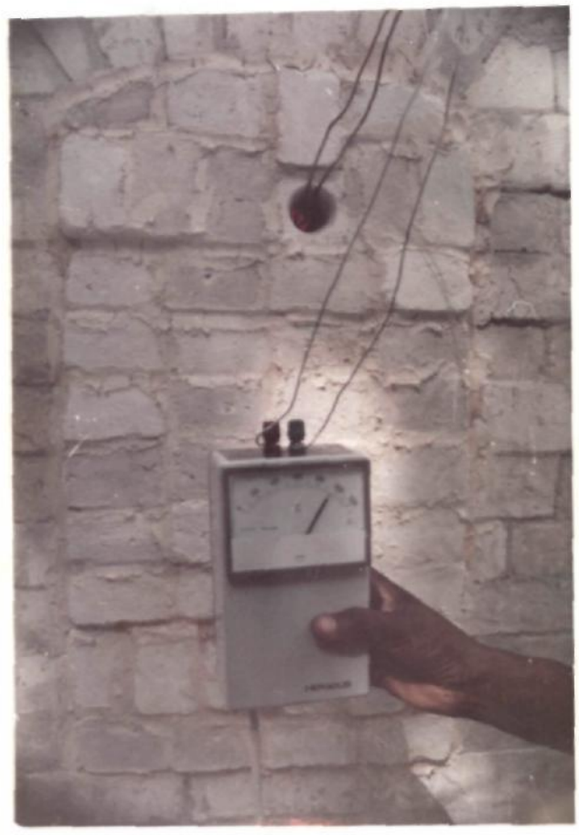
5.2.1 Preheating

The firing process and its relation to creative work in pottery is important. Rhodes (ibid) saw it as critical but when successful the fruits of all the other processes

are realized. But by the same token if the firing process failed all else is cancelled and counts for nothing. At this stage, the firing was gradual by setting the pressure low to develop a slow heat below 500°C. This was also to allow moisture escape and the silica inversion took place before the full firing. The damper was set at maximum opening with the spy holes opened for about 30 minutes when firing started. The omission of preheating could likely cause explosion of green ware when the contained moisture within the ware expands as steam faster than it could escape.

5.2.2 Full Firing

The proper damper setting was achieved by pushing in the damper brick until there was back pressure out of the top spy hole and neutral pressure at the bottom hole. Neutral pressure can be determined by placing a lighted paper at the bottom spy hole. If it is not blown out or drawn in, then the damper is in the correct position. Each time the pressure was turned up the damper was readjusted. Brodie (1982) noted back pressure to be directly related to the volume of the heated gases produced by the burners and by the size of the exit flue (controlled by the damper), the flue cross-section, the chimney cross-section and the height of the chimney. The damper was used as the primary means of controlling the out draught or back pressure in the kiln. Without this the heat would have gone right out of the chimney and it would be only the chimney heated not the kiln chamber.



CHECKING THE TEMPERATURE WITH A PYROMETER

The actual firing programme and cycle is better determined by each person firing a kiln, however, typical firing graphs for the first three test firings are included with their results for individual to choose what kind of firing is desired. Hence firing is a basic design choice.

Generally speaking, if one lights up the burners and build up the gas pressure gradually and do not restrict the chimney opening at all, a temperature of 1280°C could be reached in a short time. Once the idea of reduction firing is introduced the cycle changes as noticed in the

second firing where the top temperature is held longer, with the ratio of 5:3, than the first firing.

5.2.3 Cooling

The kiln was left to cool gradually after it was turned off. First, the damper was fully pushed in, the secondary holes closed and spy holes remained closed. If rapid cooling is desired the reverse is the case. As the door was made by bricking, the bricks were taken down slowly brick by brick. A row or two rows at every fifteen minutes to prevent sudden draft of cold air to strike on the pots which might cause a hairline crack which is dunting.

The colour and finish of both glaze and clay body could be affected by the cooling rate of the kiln. According to Green (1973) there are three important points to watch for in cooling a glaze firing.

1. Slow cooling between 900°C - 800°C will encourage crystals to grow in glazes. This growth is essential for the formation of matt glazes. Noncrystalline shinny glazes can be cooled rapidly down to 700°C.
2. Between 600°C and 500°C the invasion of the beta quartz to alpha quartz takes place. This is accompanied by 1 percent shrinkage.

3. The beta cristobalite that was formed between 1100°C and 1300°C during the firing, on cooling reverts to alpha cristobalite at between 260°C and 220°C with a shrinkage of 3 percent.

5.3 FIRST FIRING

The pressure was set to 3 psi/pounds per square inch) initially when the kiln was lighted. Two and half hours was used as the preheating period. With the pressure at 5psi in the third hour, it was left at this setting throughout the firing. There was no move to introduce reduction firing as one could noticed flame in the top spy hole which was an indication of back pressure and reduction. The pressure could have been increased higher which would shorten the firing period, but this would not be healthy for the glazes and the structure, therefore it was maintained at 5psi. The first firing took a total of eight and half hours to reach cone 9 (1280°C) the required temperature including the period of soaking.

At the end of firing it was discovered that the two 50kg gas cylinders were used up half way which is quite economical.

5.3.1 RESULT

As noticed above, the firing took a total of eight and half hours duration to reach the operational temperature of cone 9 (1280°C). The top cone was fully bent while the bottom cone slightly bent. It was noticed to

have been underfired at the bottom which could have resulted to short pieces packed at the base instead of tall ones to start with. If the space at the bottom was not big enough, with the suction effect of the chimney pulling out draft, the temperature at the base would not even up with the top. Packing tall piece first allowed in maximum draft and free circulation to enable the temperature to even up.

The soap bricks (23cm x 7cm x 6cm)used before laying the floor shelves were small. Without sufficient space for the draught to pass, a constriction is caused thereby making it impossible for temperature to rise. It would be necessary to increase the flue passage at the bottom by using bigger bricks, preferably standard bricks.

It was noticed that the kiln cracked along the mortar line. Cardew (1969) suggested the use of 10 percent of fine grog made from kaolin for mortar. Having used the unfired Kankara clay with saw dust a strong bond and uniformity was not insured. With additional grog into the mixture the fault would have been reduced. All that was left to be done was to fill the crack with a mixture of Kaolin and refractory fine grog.



FIRST FIRING RESULT

5.4 SECOND FIRING

Having seen the result of the first firing, the method of firing cycle was changed as a result of some variables that might have worked against the complete regularization of the first firing. Among these variables are the differences in the setting, in the shelf arrangement, the variety of the pieces in size and shape and even in the setting of the gas regulator which may affect the draught. At this point the kiln should

have receive maximum heat that a lot of heat will not be used for the furniture and wall.

Taller pieces were packed at the lower part to allow maximum draught and free circulation to enable the temperature rise.

After about 5 hours firing, the gas began to be cold, a condition which came as a result of pressure drop. This would ultimately mean a temeparture drop.

This problem can be solved by having a gas storage tank, in the alternative, additonal cylinders were used by changing the cylinders to finish up the firing.

5.4.1 Result

The firing was more even than the first one, however the readjustment expected to have been done on the flue passage was not done nor the cracks along the mortar filling filled. As a result of the longer period of firing it would be argued that it helped the temperature to even up in the kiln rather than a fast firing. There was no doubt that the adjustment made on packing and selves arrangements helped to improve the firing. Further adjustment on the floor bricks would be made in the next firing plus filling the cracks.



