PROPOSAL OF CERAMIC COURSE ART DEPARTMENT
UNIVERSITY OF EL-FATAH, LIBYA

by

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A Thesis Submitted to the Faculty of the
DEPARTMENT OF ART
In Partial Fulfillment of the Requirements
For the Degree of
MASTER OF ARTS
In the Graduate College
THE UNIVERSITY OF ARIZONA

1981
STATEMENT BY AUTHOR

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ACKNOWLEDGEMENTS

I wish to extend thanks to my thesis committee, Dr. Jean C. Rush, Dr. Maurice K. Grossman, and Dr. Robert L. Cardinale for their assistance and advice during the preparation of this thesis. Sincere thanks and gratitude to my major advisor, Dr. Jean C. Rush and Dr. Maurice K. Grossman for their constructive advice, guidance, and help throughout the graduate program.
TABLE OF CONTENTS

Page

LIST OF ILLUSTRATIONS ........................................... vii
LIST OF TABLES ....................................................... ix
ABSTRACT .............................................................. x

CHAPTER

I. INTRODUCTION ...................................................... 1

Course Curriculum .................................................. 3
  Properties of Ceramic Materials ......................... 3
  Technology of Ceramic Production ....................... 4
  Methods and Techniques ...................................... 5

II. CERAMIC PLASTIC MATERIAL .................................... 6

Natural Clay .......................................................... 6
Geological Classification ......................................... 7
  Primary Clay ..................................................... 7
  Secondary Clay ................................................... 7
Types of Clays ...................................................... 8
  Kaolin Clay ..................................................... 8
  Ball Clay ........................................................ 9
  Earthenware Clay ............................................... 9
  Stone-ware Clay ................................................ 10
  Fire Clay ........................................................ 10
  Bentonite Clay ................................................ 11
  Raku Clay ....................................................... 11
  Slip Clay ......................................................... 12
  Local Clay ......................................................... 12
Clay Properties ................................................... 13
  Dry Strength ..................................................... 13
  Dry Shrinkage ................................................... 13
  Plasticity ........................................................ 14
  Clay Body Formula ............................................. 15
Preparing Your Own Clay ......................................... 17
Clay Analysis ........................................................ 18
  Electron Microscope ........................................... 19
  X-ray Diffraction ............................................... 19
### TABLE OF CONTENTS—Continued

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>III. CERAMIC NONPLASTIC MATERIALS</td>
<td>23</td>
</tr>
<tr>
<td>Flux Materials</td>
<td>23</td>
</tr>
<tr>
<td>Refractory Materials</td>
<td>24</td>
</tr>
<tr>
<td>IV. TECHNIQUES OF CLAY FORMATION</td>
<td>26</td>
</tr>
<tr>
<td>Hand Building</td>
<td>26</td>
</tr>
<tr>
<td>Coil Method</td>
<td>26</td>
</tr>
<tr>
<td>Slab Method</td>
<td>27</td>
</tr>
<tr>
<td>Throwing on the Potter's Wheel</td>
<td>29</td>
</tr>
<tr>
<td>Molding</td>
<td>32</td>
</tr>
<tr>
<td>Plaster Mold</td>
<td>32</td>
</tr>
<tr>
<td>Hump Mold</td>
<td>36</td>
</tr>
<tr>
<td>Press Mold</td>
<td>36</td>
</tr>
<tr>
<td>Newspaper Mold</td>
<td>36</td>
</tr>
<tr>
<td>Slip-Casting</td>
<td>39</td>
</tr>
<tr>
<td>V. DECORATION AND TOOLS</td>
<td>43</td>
</tr>
<tr>
<td>Marble Decoration</td>
<td>43</td>
</tr>
<tr>
<td>Carved Decoration</td>
<td>44</td>
</tr>
<tr>
<td>Piercing Decoration</td>
<td>44</td>
</tr>
<tr>
<td>Impressed Decoration</td>
<td>47</td>
</tr>
<tr>
<td>Adding Decoration</td>
<td>47</td>
</tr>
<tr>
<td>Decal Decoration</td>
<td>49</td>
</tr>
<tr>
<td>Wax-Resistance Decoration</td>
<td>49</td>
</tr>
<tr>
<td>Engobe Decoration</td>
<td>50</td>
</tr>
<tr>
<td>Glaze Decoration</td>
<td>51</td>
</tr>
<tr>
<td>Transparent Glaze</td>
<td>51</td>
</tr>
<tr>
<td>Matt Glaze</td>
<td>51</td>
</tr>
<tr>
<td>Colorant Glaze</td>
<td>51</td>
</tr>
<tr>
<td>Overglaze</td>
<td>55</td>
</tr>
<tr>
<td>Frit Glaze</td>
<td>55</td>
</tr>
<tr>
<td>Ash Glaze</td>
<td>56</td>
</tr>
<tr>
<td>Raku Glaze</td>
<td>56</td>
</tr>
<tr>
<td>Salt Glaze</td>
<td>57</td>
</tr>
<tr>
<td>Crystal Glaze</td>
<td>58</td>
</tr>
<tr>
<td>Reduction Glaze</td>
<td>60</td>
</tr>
<tr>
<td>Glaze Application</td>
<td>62</td>
</tr>
<tr>
<td>Spraying</td>
<td>62</td>
</tr>
<tr>
<td>Dipping</td>
<td>62</td>
</tr>
<tr>
<td>Pouring</td>
<td>62</td>
</tr>
<tr>
<td>Painting</td>
<td>63</td>
</tr>
<tr>
<td>Tools</td>
<td>63</td>
</tr>
</tbody>
</table>

