THE ADOPTION OF AN APPROPRIATE OIL BURNING SYSTEM FOR SMALL SCALE CERAMIC FIRING IN NIGERIA

BY

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

DEPARTMENT OF INDUSTRIAL DESIGN

FACULTY OF ENVIRONMENTAL DESIGN

AHMADU BELLO UNIVERSITY

ZARIA

AUGUST, 1991

DECLARATION

I, ALI, Edwin Adoyi, solemnly declare that the contents of this thesis is the report of my studies on "The Adaption of an Appropriate Oil Burning System for Small Scale Ceramic Firing in Nigeria". I collected the necessary materials, took photographs, designed and fabricated the burner and carried out the tests as stated in this thesis. I took and passed the specified courses below as prerequisite for the thesis.

Furnaces, Fuels and Refractories
Advanced Studio Practice I
Advanced Studio Practice II
Special Research Project
Research Technique



SIGNATURE

18-08-91
DATE

CERTIFICATION

This thesis entitled "The Adoption of an Appropriate Oil Burning System for Small Scale Ceramic Firing in Nigeria" by ALI, Edwin Adoyi, 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.

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DEDICATION

This thesis is dedicated to
my mother, Theresa Ajuma Ali

ACKNOWLEDGEMENTS

I wish to express my profound gratitude to all these who in one way or the other helped me to a successful end of this work.

First and foremost, my thanks go to Dr. Abashiya Ahuwan who as the major supervisor, gave me steady guidance throughout the period I worked with him. His keen interest in the work urged me on at very critical moments. I want to also thank him in his capacity as the Head of Department for allowing me free access to departmental facilities which formed vital tools for the execution of this project. My thanks also go to Alhaji A.A. Abede for obliging to be my second supervisor at a very short notice. Above all, I cherish his thoroughness in pointing out my mistakes. Dr. Betty Kpaɛvzua as the departmental post-graduate programme made her imput into this work and Dr. S.B. Dikko who was the Chairperson at my post-graduate seminar presentation also made useful contributions; for all these, I remain grateful.

There are friends who do not lay claim to any objectivity in matters that concern me - individuals who threw their weights behind me in all the troubles I went through. They have always urged, inspired and encouraged me without compromising criticisms when the need arose. To all these I confess my total indebtedness and gratitude for without them this work would not have seen the light of the day.

Special mention need be made of the following to whom I am indebted: Dr. Augustine Ebonyi, Messrs. Charles Osinem and Simon Chieshe for their encouraging words at critical moments; my sister Anna and her husband, Mr. Joseph Ojile for rallying round me at a moment when I needed their support financially to bring this work to an end.

My sincere thanks also go to Mallam Aliyu and Mr. and Mrs. James Ewule for giving me useful advice at the stage of testing the equipment. I wish to also thank members of my family particularly Jecinta and Abigail for their supports. Miss Juliana James, Messrs. Peter A. Egaji and Titus Ubagu all helped willingly with the typing work while Mallam Abdullahi Adamu of the Departmental Office gave assistance in some other ways. My colleagues in the Glass Technology Section, Messrs Alex Fwatmwoi , Isaac Akomolafe, Clement Gonah and students of the section also gave very useful advice to me. To my wife, Martina, whose persistent encouragement and criticisms made this work possible, I lack the words to express my inner feelings towards her.

On a final note, I am grateful to the University Authority for aggreing in principle to bear the cost of this research work.

ABSTRACT

In the course of the research, three different designs of oil burners were identified for adoption and the one considered the most viable among the three was carried through the stage of fabrication. Tests were then administered to Justify claims of reliability.

The tests involved firing glazed bodies up to 1250°C in five trial runs of 11; hours each. Kerosine was used as the operating fuel in the first three firings and diesel was used for the subsequent firings. Visual inspection, pyrometric cones and the texture and colour of the. glazed bodies were used to assess the success of the experiment. The outcome of the firings could be considered a success as the temperature of stoneware (1250^{0}C) was attained in reasonable time (12 hours).

However, it is an irony of nature that any solution deviced by man is bound to bring into focus new unexpected problems; thus the pre-heating coil introduced to aid the process of atomisation resulted in the premature decomposition of the fuel component as indicated by the deposition of carbon particles around the burner nozzle. The solution to this problem of carbon deposition will require further studies.

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DEFINITION OF SOME SPECIAL TERMS

Boiler - A water heater for generating steam

Bond (Chemical) - The strong attraction that holds together atoms in molecules and crystalline salts

Burner Pulsation - Momentary ceasure of the burning process usually accompanied by some form of sound.

Caburisation - The process of mixing fuel and air for controlled combustion.

Calorific Value - (C.V) - Heat obtained by complete combustion of unit mass of fuel; expressed as Joules/kilogramme (J/kg) for solids (Kilo Joules/ metre^3) KJ/m^3 on volume basis (e.g. for liquid and gaseous fuels). The C.V is in the net form if the water formed in the combustion process is in the vapour phase and in the gross form if the water formed is in the liquid state.

Chinaware - Fine procelain made of clay imported originally from China.

Distillate fuel - Any one of the wide variety of fuels obtained from fractions boiling above the temperature at which gasoline comes off from the distillation of petroleum.

Drier - A device to remove moisture

Dry product of combustion - The product of the combustion process taken into consideration without the water evolved in the process.

Equilibrium temperature - The temperature at which heat loss equals heat gain.

Exothermic reaction - A reaction that involves heat evolution.

Furnace - An industrial appliance constructed to carry a material through a heat cycle involving temperatures above 600^{o}C.

Glaze - A glossy material made from the same materials as glass and melted in place on Ceramics bodies to make them water resistant.

Kiln - A heated enclosure used for drying burning or firing of Ceramic materials.

Load range (Turn down ratio) - The ratio between maximum and minimum output of a burner.

Oven - A heated enclosure for baking, drying or heating.

Oxidation - A chemical reaction that increases the oxygen content of a compound.

Porcelain - A high grade ceramic ware characterized by high strength, a white colour, very low absorption, transluscency and a hard glaze.

Pour point - Lowest test temperature at which a liquid will flow. High pour oils have high pour point. Conversely, low pour oils have low pour points.

Reduction - A reaction that decreases the oxygen content of a compound.