SECOND FIRING RESULT

309806

5.5 THIRD FIRING

By laying the soap bricks on their sides, the flue passage was slightly increased by 2cm, and the opening into the chimney above the bottom shelf reduced. A mixture of fine grog from Kaolin, unfired sieved Kaolin and transparent cone 9 glaze was used to fill some of the cracks in the mortar line. It was hoped that after it is found to be successful then the rest of the cracks will be filled or else an alternative composition be made.

The packing of the kiln was very dense but not neglecting to stack the bottom with tall pieces and equally staggaring the shelves to prevent any flue blockage.

The preheating was done on a low pressure 2psi, for an hour before increasing the pressure to 5psi. The rise to top temperature was rapid, 3 hours while the first and second firings were for 4 hours duration. This would enable the kiln to be fired longer in the top temperature before reaching the operational temperature of 1280°C. This will give an even temperature in the kiln as seen in the second firing which lasted for 5 hours. The first firing took only 3 hours in the top temperature and the result was underfiring at the bottom.

While monitoring the temperature in the kiln with a pyrometer, the only cone fixed at the bottom was pushed down. The pyrometer can only indicate the temperature up to 1200°C whereas the firing was expected to continue till 1280°C. An effort was made to fix another cone, used once but not fused, into the kiln through the spy hole. The cone was reduced to a stump as it would not pass through the spy hole in its full length. Luckily, this was made possible and the firing continued. Cones should be placed in the kiln thoughtfully if they are to be accurately used. Hamer (ibid) did not encourage the use of cones that have not collapse in a previous firing, according to him, the cones have been subjected to an amount of heat work which will make them inaccurate. The

firing continued until the cone fused. It lasted for 7½ hours, less than 1½ hours than the second firing with a period of 20 minutes soaking.

5.5.1 Result

The kiln was allowed to cool for 24 hours and opened the second day later. There was clearly an even overfiring. The tenmaku glaze came out red instead of black and the distribution of heat in the chamber was even. The overfiring could be as a result of firing to get the stump cone bent. Since the cone has been reduced to a stump it would take time before bending. This problem can be solved by putting in more than one cone in the firing, both at the top and bottom. In case if one fell off the other could be used in monitoring the temperature. The firing showed an evidence of the kiln reaching cone 9 (1280°C) in less than seven hours.



THIRD FIRING RESULT

5.6 ADVANTAGE OF GAS FIRING

It is appropriate to summarize the advantages of gas firing, particularly for ceramics manufacturing. Experience from the test firings have shown the following:-

1. Readily controlled heat imput with burners programmed to fire on high or low ratios.
2. Minimal smoke or sulphurous chimney emissions even during a reducing atmosphere operation which might otherwise be marked by a black smoke condition.

3. Reduced labour costs as the actual firing capability of 2 gas cylinders for the cost is ₦40 whereas a wood kiln of the same capacity would cost ₦100 to fire.
4. Less labour intensive, several people would be required in attending a similar wood kiln. For gas kiln firing, the labour requirement is cut to one person to attend to the kiln or three to four kilns could be attended to by one person simultaneously.
5. Increase in production of ware due to better temperature control across the kiln and the non usuage of saggars.
6. Control of colour and shade by actually maintaining oxidizing or reducing conditions in the kiln firing.
7. Less environmental hazards due to combustible nature of gas.

5.7 DISADVANTAGES OF GAS FIRING

The gas kiln firing is not without problems. Some of these problems include:

1. Gas Leakage: As a result of not checking the clipped points to detect leakages using soap and water, gas leakage at such points could be very disasterous when the kiln is lit.
2. Gas blowing back when lighting the burners. The valves must be closed after every firing so that when the gas is opened from the cylinders the gas will not

flow to fill the kiln chamber before lighting.

3. If the kiln is not housed, it will be difficult to fire it during the raining season, since this is the time that the relative humidity is very high which could cause a drop in pressure.

There is no doubt that the advantages outweighs the disadvantages, and disadvantages could be controlled, therefore the effort of building and using a gas kiln is worthwhile.

5.8 OBSERVATIONS AND CONCLUSIONS

Cost of meterials in the market are not stable. The prices quoted may not be appropriate for the future. Distance from the source of supply cannot be overlooked as a factor which will affect the prices of materials also.

Based on the analysis and findings the following conclusions were drawn:

1. That the construction of the intermittent gas kiln and burners requires great care and precision for an efficient functioning of such a kiln.

2. That a high degree of skill, a knowledge of function of every part and the selection of correct materials for the construction and fabrication of every part is crucial to the success.

3. There is sufficient gas reserve and kankara clay (kaolin) to last a long period of time in the country (Nigeria Technical Review, October, 1986).

4. Based on the model kiln, some small scale ceramic industries like Jacaranda Pottery, Kaduna and Datiri Pottery studio in Barikin Ladi, Plateau State have constructed their kilns which are functioning very well.

5. The students are optimistic in establishing their ceramics studios after graduating, seeing the performance of the kiln, felt, importing gas kiln would not be necessary.

6. It was discovered that the cost of pre-fabricated gas kiln cost far more than the prototype built (see appendix for the cost of materials).

7. The kiln is capable of being fired to 1300^{o}C and above but for the kiln to last longer, the operational temperature is 1280^{o}C.

8. The kiln and burner designed, are quite adequate for appropriate ceramic productions to be used by institutions and small scale ceramic entrepreneurs.

5.9 RECOMMENDATIONS

The following points are the recommendations from this study for further research:

1. If the combustion of gas kilns was encouraged, more professional potters and small scale ceramic industrialists would be encouraged, consequently further research should be conducted to determine the importance of gas kiln in our society in terms of job opportunity and self reliance.

2. It is recommended that the abundant ceramics raw materials be tapped, experimented with and use, to cut down the difficulties encountered in ordering ceramic equipments, to reduce the large amount of our currency that goes into the foreign exchange.
3. This study did not expand on the gas flame strength, temperature and other unknowable parameters, this will be worth investigating.
4. The joints that developed overlarge cracks after the first firing was an indication of the mortar not quite suitable for construction. This calls for a workable mortar for gas kiln construction instead of finding a right mixture to mend the damage.

REFERENCES

Adetoro, Sheriffdeen Abayomi (1985): Research Techniques. Gaskiya Corporation, Zaria, Nigeria.

Ahmed, K.S. (1986). "Development of Phosphate Bonded Fire Clay Refractory Castables". A Masters Degree Thesis, Chemical Engineering, Ahmadu Bello University, Zaria.

Ahuwan Abbas (1987): "The Importance of Ceramics in National Development. The Nigerian Experience". A Lecture delivered on the occasion of the annual conference of Ceramic Association of Nigeria - Zaria.

Bradshaw and Emery: "Notes on Joining Materials for Refractories". Transaction British Ceramic Society. (B.Sc.) 1921 - 22, pages 107-112.

Bradshaw "Symposium on Gas Firing", B.Sc. 1921-22, pages 198 - 200, 1931 - 32, pages 77-80.

Brodie C. Regis (1982): The Energy Efficient Potter Watson Guptil Pub. a Division of Billboard Pub. Inc. New York.

Brookshaw Doreen (1967): Pottery Craft. .Frederick Warne and Co. Litd., London.

Cardew Michael (1969): Pioneer Pottery. Longman Group Limited, London, New Impression.

Conrad W. John (1973): Ceramics Formulas, The Complete Conpendium. MacMillian Pub. Co. Inc., New York.

Counts Charles (1973: Pottery Workshop. McMillian Pub. Co. Inc. New York.

Coysh, A. Wilfred (1976): British Art Pottery. Newton Abbot. David and Charles, 1976.