Stack (Flue) - Tall vertical conduit for venting of waste gases of combustion.

Squatting temperature - The temperature at which the tip of a pyrometric cone bends to touch the base.

Stoichiometric ratio - The numerical relationship of the fuel and the oxygen of the air as reactants in the combustion process.

Stoneware - Vitrified ware with impermeable surface.

Vaporization (Volatilization) - The conversion of a chemical substance from the solid or liquid state to the gaseous state (in most cases) by the application of heat.

Windbox - refers to the passage of primary air linking up the burner nozzle with the air inlet.

Chapter 1

INTRODUCTION

Our ancestors know from ancient times that clay pots and jars could be made stronger and water resistant by subjecting them to prolonged heating. Wood was pioneered as the sole fuel in those days with the firing being carried out in an open flame.

In line with advances made in the field of science and technology, in what can be simplified as man's constant effort to conquer his environment, the process of firing has now taken the form of employing the burner as the special heat release equipment. The range of fuels at the disposal of the burner operator has widened to include liquid and gaseous fuels. The range of use of burners has also widened to include a variety of industrial plants ranging from driers, ovens and kilns to furnaces and boilers (Wright, 1977).

Burner designs naturally vary widely in response to the wide ranging fuel properties and the peculiar needs of the thermal plants where they are installed. Its acceptance in relation to cost is of universal consideration in the adoption of a particular design of burner. The level of technological advancement of a country is also a key factor in the choice of a particular burner. The latter factor is of specific importance as it relates to the capacity of the operator to operate, maintain and repair the hardware involved in the construction (Omorodion, 1979).

In present day Nigeria, the use of fire wood in the process of firing is being discouraged against the background of a new ecological consciousness that has witnessed millions of naira being spent in anafforestation programme stretching over several years (New Nigerian, June 15th, 1989). To find solace in gas burning as a way of reducing the pressure on our forest reserves at a glance, becomes most appropriate. Unfortunately, the country at the moment lacks the basic infrastructures that can sustain a domestic gas market. The incessant gas shortages experienced in this country lay credence to this assertion.

Against the inhibitions of the use of wood as a reliable fuel and the uncertainties of the gas market, liquid fuels constitute the most reliable form of fuels used in the country's major industries, the case of the glass factories serving as a good illustration. Experience however shows that the burners employed in these industries are usually of high capacities for large scale industries and in all cases are of European manufacture.

For Nigeria to be truly industrialized there is the need for an equipment as vital to the sustainance of the industry as the burner to be developed locally to reflect the peculiar needs of the environment. In this study, an attempt will be made to tackle this technological problem by selecting a burner design most suited to the environment and going a step further to fabricate it, using locally sourced materials. Furthermore tests will be administered to establish the reliability (or otherwise) of the product of the experiment.

1.1 Problems of the Study

Nigeria is indowed with fuels existing virtually in all the States

Federation. With the exception of the gas sector that has been largely underdeveloped, Nigerians are culturally attuned to the use of petroluem oils and solid fuels especially wood. At the level of the small scale industry however, the use of liquid fuels for burner operation is difficult to come by. On close observation the problem of the lack of a proper equipment for harnessing the energy ascribed to petroleum oils at the small scale level emerges. This problem forms the bedrock of this study.

1.2 Purpose/Objective of the Study

The objective is three fold

1) To expand the range of choice available to the small-scale burner operator.

2) To find a way of using petroleum oils as some form of solution to the incessant shortages of liquified petroleum gas in the market.

3) To find a way of easing pressure on wood derivatives as fuels for industrial firing.

1.3 The significance of the Study

There is enough ground to justify any development in favour of the use of liquid burners in the country at the present time.

To begin with, wood which had hitherto been unchallenged for centuries as a reliable fuel in our traditional thermal plants (pottery ceramic plants) is now at a premium as a domestic fuel. Even then its continual use as a fuel is questionable on the basis of the consequent deforestation and dislocation of the country's ecological balance.

According to a recent report in the "New Nigerian" (June 15, 1989), the Federal Government will be spending a whopping sum of 0.5 billion naira spread over the next eight years in an afforestation programme that involves the distribution of 41 million tree seedlings.

One other argument against the use of wood as a fuel is the immediate health harzards created by poisonous fumes from wood fires.

As for the argument in support of petroleum gas as the most viable alternative, the basis of it is that the country's grossly under-utilized gas reserve put at 4 billion metric tonnes is capable of meeting both export and domestic needs in the next one hundred years. (The Reporter, June 21, 1989). This argument, factual as it is fails to recognise the prevailing circumstances in the country today. A thriving domestic gas market requires special modes of transport and storage that are cost intensive. The uncertainties of the country's gas market attended by shortages and price fluctuations can be traced to this infrastructural problem.

The government's concern for the domestic gas market can be desoribed as mild as she is pre-occupied with the fulfilment of a 25-year ambition of becoming a major gas exporter by 1995 (NNPC 1989). The President in his 1989 Budget Speech reaffirmed the government's position when he stated that the development of gas based export oriented projects is a government priority concern.

The discussion so far goes to support an intensive research in the area of burners operating on petroleum oils. The transport and storage of these oils are relatively less involving economical and petroleum oils especially kerosine enjoy a wide cultural acceptance that span the length and breadth of this country. Nigeria

as an oil exporting country should be able to satisfy her domestic needs in this sector in the next several years. A burner operating on petroleum oils will therefore be guaranteed a steady supply of feedstock especially when the equipment is made flexible enough to accommodate oils of wide ranging properties (both high and low pour oils).

1.4 The Scope of the Study

The area of burner development has witnessed increased activities in the last twenty years at the global level (Wright, 1971). For the purpose of a thorough but nevertheless an inexhaustible study, the researcher would wish to limit the scope of his study to the development a particular design of oil burner and advance arguments for its adaptation to the local situation. In line with current international standards, the range of burners that fall under the scope of this study are those burners whose capacities are below 36 litres/hr. (Wright Ibid).

1.5 The Limitations of the Study

It is to be expected that a study of this nature should be faced with a number of constraints; chief among them are:

(1) Absence of a suitable environment for accurate calibration of the instruments used in the experiment.

(2) The lack of adequate facilities for carrying out reliability tests.

(3) The extremely limited literature available in the area of burner development stands in the way of acquiring an up to the moment knowledge of progress or advances in this importa field.

4. The inconsistency in supply and availability of burning fuels.

1.6 Basic Assumptions

It is assumed that:

(1) Designs in so far as they are projections are subject to modifications in their implementations.

(2) Modifications made in the course of adopting a particular design of burner is done without prejudice to the credit owed the originator of the design.

(3) In the absence of adequate facilities to establish the validity of any claim made in this study, simulated tests would suffice.

(4) Local environment implies the territories defined by the boundaries of the geographical entity called Nigeria.

1.7 Research Questions:

The research sets out to as much as possible provide answers to the following questions.

1) If the success of any combustion operation depends largely on the inter-mixing of the fuel and air imputs in the proper stoichiometric ratio, will the proposed burner make provision for the predetermination of the two variables, independent of each other ?

2) Can the burner cope with the demanded load of the kiln where it is to be installed ?

3) Is there a guarantee of uninterrupted supplies of both fuel and air while the equipment is in operation ?

4) Is the safety of the operator guaranteed under all conditions of operation ?

5) For the convenience of maintenance, can the burner assembly be dismantled and re-assembled without necessarily involving the specialist/technician ?.

Chapter 2

REVIEW OF RELATED LITERATURE

2.1 Definition

Wright (1971) gave a concise definition of the burner as "the equipment for mixing fuel and air to give controlled combustion."

A fuel may be defined as any substance containing energy rich bonds such as carbon-carbon, carbon-hydrogen and hydrogen-hydrogen bonds. The commonest fuels available in Nigeria are wood, coal and petroleum based oil and gas.

Combustion refers to the rapid combination of the oxygen of the air and the combustible elements of a fuel to yield heat energy. These combustible elements include carbon, hydrogen and sulphur. The significance of sulphur as a combustible element is seen not as a source of heat but as a contaminent in the combustion process.

2.2 Function

Burners as used in industrial plants function to fulfil the purpose of firing which according to Gunther (1958) " is to convey the necessary quantity of heat due to a given fuel in the most economical manner without adversely affecting the quality " of the product of the thermal plant. In a firing operation the heat is carried by the gasses of the flame and given off as long as the temperature of the flame is higher than that of the material being processed. It is therefore impracticable to heat the material up to the flame temperature.

Although the heat transfer process can be facilitated separetely or jointly by the three processes of conduction, convection and radiation, the prevailent mode at the high temperature typical of industrial plants is heat radiation.

2.3 The Burner and Combustion Reactions

Combustion is essentially a gas phase process. The burner as the principal heat release equipment must reflect in its design the ability to carry any fuel component whether solid or liquid through the stage of gasification as a precondition for the participation of that component in the reactions. A burner by its very nature must be able to create the three conditions of time, turbulence and temperature often referred to as the three 'Ts' of combustion to susbtain the exothermic reactions culminating in combustion (Considine, 1976).

Time would be required to supply oxygen to the surface of the fuel and to create the necessary turbulence which favours what Bullavin et al (1986) would describe as " the intensive intermixing " of the fuel and air. At low temperatures, the time of chemical reactions and subsequent removal of the combustion products is considerably lower than the time needed to supply oxygen to the surface of the fuel. The reverse situation becomes obvious with reactions at high temperatures.

Once the conditions have been set, the combustion reactions begin with the ignition of the fuel in the presence of oxygen marked by the loss of the inherent moisture of the fuel usually at 105 - 110°C. At approximately 150 - 180°C, the fuel attains a temperature - the ignition point - at which the reactions become self-sustaining with the oxidation proceeding at an increasing rate. As a rule, the ignition point of a fuel is lower, the higher the amount of volatile matter evolved. Other factors that influence the ignition point of a fuel include pressure, velocity, enclosure configuration, catalytic materials, air-mixture uniformity, moisture content of the air and source of ignition. Although the supply of air in excess of theoretical requirement is necessary to guarantee a complete combustion, the excess air should be just above the theoretical requirement to avoid the loss of available heat to the stack gases.

2.4 Factors That Influence a Burner Effectiveness

An entry for the Nostrand's Scientific Encyclopedia (1976) highlighted a number of factors that influence burner effectiveness which can be summed up as follows:

1) The rate of fuel intake must cope with the load demand on the thermal plant.

2) There should be a balance of maximum saving in fuel intake against the effectiveness of the heat release with a minimum of unburnt combustibles and excess air in the product.

3) The physical size and complexity of the burner must be kept at a minimum to reduce weight, space, investments and flexibility of service conditions.

4) The design of the burner including the material used shall provide reliable operation under specific service conditions in addition to measuring up to standard of maintenance for the burner and the thermal plant.

5) Safety is paramount under all conditions of operation so there must be provisions for starting, stopping and varying fuel intakes.

2.5 The Peculiar Requirements of An Oil Burner

A burner assembly designed to operate on liquid fuels must be capable of carrying the fuel through the following steps:

1) Atomisation which is the conversion of the liquid to a finely dispersed state resembling a fog in particle size.

2) Vaporisation of the dispersed phase.

3) Mixing of the vaporised fuel with oxygen of the air.

4) Ignition of the fuel-oxygen mixture and flame stabilization.

2.6 Choosing An Appropriate Burner Design for Development

From the foregoing discussion, the criteria of efficient

fuel utility does not come into play in the choice of an appropriate burner design for development, since it is a fundamental requirement that all burners burn the fuel component efficiently.

The pertinent consideration here is the reflection of environmental peculiarities in the adoption of the technological innovation.

Durability, lpwer maintenance costs as well as the ease of repair or replacement of the hardware involved in the construction, were placed above other considerations in the selection of the appropriate burner design. Within the scope of this study, three designs were identified and to further demonstrate the researcher's arguments, one of the identified designs was carried to the next stage of fabrication.

2.6.1 The medium pressure atomiser(MPA).

Most industrial medium pressure atomisers are designed to use light fuel oil and the atomisation is achieved by the blast effect of a high velocity steam of air or steam.

In the simplified form of the MPA described by Harvey et al (1975) (see appendix A.1) the shearing effect is produced by a stream of air under a pressure of 80 in. H_2O (2.67 atm). In this design the fuel runs perpendicular to the direction of air flow for maximum shearing effect.