Dayo Alao (1986). "The Koma's dilemma". Times International, Volume seven No.29, April 21.

Fournier Robert (1977): Electric Kiln Construction for the Potter. Van Nostrand Reinhold Company, New York.

Gilchrist J.D. (1963): Fuels and Refractories. Pergamon Press, Oxford, London. Volume One.

Griffiths and Rodford (1965): Calculations in Ceramics, Maclaren and Sons Limited, London, England.

Gukas, Habila (1985): "A Feasibility Study of Formulating Some Porcelain Bodies from Local Raw Materials in Kaduna State". A Masters Degree Thesis.

Hagger R.G. (1959): Pottery Through the Ages. Methuen, London.

Hamer Frank (1975): The Potters Dictionary of Materials Techniques. Pitman Publishing.

Hamilton, David (1974): Pottery and Ceramics, The thames and Hudsow Manual, London.

Ian Gragory (1977): Kiln Building, Adam and Charles Black Publishers, London, 1977 2nd edition.

Leach Bernard (1976): A Potter's Book. Faber and Faber, London. 15th Impression.

Lom W.L. (1974): Liquified Natural Gas. Applied Science Publishers Limited, London.

Maurice Chandler (1967): Ceramics in the Modern World. Aldus Books, London.

McMeekin Ivan (1967): Notes for the Potters in Australia, Raw Materials and Clay Bodies. South Wales University Press Limited, Sydney.

Nelson Glen (1971): Ceramics, a Potter's Handbook. Holt, Rinehart and Winston.

Okoruwa Pedro (1986): "The Utilization of Some Selected Raw Materials for Porcelain Slip Casting and Glazing of Moulded Ceramics". M.A. unpublished Thesis.

Olsen L. Frederich (1973): The Kiln Book. Keramos Books Basset, California.

Pat Oyelola (1981): Nigerian Crafts. Published by Macmillian Education Limited, London and Basigstoke, Pages 1-10.

Paul Soldner (1966): Kiln Construction. American Craftsmen's Council, New York.

Pottery Craft Limited. "Materials and Equipment for the Craft Potter". Catalogue 1984.

Pritchard R. Guy J.J. Connor N.E. (1977): Industrial Gas Utilization. Bonker Publishing Company Limited, Epping, Essex.

Rhodes Daniel (1968): Kiln Design Construction and Operation: Chilton Book Company, Radnor Pennsylvania.

Rhodes " Clay and Glazes for the Potter: Chilton Book Company, Radnor Pennsylvania.

Ritchie, W. Ralph (1975): Gas Kiln Firing, Keramos Books, Bassett, California.

Roberts D. "Nigeria Pottery" Transaction. British Ceramic Society, 1918 - 19

Saville A.G. (1951): "The Okigwi Local Craft and Industries Exhibition". Nigeria Magazine No.36, 1951, pages 441 - 468.

Warren Gilvertson: "The Kiln". American Ceramics Society, Volume 33, 1950, pages 297 - 298.

Wren Denise and Wren Rosemary (1985): Pottery Making. Sir Isaac Pitman and Sons Limited, London.

APPENDIX I

COLOUR WITHIN A KILN DURING FIRING

Temperature (^{o}C)	Colour	Fired ware
500	dull red	
750	red	enamels
1,000	Bright red	bisquit and earthenware
1,100	Orange red	glaze
1,150	Bright red	high bigquit
1,200	White orange	Stoneware;
1,300	White	bone china bisquite
1,350	Blue white	Porcelain

David Hamilton (1974)
Pottery and Ceramics the thames and Hudson Manual, London.