The problem with this type of atomiser is that a powerfu industrial blower capable of delivering about 6 to 100 cubic

feet of air per minute is almost always required to produce the tangential force that yields the atomisation. The cost involvement therefore becomes the prohibiting factor with the use of this burner at the level of the small-scale industry.

2.6.2 The pressure jet atomiser:

The typical pressure jet atomiser used in the industry has as its main feature a swirl chamber where oil injected through a number of tangential slots rotates at high speed and escapes by spreading as a thin rotating film along the orifice. A hollow conical sheet emerges at the orifice and the resulting flame takes the form of a characteristic conical shape. The pressure jet burner is the oldest and most widely used type of atomiser, apparently because of its simplicity.

Already a simplified form of this type of atomiser has been fabricated and put to use at the ceramic section of the Department of Industrial Design of the University (see appendix A.2). The good thing with the system presently in use is that, the atomisation is achieved by the combined effect of the pressure due to the gravity flow of oil and the vapour generated by the pre-heating coil that marks the heating end of the burner. By implication, no extra source of energy is reauired in generating the atomising medium.

This burner like any other technological tool has its own short-comings. Cleaning operations normally carried out by chemical means require great caution to avoid any chip on the exit edge or scratch in the bore. Apart from the problem of carbon build up, leakages resulting from prolonged usage are often associated with this type of burner. The extremely limited operating turn down (hardly beyond 1.4:1 for most pressure jet atomisers) does not promote flexibility of service conditions.

2.6.3 The assisted Pressure Jet Atomiser:

The atomiser is essentially a pressure jet tip with the a atomising slots arranged such that they inject steam or air into the root of the fuel spray cone. This design seeks to extend the limited turn down of the pressure jet atomiser by providing supplementary atomisation at low pressures.

The simplified model of the assisted pressure-jet atomiser described by Holdens (1982) (see appendix A.3) has a number of attracting features that could form the basis for a technological innovation that suits the Nigerian environment. Judging by the design given by the author, a local equivalent can be constructed employing mainly materials sampled from pipes and fittings in the plumber's shop. One other attracting feature of the model is that the burner is a complete unit free from the intricacies of mechanical control that has been the bane of our past failures in attempts to adopt technological innovations that are trully Nigerian in both material and skill input. Typical of assisted pressure jet atomisers, this model requires a blower

of a moderate size to generate the atomising air. Compared with the MPA model identified for possible adoption, the assisted pressure jet model is a far reduction in investiment. On the other hand, the cost of providing an extra source of atomising energy for the assisted pressure jet model compared with the coil burner that does not require any prime mover in the atomisation process is justified on the ground of flexibility of service conditions attainable with the former.

Chapter 3

THE RE-DESIGN AND FABRICATION

This project is essentially a re-design experiment. To establish the reliability of the new design, it is incumbent upon the researcher to cause the burner set to be fabricated and tested in a number of firing runs.

The chosen model remains the Holden's model and the steps followed in the processes of redesigning and fabricating the local equivalent constitute the next part of this discussion.

3.1 The Market Survey

This stage involved a number of field trips mainly to Sabon Gari to ascentain the available materials that could form possible inputs for the proposed burner. In the process, scrap shops as well as the plumber's shop were visited. This stage also involved price evaluations, being fully conscious of the fact that choices should be made within the realms of basic economics - a balance of need against cost.

At this stage too, the researcher had to maintain a close watch on refuse dumps and other places where junks that could serve as inputs for the experiment could be picked up. In this way a used refridgeration pipe was found useful as the oil dispesing tube.

3.2 Materials Sampled

The materials sampled were mainly steel pipes and fittings of various sizes. Other materials include

copper tubing, bolts, rubber hoses, pumping homes and clips.

3.3 The New Design

This could best be illustrated by the sketch in Appendix A4.

3.4 The Fabrication *

The Holdens model is an European based model as implied by the author's suggestion that "the parts can be bought from the local plumber or builders merchant" (Ibid). In the Nigerian context, it is imperative that a number of improvisations be made towards attaining the same goal especially in the area of materials input.

The fabrication was carried out in two stages employing the common tools used for bench work such as the vice, the hammer, hacksaw blades and files. In the process, assistance was sort from technicians mainly in the Faculty of Engineering in areas that required special skill.

3.4.1 The First Stage

This involved the fabrication of the components of the burner unit and the steps taken are as follows:

Three 63.50mm lengths of pipe of 38.25mm internal miameter (parts B, C and D) were cut out and each of the cut out parts were threaded on the two ends. Two caps (Parts A and E), threaded internally to match the cut out internally to match the cut out pipes were made available using pipe

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* Note that "mm" is the standard abbreviation for millimetre and "m" is the abbreviation for metre.

reducers. One T-junction (part G) designed to fit the 38.25mm internal diameter pipes was also put in place. One brass tube, 0.33mm long and 2mm internal diameter (Part H) was made available.

Three bolts of 38.25mm lenghts with threading (Part F) were then made available to serve as the guide of the fragile dispensing brass tubing. One 0.13mm long threaded internal diameter sucket (Part I) was perforated with holes on the threaded side with the holes running through semi-circles. This sucket was intended to serve as the air leak system. A 50.58mm by 33.25mm reducer that would link the air intake control system was then made available and an adjustable screw (Part I) was also made available to br.. g the first stage of the fabrication to an end.

4.4.2 <u>The Second Stage</u>

An eliptical hole measuring 7.62 by 5.08mm as cut in the centre of part A. Three holes were then drilled equal distances apart in part B and the holes were tapped to fit bolts (Part F) intended to hold the dispensing tube in a central position. Finally part H was braced on drilled plug to form one continuous link with the 12.70mm pipe screwed into the value that connects the burner unit to the fuel line.

3.5 The Coil Mechanism

This involved the linking up of the fuel line with a pre-heating copper coil. The instroduction of the pre-heating coil was an innovation that came into play after the first two major firings. The purpose of the coil was to give the fuel moderate pre-heating to aid the process of atomisation. The reason for contemplating on the coil is that the 2mm jet of the fuel outlet was probably too wide for good atomisation as smaller diameters of jets are known to function better in the atomisation process (Wright, Ibid).

3.6 Cost Estimates

The breakdown of the costs of labour and components of the final assembly of the burner unit (see Appendix A5) is as follows:

	Input	Cost (₦)
1.	Labour (including welding and machining)	85.00
2.	1 metre length of pre-heating coil	20.00
3.	One valve for fuel line	20.00
4.	1 metre length of steel pipe (12.25mm diameter)	20.00
5.	0.25 metre length of steel pipe (58mm diameter)	5.00
6.	0.25 metre length of steel pipe (37.6mm ")	3.00
7.	Two 58 by 37.6mm reducer	14.00
8.	Three tapping nuts	6.00
9.	One 37.6 by 12.25mm reducer	4.00
	Total =	₦177.00

Chapter 4

PUTTING THE BURNER TO THE TEST

A study of this nature cannot be assessed conclusive if the important step of operating the product of the experiment is overlooked. Putting the burner to the test will provide empirical evidences required in assessing the viability of the project, i.e. striking a balance between its successes and shortcoming.

The practical involvement was the use of the fabricated burner to fire glazed bodies in a kiln which served as the control equipment. A number of instruments including visual inspection, pyrometric cones and the glazed bodies were used to assess the operational conditions. Successes and problems resulting from the operations were noted and where possible adjustments aimed at improving the operational efficiency were made.

4.1 The Kiln as the Control Equipment

The kiln as a heated enclosure served the good purpose of ensuring a temperature rise thereby setting in motion the necessary conditions required by the researcher to have a better control over the working efficiency of his technological innovation. It is therefore desirable that some salient points about kilns be noted so as to come to terms with the operational conditions of the test burner.

Kilns that have not been fired for a long time will require between one and two hours of pre-heating before an appreciable rise in temperature is obtained. Kilns as heating enclosures have maximum temperatures which diminish with the age of a

particular kiln. Since the kiln is not a perfect heating enclosure, heat can be lost to the environment, through the escaping waste gases, cracks, pores and other outlets. A temperature climb is only possible when the amount of heat gained by the kiln is higher than the amount of heat being lost to the environment as a result of the imperfections in its functioning. The rate of heat loss increases with rising temperature. (Table 1, Appendix B shows the heat loss to waste gases with rising temperature at 20% excess air for fuel oil). A time is reached in the heating process when an equilibrium is established between heat gained by the kiln and heat lost to the environment. The equilibrium temperature which varies with burner capacity becomes the maximum operating temperature of the kiln.

The kiln used in this experiment is 0.8 cubic m. in capacity. It is a down draft kiln built some eight years ago originally for gas firing. This kiln was later adopted for firing with kerosine with the last of such firings done about a year before the commencement of this test. As it is to be expected, the kiln is no longer in its original form. Cracks and slags resulting from intermittent firings over a long period has altered its original efficiency with the attendant effect of a lowered maximum temperature obtainable for a given burner.

In a downdraft kiln, the burner is positioned at the bottom front and the flue exit is located at the bottom back of the kiln. The flame entry therefore is through the bottom and as it enters, it is deflected to the top of the kiln and pulled down through the wares with the heat in turn being vented out through the exit flue linking up the chimney.

The downdraft kiln is considered the most efficient traditional system (Harvey et al, Ibid). The design prolongs the heat stay in the kiln such that a substantial part of the heat is liberated before it finds its way out.

4.2. The Inputs Variables

4.2.1 The fuel

Two types of petroluem oils - kerosine and diesel- were used as the fuels. Distillate fuels (kerosine and diesel) do not require any form of pre-heating in storage or at the burner in normal industrial practices (Short, 1979). The purpose of pre-heating fuels is to bring the fuel to the viscosity that will promote flow and good atomisation. Since visiosity is a strong function of temperature, the temperature co-efficient serves as the indicator of the atomising viscosity of a given fuel composition.

Where it becomes necessary to pre-heat a fuel as the case is with the heavier oils, the temperature of pre-heating hardly goes beyond 104^{o}C (Considine, Ibid). The reason is that excessive pre-heating causes vapour binding with the consequence of flow interruptions and increased loss of ignition due to the carbon particles that result from premature decomposition of hydrocarbons. The incidence of deposition of carbon particles is most common with fuels of high hydrocarbon content (Gunther, 1958).

The use of the heavier oils falls outside the scope of this study since they are reserved for the "big" users and are only made available to them on contract basis because they (the fuels) have no established marketing system.

Otherwise, there is no special limitation in the choice of fuel as the volume of the combustion chamber can be varied to cope with the quantity of fuel being issued at the burner nozzle. Any increase in volume of the combustion chamber should however be kept at a minimum to ensure complete combustion at the lowest excess air ratio.

Diesel is given precedence over kerosine in kiln firings because diesel has a higher heat value compared with kerosine. The difference in their gross calorific values is reflected in their relative densities. Their specific gravities as determined by the researcher using simple laboratory methods were 0.80g/cm^3 for kerosine and 0.85 g/cm^3 for diesel. These figures agree with those often quoted for these fuels by petroleum marketers.

Kerosine is generally used as the start up fuel in oil fired kilns (Harvey et al, Ibid). This is because kerosine does not smoke at low temperatures and ignites quite easily.

4.2.2 The Air Variable

The air input served the dual purpose of partaking in the combustion reactions as well as creating the condition for combustion in its pressurised form as the atomising medium. In the process of atomisation pressurised air at 100 p.s.i (6.56 atm.) expands rapidly resulting in the breaking up of the fuel component of the mixture into particle sizes. Short (ibid) argues that the accurate maintenance of the correct fuel/air ratio is the most important single factor in ensuring good operating efficiency.

The supply of air in excess of normal requirement is

desirable to ensure complete combustion because air utilization in the burner wind box at high load distribution is not perfect. The excess air must however be kept at a minimum to prevent the incidence of reduced combustion efficiency and heat wastages in the sense that heated air will be carried away as additional sensible heat (Table 2; Appendix B shows the loss in heat content of the waste gases with increasing excess air as a percentage of the dry products).

In addition to increasing waste gas losses, air in excess of theoretical requirement reduces flame temperature. It has an adverse effect on heat transfer and kiln at atmosphere. It becomes imperative that the amount of air used in combustion processes should always be the smallest quantity that will enable the fuel to be burned in the prevailing circumstances. The carbon dioxide ratio in the waste gas is an index of the excess air in the combustion products as increasing excess air at any given temperature lowers the carbon dioxide ratio (See Table 3, Appendix B).