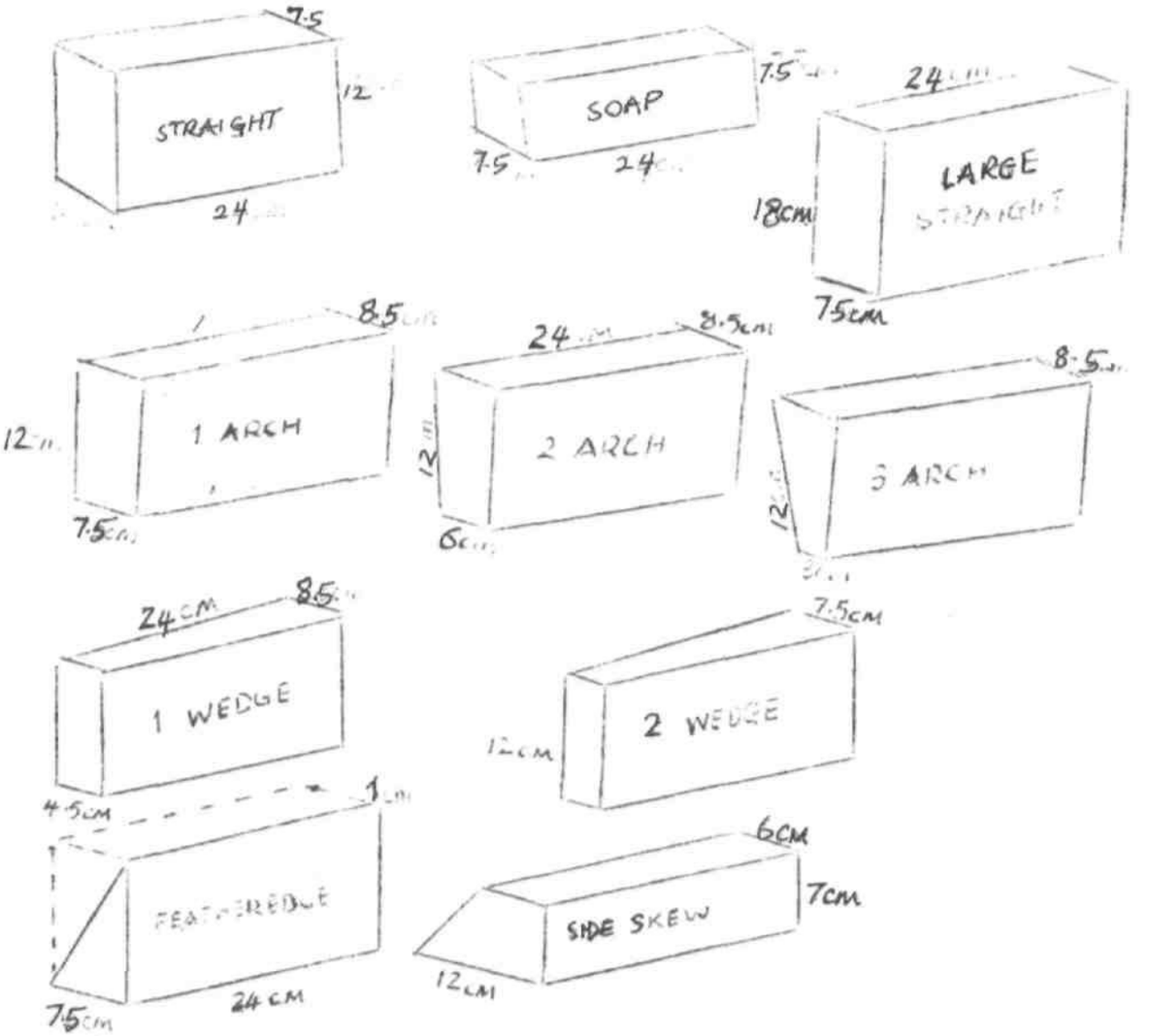
APPENDIX II

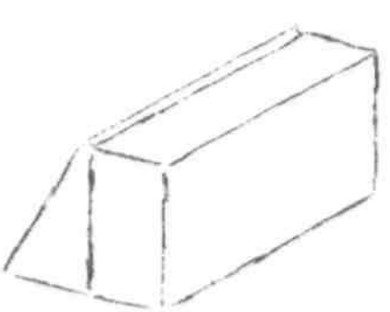
COST OF MATERIALS

				₦	K
1.	Standard bricks 24cm x 11cm x 8.5cm	920		1,840	00
2.	Arch bricks 24cm x 11cm x 6cm x 5cm	100		250	00
3.	Dense bricks 24 cm x 11cm x 8.5cm	40		120	00
4.	Angle iron 4cm x 59cm	6		300	00
5.	Metal sheet 0.2cm thick, 1344cm x 246cm	1		80	00
6.	Plywood 0.6cm thick, 120cm x 240cm	1		70	00
7.	Burners, 7.5cm tip, and 5cm tip	4		1,100	00
8.	Rubber hose (gas) 10 metres long			150	00
9.	Connectors	9		120	00
10.	Clips	20		40	00
11.	Plank (hardwood) 5cm x 31cm x 360cm	1		36	00
12.	Nails (1kg weight) 2.5cm long	1	pkt.	5	00
13.	Pressure Guage regulator	1		300	00
14.	Cement	4	bags	80	00
15.	Metal paint (iron oxide)	1	gal.	90	00
16.	Saw dust			10	00
	Total			₦4,591	00

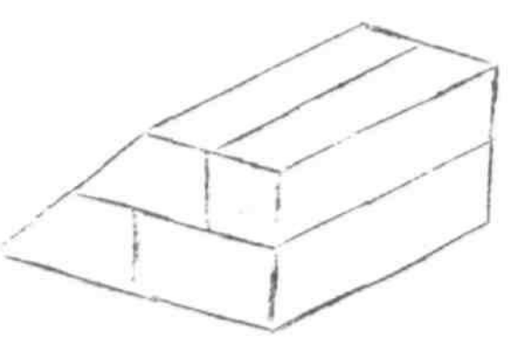
APPENDIX III

STANDARD FIREBRICK SHAPES





For 12cm ARCH RISE = 4cm PER FOOT OF SPAN Use One Featheredge 24cm x 12cm x (7cm - 1cm)

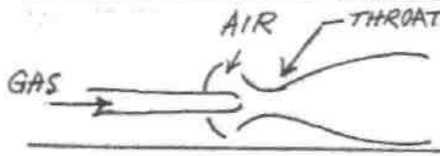
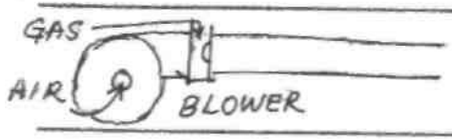
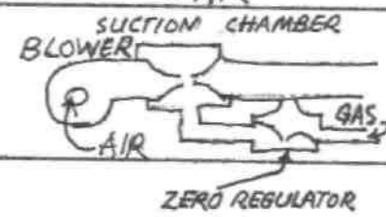


For 12cm ARCH RISE = 6cm PER FOOT OF SPAN Use two side skew; 24cm x 12cm 7cm and one soap brick 24cm x 7cm x 6cm.

SOURCE: RHODES (1968)

APPENDIX IV

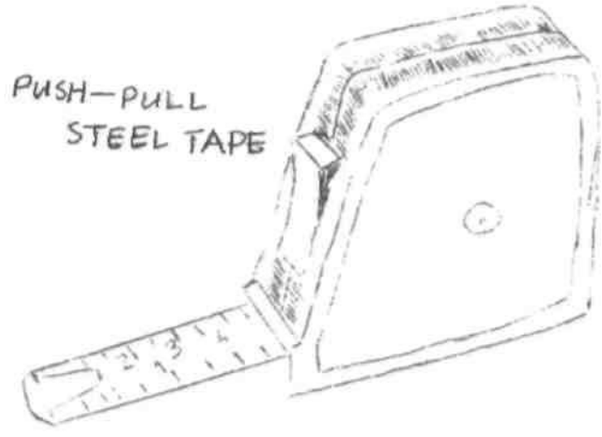
BURNER TYPE

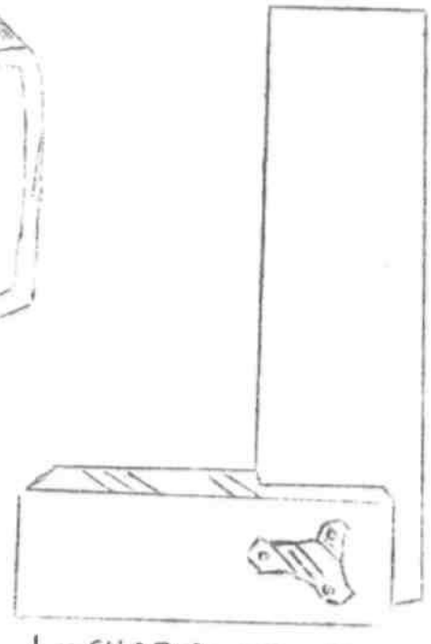
DIAGRAM	OPERATION	TRAITS/PROBLEMS	ADVANTAGES/DISADVANTAGES
	Modified Venturi using a pipe Section. Primary air is entrained only by velocity of gas stream.	Needs highest gas pressure available to draw in sufficient air for combustion.	Burns back into tube with reduced gas pressure. Least efficient.
	Venturi Burner. Gas velocity causes partial vacuum at throat, draws in air which mixes in tube and burns at mounth.	Needs air to complete fuel combustion in firing chamber.	Efficiency can be maintain by changing orifice with change in gas pressure. Minimum maintenance. Economical.
	High BTU Gas Venturi Double Throat. Enables adequate air entrainment with high BTU gas stream. For propane and butane.	Solves the problem which exists when trying to maintain same heat output from Venturi Burner above, that was available from natural gas.	Same advantages as above. Most expensive Venturi Burner.
	Forced Air Burners. Offer most concentrated heat from given burner size.	Blower speed affects heat output Dangerous if blower fails.	Should be equiped with an automatic shut-off. Higher initial cost. More efficient.
	Forced Air Mechanical Mix Burner. Gas is fed into blower intake. Blower does effficient mixing of gas/air mixture for better burning.	Same problems as above. Good burning rate. Requires blower with sealed case.	Same as above. Better efficiency than above.
	Zero Pressure Regulator Mixer. Allows control of burner output. governed by air flow only. Adapts well to automatic system. No gas flow without air flow.	Quiet, most complete combustion, smallest combustion chamber, fastest combustion speed.	Same as above. Excellent efficiency. Most costly. Safe.

Cockburn (1978) "Flames Across the Tasman" New Zealand Potter - Journal.