The trend in the industry today is to pre-heat the air using part of the waste gas heat. The heat recovery process employs a special heat exchanger called the recuperator, but the details of its operation falls outside the scope of this study. The saving in fuel when air is pre-heated to 538^{o}C for a kiln fired to 1288^{o}C is between 20 and 38% (Harvey et al., Ibid). The saving is achieved by employing a heat exchanger which permits the transfer of heat from the out-going waste gases to the incoming air required in the combustion process.

4.3 Instrumentation

4.3.1 Visual Inspection

The unaided eye plays a unique role as the oldest form of instrument at man's disposal in essessing operating conditions. Visual examination is of singular importance in the circumstances that prevailed throughout the experiment, i.e. the extremely limited facilities placed before the researcher for assessing operating conditions.

It is an established fact that flame colours could be assessed and conclusions drawn as to the heat intensity, e.g. all kinds of liquid fuels are known to form luminous flames and flame brighteness is the greatest asset in the organisation of the radiant mode of heat transfer prevalent at high temperatures.

Adept kiln operators are agreed through visual examinnation that the heat intensity of a heated enclosure could be judged as follows:

Starting red heat	-	$560^{o}C \pm 100^{o}C$
Dark red heat	-	$600^{o}C \pm 100^{o}C$
Cherry red heat	-	$700^{o}C \pm 100^{o}C$
Bright red heat	-	$850^{o}C \pm 100^{o}C$
Yellow red heat		$1000^{o}C \pm 100^{o}C$
Starting white heat	-	$1150^{o}C \pm 100^{o}C$
Glare white heat	-	$1350 - 1650^{o}C$

Source: Ezike R.N. (Ibid).

Much as there is no substitute to visual inspection in assessing operating conditions, the point has to be made that this form of assessment remains a matter of value judgement which varies with experience. In an experiment of this kind, it is necessary to resort to a more scientific means of assessing conditions of operations.

4.3.2 Glazed Bodies

Glazes as glassy coatings melted in place on ceramic bodies are prepared from given recipes and each composition has a definite melting temperature. It is part of the fulfilment of this study to heat these glazed bodies to the temperatures at which the glazes fuse on the clay bodies (Table 4 Appendix B shows the processing temperature of various ceramic bodies). Known melting temperatures of the glaze compositions could serve as indicators of temperatures attainable by the burner in association with the kiln. Glazed bodies could also be of use when assessing the effectiveness of heat circulation as it had quite often been observed throughout the experiment that glazes of the same composition placed in different parts of the kiln fused at varying times. This method of temperature sensing leaves a lot to be desired when it amounts to knowing definite temperatures arrived at in definite time.

4.3.3 Pyrometric cones (Pyroscopes)

The cones appear to be the most reliable form of temperature sensing material used in the experiment. The cones as truncated diagonal pyramids are composites of carefully selected and uniformly mixed ceramic materials which were

invariably developed from the same raw materials as the ceramic bodies and glazes. They bend or squat at definite temperatures which according to Musoke (1979), restating an earlier claim made by Sosman (1913), are indications of the "heat effect" rather than the exact temperatures.

The cones used could only sense temperatures between 1100 and 1200°C as higher number cones were not available. The intervening numbers between these cones were however not uniformly spaced so as to help the researcher monitor the rate of rise in temperature with time. One other problem encountered when cones were used as temperature sensing materials was that their squatting temperatures only served as indicators of the temperatures of the spots where they were positioned. To obtain the mean operating temperature the cones were placed mid-point in the kiln. Table 5 Appendix B shows the squatting temperatures of cones commonly used in ceramic processing.

4.4 The Principle of the Burner Operation

The fuel line terminates with a jet where the fuel flowing by gravitation comes in contact with pressurised air in the wind box. The static pressure of the atomizing air is transformed into a velocity head as the fuel/air mixture proceeds through the burner outlet. In the narrow passage that marks the burner outlet, the fuel is accelerated to a high velocity and consequently disintergrates into fine droplets as it emerges at the burner nozzle.

The burner is designed so as to favour natural caburisation as the intermixing of the air and fuel for the most part takes place outside the burner.

4.5 Starting Up a Fire

The approach at starting up a fire was arrived at empirically. The blower is switched on and the air leak closed completely. The fuel line is then opened and a lit splint is brought close to the burner nozzle to ignite the kerosine spray. As the burning process progresses with improved efficiency, the air leak is opened gradually to cope with the rate of fuel flow. After firing with kerosine for 30 to 45 minutes, diesel could then be introduced as the operating fuel.

4.6 The Test Runs

This stage was marked by a series of firings, each running for 14 hours. Observations were made and inferences drawn as a result of which the pre-heating coil was introduced and the burner air line constricted at some stage to improve the operational efficiency.

Altogether, five firing runs were carried out; three consecutive firings were done with kerosine before switching over to diesel oil as the operating fuel. Burner pulsation and poor temperature climb above 1000^{o}C necessitated the reconstruction of the air line and the use of an alternative fuel.

4.6.1 The two initial firings

Kerosine was used as the operating fuel.

Observation: The ignition posed no problem, luminosity was seen to be alright.

There were however problems of flame stability and poor temperature climb above 1000°C. There was no noticeable change in the situation after two firings.

Inference: The persistent adjustment needed to stabilize the flame was reflected in a most unsteady kiln atmosphere which in turn resulted in the poor temperature climb. A possible cause of the lack of a stable flame is the poor air adjustment of the burner.

The poor temperature climb could also be attributed to excessive heat loss to the environment by the kiln.

The possible solutions would be to improve on the kiln conservation characteristics as well as the burner efficiency. However limitations arising from the kiln was outside the scope of this study so the researcher could only focus his attention on improving the shortcomings of the burner unit.

Reconstruction: A constriction was created on the air line adjoining the burner windbox and the air leak-off system through the use of a smaller diameter pipe (see figure 5, Appendix A). A pre-heating coil was also introduced to aid the process of atomisation.

4.6.2 The third firing

The third firing was done after the minor reconstruction and introduction of the pre-heating coil as a feature of the burner. Kerosine was used as the operating fuel.

Observation: The ignition and flame luminosity were alright. The flame was fairly stable as the system could work for between 10 and 20 minutes without adjustment. The temperature climb beyond 1000°C improved considerably as cone 3 having a squatting temperature of 1140°C flattened after 11 hours of firing.

Inference: The short interval of air adjustment could be due to the sensitivity of kerosine as a light fuel to its own vapour pressure generated in the preheating coil. The effect of the vapour pressure on the fuel line increases in magnitude with thedecreasing pressure of the kerosine in the storage tank as it is being continously used up in the burning process. A possible solution could be found in the use of a denser fuel.

4.6.3 The last two firings

Diesel was used as the operating fuel. There was no significant difference in the outcome of the two firings.

Observations: The flame stability and luminosity were alright. The system could be kept working for between 30 to 60 minutes without adjustment. The temperature climb beyond improved significantly.

The only problem encountered was the incidence of carbon deposits in the fire box.

Inference: The carbon particles were generated through the pre-mature decomposition of hydrocarbons in the pre-heating coil as a result of excessive pre-heating. This feature is common with fuels of high carbon concentration (Gunther, ibid).

The problem of carbon deposition could be helped by pushing the pre-heating coil farther away from the burner nozzle to avoid its contact with direct flame. To eliminate the incidence of carbon deposition totally would require further studies.

Chapter 5

FINDINGS AND GENERAL CONCLUSION

5.1 Findings

5.1.1 Stoichiometric Ratio:

The stoichiometric ratio of the fuel and air was determined empirically by varying the air supply system to cope with the amount of fuel intake at any given moment. Smoky flame with reduced luminosity signified reduction (see Plate I, Appendix C). On the other hand, excessive air supply could result in an unstable flame formation at a significant distance from the burner nozzle, (See plate III, Appendix C).

5.1.2 Burner Capacity:

The burner capacity when measured as the amount of fuel used over time was found to be approximately 5 litres per hour. The exact amount used over time is a matter that should be reserved for further studies. The problems faced in the test process such as power failure, the effect of the pre-heating coil, the unsteady atmosphere at the initial stages of the firings and the use of an alternative fuel, all militated against the determination of the exact burner capacity.

Under the same circumstances, the turn down ratio which is the ratio of the maximum capacity to the minimum operating capacity could not be determined.

5.1.3 Maximum operating temperatures:

Since the cones used measured only 1200°C and below, it was difficult to know the maximum temperatures of the different firing operations. The consistent cone number that was used throughout the firing was cone 3 having a squatting temperature of 1140°C.

To be sure that the temperature of stone ware was attained an extra time of three hours was allowed for heating after 1140°C temperature had been attained. There is therefore need for further studies on the maximum operating temperature of the fuel in association with the kiln used in this experiment.

The wares fired to stone wares during the tests indicate that the maximum operating temperature is in the upwards of 1250°C. By implication, the burner is suitable for most ceramic processings (See Table 4, Appendix B also See Plate IV Appendix).

5.1.4 Safety of operation:

For all practical purposes, the burner proved a safe operating device as the shut-off valve is conveniently placed at a distance free from excessive heat radiation (See Plate V; Appendix C). The operation of oil burners require constant supervision by the operator. To make his work less taxing, there is the need to develop a self-proportioning device that will always measure out the correct fuel intake against the air intake. Such a device should be able to shut-off the fuel line completely in the case of power failures. This could serve as an accident prevention measure.

5.1.6 The Coil Mechanism as a Special Feature of Burner

The pre-heating coil could serve a very useful purpose in times of power failure as the fuel vapour generated in the coil could make the burner function without any form of assistance. In this case, kerosine is the prefered fuel and the coil has to be moved close to the fire box for maximum effectiveness of heat transfer.

The researcher put the coil to maximum advantage when power failure was experienced during one of the firing schedules.

5.2.0 General Conclusion

On the whole, the burner could be judged a success as its operation was not marked by serious trouble shooting and the unit is cheap to maintain as the burner can be easily dismantled for cleaning and the parts could be fabricated in time of repairs.

Inspite of the achievements of this study, its objectivity will be in question if known shortcomings are not brought into focus. These shortcomings will provide the framework for further research that could lead to drastic improvements in the burner efficiency in addition to bringing about predictable operating conditions.

Areas that will require immediate attention as already highlighted would be the determination of operating turn down, the exact burner capacity and automatic proportioning of fuel/air ratio.

One other area that demands equal attention is the need to optimise the advantages tied with the pre-heating coil as a special feature of the burner.

Finally, a study of this nature cannot be said to be exhaustible. What the researcher has done in fulfilling the objective of this study is to make his little impact felt in the on-going debate geared towards creating a standard for assessing the test results of burner operations. According to Considine (1976) erroneous interpretation of the test results has led to performance predictions that could not be substantiated. The most persistent differences in opinion has been in the area of flame appearance, the length of time, the unit is operated under minimum load and the evaluations of potential harzards associated with deposits that may occur during the low test loads.