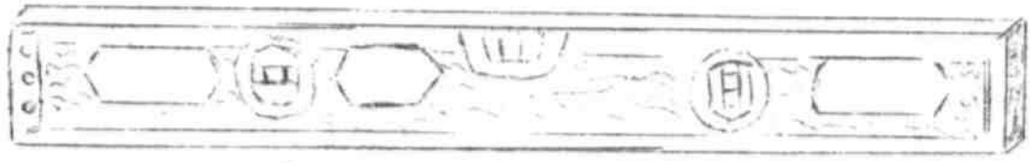
APPENDIX V

SOME OF THE TOOLS USED DURING THE KILN CONSTRUCTION

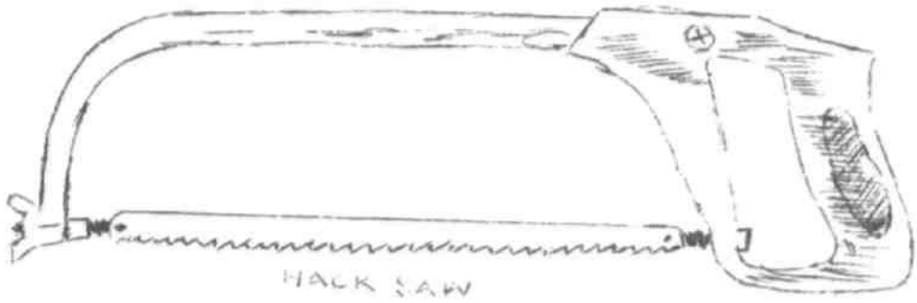




L–SHAPED SQUARE

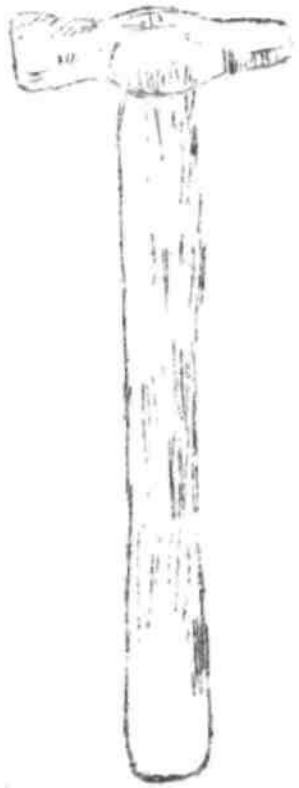


PLUMB & LEVEL

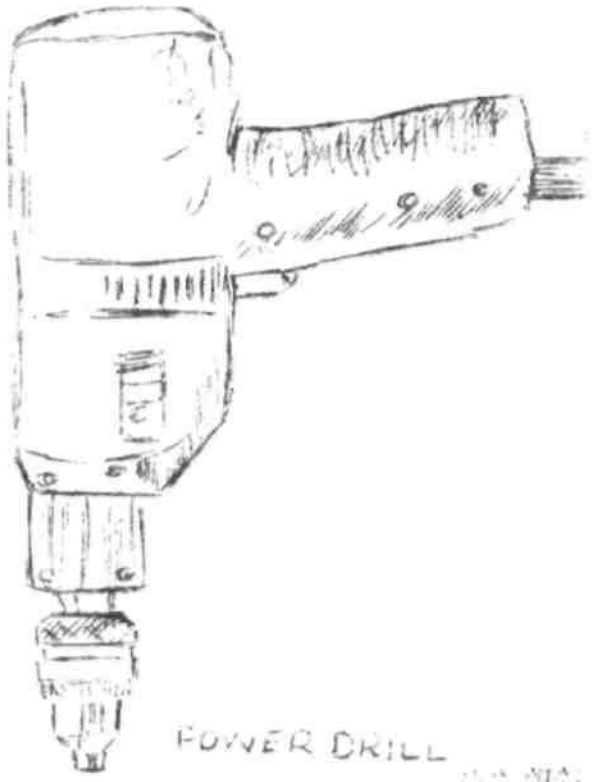


HACK SAW

APPENDIX V (CONT.)



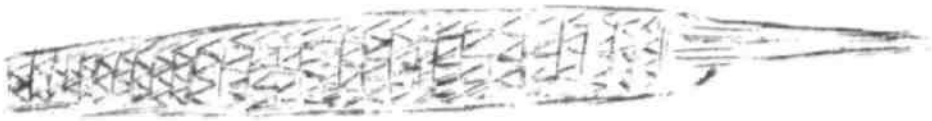
CROSS PEIN HAMMER



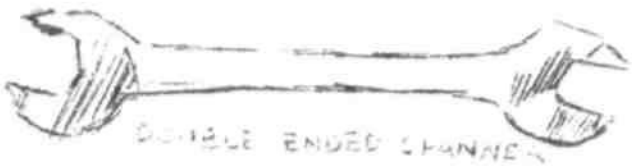
POWER DRILL



ROUND WOOD RASP



HALF ROUND WOOD RASP

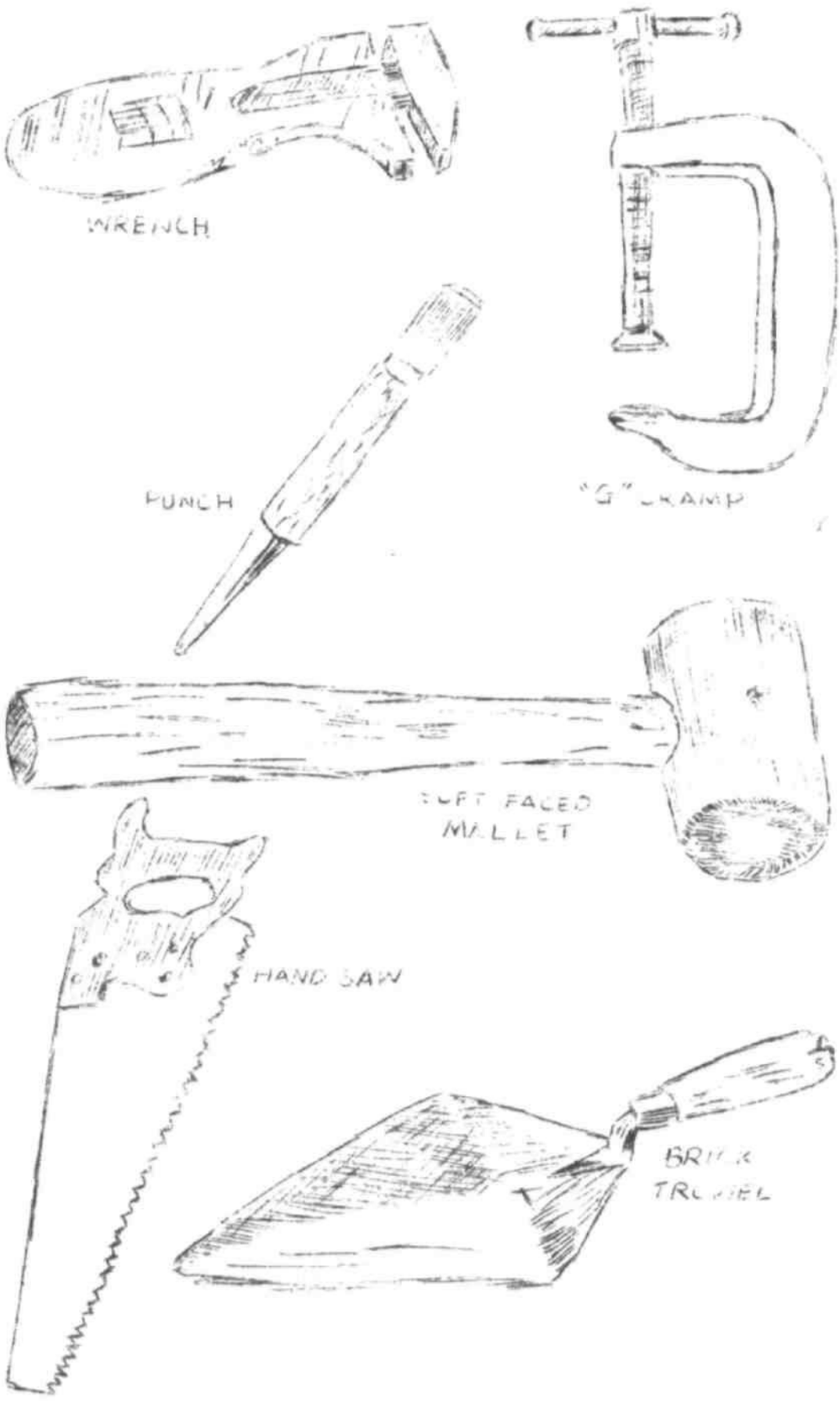


DOUBLE ENDED HAMMER



FLAT PAINT BRUSH

APPENDIX V (CONT.)