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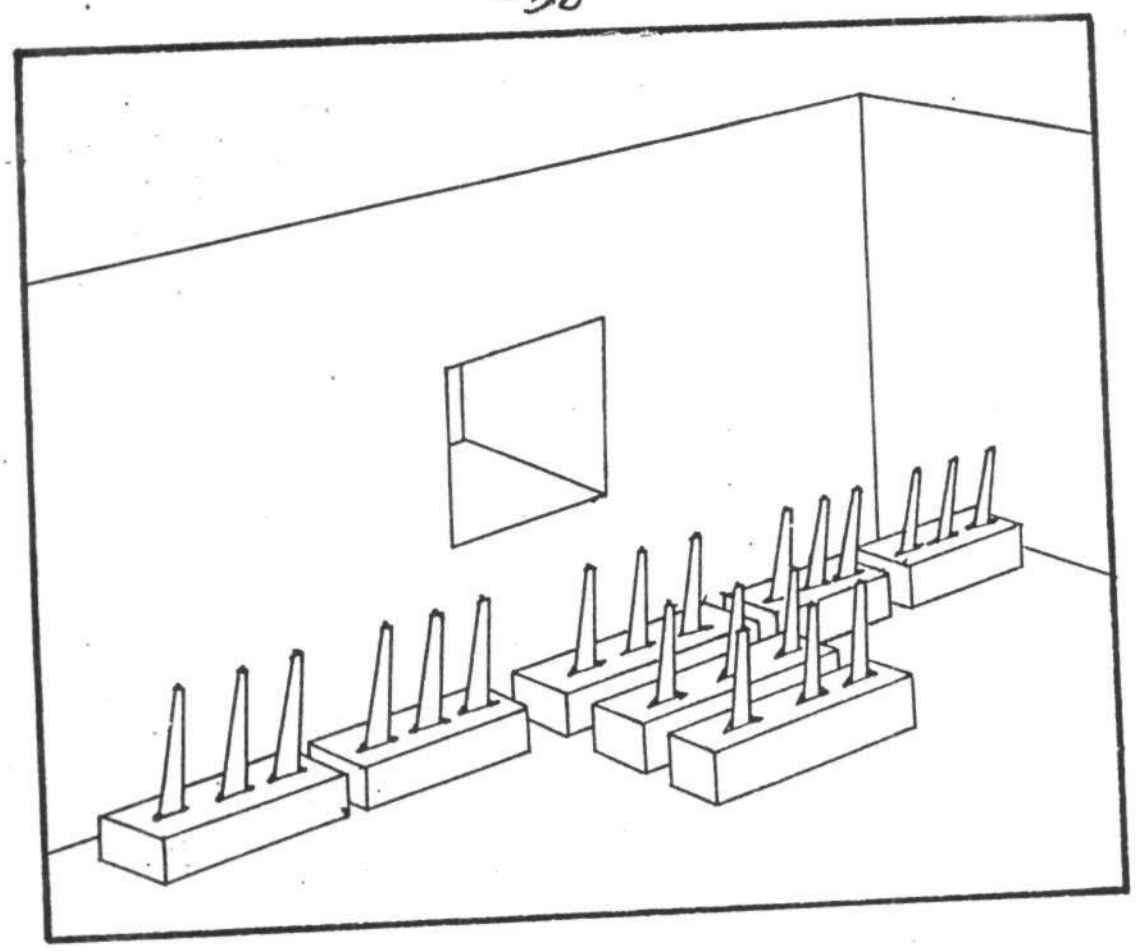


Figure 6: The typical arrangement of cones in a kiln

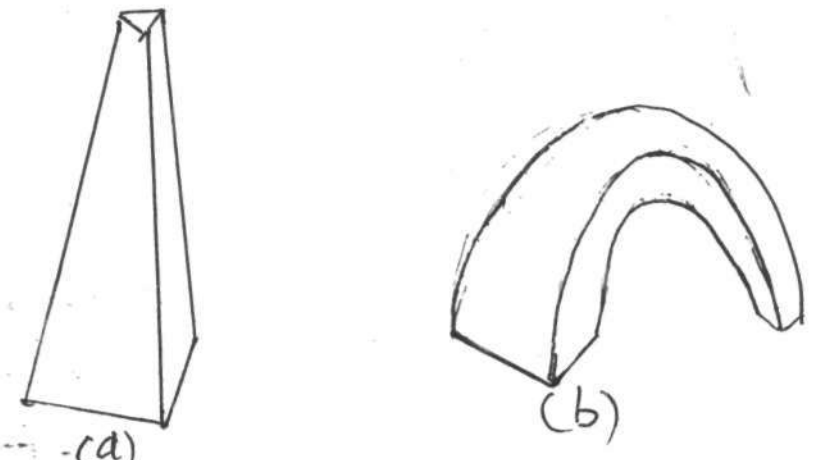


Figure 7: The profile of a cone (a) In an erect position, (b) Bent under the influence of heat.

APPENDIX B

Table 1: Relation between Gross Calorific Value and Specific Gravity:

Specific gravity (relative density) 15/4°C	Gross calorific value Catories per	
	Gramme	Cm^3
0.80	11,050	8,840
0.81	11,010	8,920
0.82	10,970	8,990
0.83	10,920	9,060
0.84	10,870	9,130
0.85	10,830	9,100
0.86	10,780	9,270
0.87	10,730	9,340
0.88	10,690	9,410
0.89	10,640	9,470
0.90	10,590	9,540
0.91	10,540	9,590
0.92	10,490	9,660
0.93	10,440	9,710
0.94	10,340	9,770
0.95	10,340	9,830
0.96	10,290	9,880
0.97	10,240	9,940
0.98	10,190	9,990
0.99	10,140	10,040
1.00	10,090	10,090

Source : Allen R.L.(1971) Diesel and Turbine Fuels

APPENDIX B

Table 2: Approximate Heat loss of waste gas from dry product of combustion as a percentage of the net calorific value at 20% excess air.

Waste gas temperature C	Loss as % Heat in fuel
100	4.0
200	9.0
400	19.0
600	29.0
800	39.0
1000	49.0
1200	59.0

Table 3: Heat loss with increasing excess air as a percentage of the dry product of combustion.

Waste Gas CO_2%	Excess Air %	Loss in Heat %
13.0	20	49
11.0	40	56
9.7	60	64
8.5	80	71.5
7.6	100	79.0
6.9	120	86.5

Source: Short, W. (1979). Fuel Economy Handbook.

Table 4: Ceramic Products and their processing Temperatures (Enamelling 750°C)

Product	Biscuit Temperature	Glaze Temperature
Earthen Ware	1140 - 1170°C	1040 - 1080°C
Bone China	1240 - 1260°C	1040 - 1080°C
Stone ware	900 - 1000C	1250 - 1300°C
Forecelaine	900 - 1000C	1300 - 1450°C

Source: Green, D. (1963). Pottery Glazes.

Table 5: Pyrometric cone numbers and bending points.

Cone number	Bending point°C
022	600
021	650
018	710
016	750
014	815
012	855
010	900
08	940
06	980
04	1020
02	1060
1A	1100
3A	1140
5A	1180
7	1230
11	1280
13	1320
15	1380
17	1435
18	1486
27	1520
32	1610
36	1710



Plate I: Reducing atmosphere



Plate II: Neutral Atmosphere



Plate III: Oxidizing Atmosphere



Plate IV: The peep hole for assessing progress of the firing process.



Plate V: The proof of the safety of operation put into consideration in the design of the burner.



Plate VI: The Burner in perspective.





Plate VII: Composite pictures of some fired wares.