APPENDIX VI

BROGNIART'S FORMULA

This formula is used for finding the dry weight of the suspended solids in a slip without the trouble of drying it. In order to find the unknown quantity - the dry weight of the suspended solid - it is necessary to know the specific gravity of the solid, the exact weight of a given volume of the slip and of an equal quantity of pure water, the specific gravity of which is 1.

The formula is expressed:

$$\text{weight of dry content} = \text{apparent dry weight} \times \frac{\text{specific gravity}}{\text{specific gravity minus one}}$$

For U.K. capacities where one pint of water weighs 20.042 oz. The formula is:

$$W = (P - 20) \times \frac{SG}{SG-1} \text{ oz}$$

W = weight of dry material in a pint

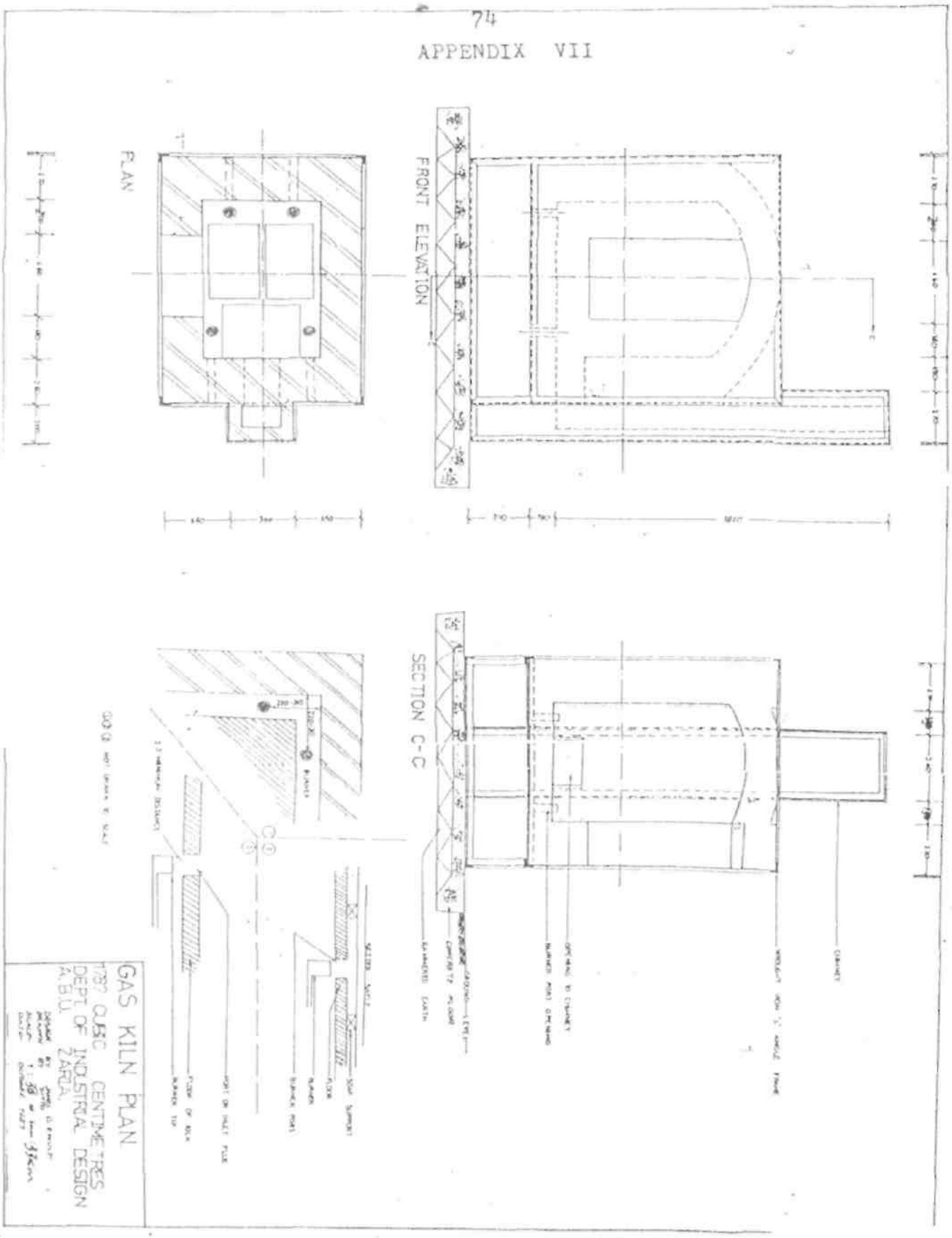
P = weight of a pint of the slip concerned

SG = Specific gravity of the clay (always taken as 2.5)

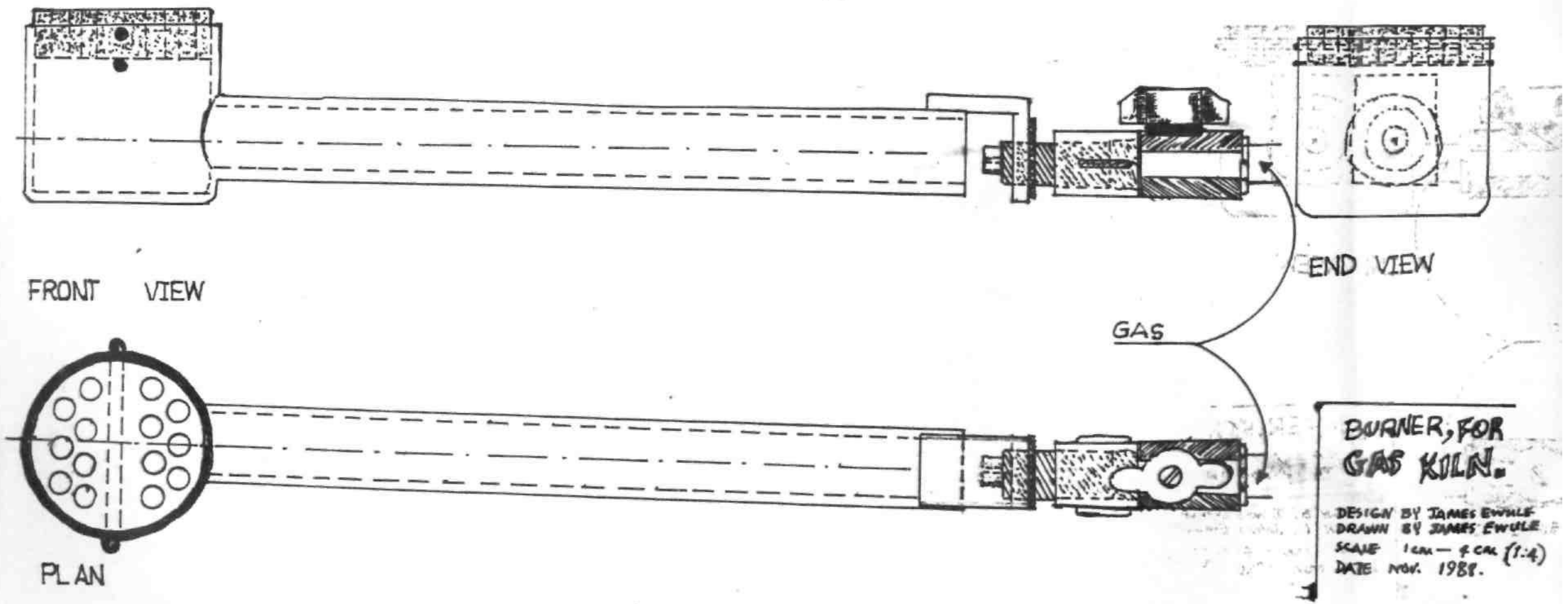
OR

$$W = (\text{Grms} - 566.5) \times \frac{SG}{SG-1} \text{ grammes.}$$

APPENDIX VII

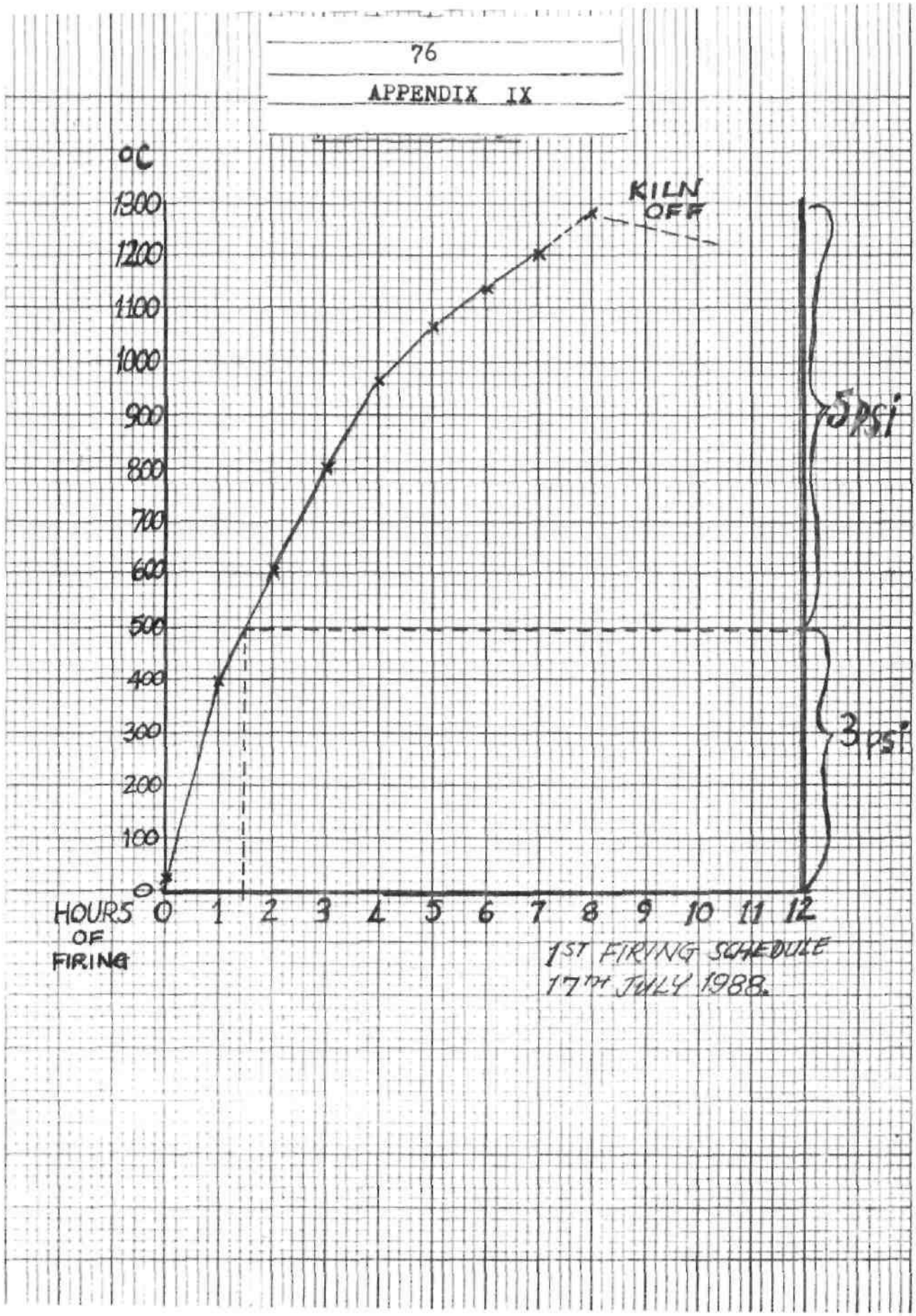


APPENDIX VI

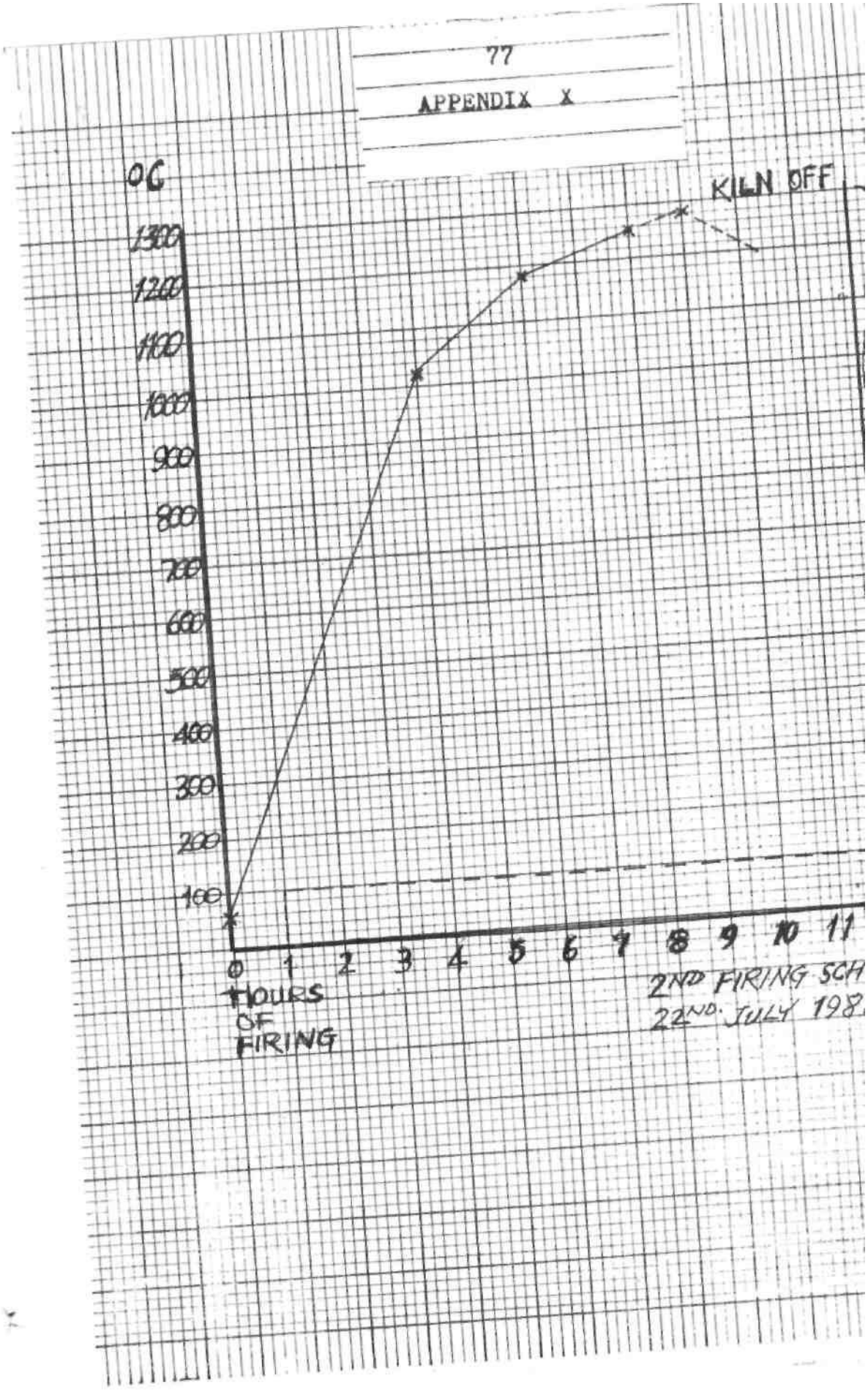


PATTERNED BY FORDHAM THERMAL SYSTEM, ENGLAND. ORIFICE AND VALVE MODIFIED.

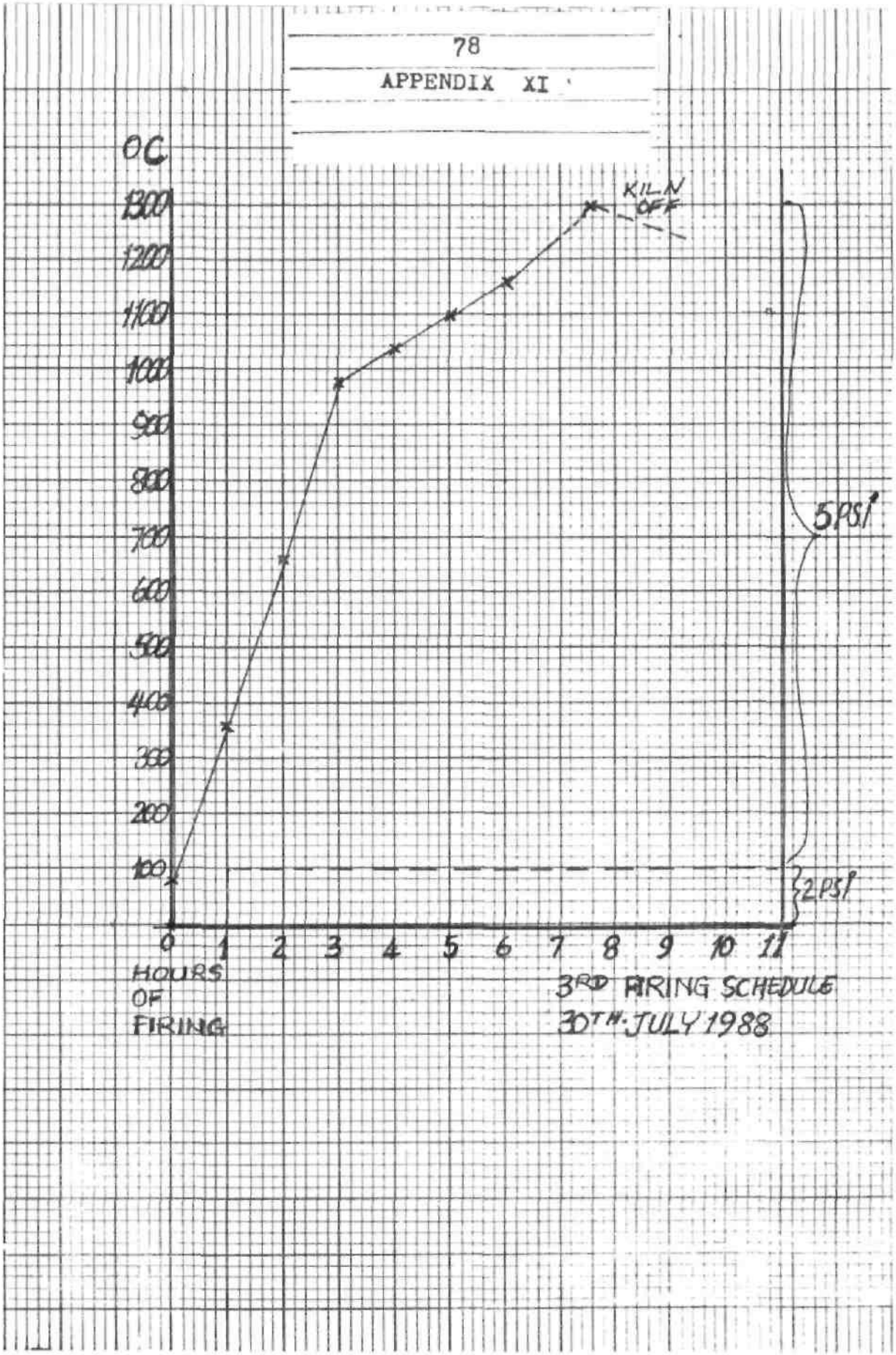
APPENDIX IX


°C
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
KILN OFF
5 PSI
3 PSI
HOURS OF FIRING
0 1 2 3 4 5 6 7 8 9 10 11 12
1ST FIRING SCHEDULE
17TH JULY 1988.

APPENDIX X


°C
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
KILN OFF
0 1 2 3 4 5 6 7 8 9 10 11
HOURS OF FIRING
2ND FIRING SCH
22ND JULY 198

APPENDIX XI


OC
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
KILN OFF
5PSI
2PSI
0 1 2 3 4 5 6 7 8 9 10 11
HOURS OF FIRING
3RD FIRING SCHEDULE
30TH JULY 1988

AHMADU BELLO UNIVERSITY
ZARIA, NIGERIA

APPENDIX XII

CRITICAL DIMENSIONS FOR ANY DOWNDRAFT KILN FIRED WITH GAS OR OIL. OPEN CLOSED BURNER PORT. BASED ON 15,000 BTU/CU.FT. OF CHAMBER VOLUME

KILN SIZE (Interior Space)		CHAMBER HEIGHT		FLUE CROSS SECTION		EXIT FLUE VELOCITY		HEIGHT OF CHINNEY	
CU.FT.	CU.M.	IN	CM	SQ.IN	SQ.CM	FT./SEC.	M/SEC	IN	M
10	0.28	26	66	25	162	15	4.6	98.4	2.50
20	0.56	32	81	42	273	15	4.6	98.4	2.50
30	0.84	37	94	62	403	15	4.6	98.4	2.50
40	1.12	41	104	83	539	15	4.6	104.6	2.66
50	1.40	44	112	104	676	15	4.6	110.7	2.81
60	1.68	47	119	125	812	15	4.6	110.7	2.81
70	1.96	49	124	125	812	18	5.5	110.7	2.81
80	2.24	52	132	125	812	20	6.0	116.9	2.97
90	2.52	54	137	139	903	20	6.0	116.9	2.97
100	2.80	56	142	156	1,014	20	6.0	116.9	2.97
120	3.36	59	150	187	1,215	20	6.0	123.0	3.12
140	3.92	62	157	218	1,417	20	6.0	129.2	3.28
160	4.48	65	165	249	1,618	20	6.0	129.2	3.28
180	5.04	68	173	282	1,833	20	6.0	129.2	3.28
200	5.60	70	178	313	2,034	20	6.0	135.4	3.44

SOURCE: Brodie Regis (1982)