TABLE OF CONTENTS—Continued
TABLE OF CONTENTS--Continued

VI. KILNS AND FIRING

<table>
<thead>
<tr>
<th>Types of Kilns</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electric Kilns</td>
<td>67</td>
</tr>
<tr>
<td>Gas Kilns</td>
<td>68</td>
</tr>
<tr>
<td>Oil-Fired and Solid-Fuel Kilns</td>
<td>69</td>
</tr>
<tr>
<td>Solar Kilns</td>
<td>69</td>
</tr>
<tr>
<td>Kiln Design and Construction</td>
<td>70</td>
</tr>
<tr>
<td>Fuels</td>
<td>72</td>
</tr>
<tr>
<td>Wood</td>
<td>72</td>
</tr>
<tr>
<td>Oil</td>
<td>72</td>
</tr>
<tr>
<td>Coal and Coke</td>
<td>73</td>
</tr>
<tr>
<td>Gas</td>
<td>73</td>
</tr>
<tr>
<td>Olive Oil Cake</td>
<td>73</td>
</tr>
<tr>
<td>Rubber</td>
<td>73</td>
</tr>
<tr>
<td>Kiln Building Materials</td>
<td>73</td>
</tr>
<tr>
<td>Refractory Materials</td>
<td>73</td>
</tr>
<tr>
<td>Heat Transfer</td>
<td>77</td>
</tr>
<tr>
<td>Kiln Stacking</td>
<td>77</td>
</tr>
<tr>
<td>Firing</td>
<td>78</td>
</tr>
<tr>
<td>Bisque Firing</td>
<td>78</td>
</tr>
<tr>
<td>Glaze Firing</td>
<td>81</td>
</tr>
<tr>
<td>Salt Firing</td>
<td>82</td>
</tr>
<tr>
<td>Crystalline and Luster-Glaze Firing</td>
<td>82</td>
</tr>
<tr>
<td>Oxidation and Reduction Firing</td>
<td>83</td>
</tr>
<tr>
<td>Temperature Control</td>
<td>85</td>
</tr>
<tr>
<td>Kiln Cooling</td>
<td>87</td>
</tr>
<tr>
<td>Safety Precautions</td>
<td>88</td>
</tr>
</tbody>
</table>

VII. CONCLUSION. 92

APPENDIX A: ANALYSIS OF COMMON CLAYS AND CHEMICALS 93

APPENDIX B: TABLE OF CERAMIC RAW MATERIALS 95

APPENDIX C: END POINTS OF ORTON PYROMETRIC CONES 99

SELECTED BIBLIOGRAPHY 103
<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Diffraction From Crystal Planes According to Bragg's Law</td>
<td>20</td>
</tr>
<tr>
<td>2.</td>
<td>Coil Building</td>
<td>28</td>
</tr>
<tr>
<td>3.</td>
<td>Slab Building</td>
<td>30</td>
</tr>
<tr>
<td>4.</td>
<td>Throw Building</td>
<td>33</td>
</tr>
<tr>
<td>5.</td>
<td>Plaster Molding</td>
<td>37</td>
</tr>
<tr>
<td>6.</td>
<td>Press Molding</td>
<td>38</td>
</tr>
<tr>
<td>7.</td>
<td>Newspaper Molding</td>
<td>40</td>
</tr>
<tr>
<td>8.</td>
<td>Marble Decoration</td>
<td>45</td>
</tr>
<tr>
<td>9A.</td>
<td>Carved Decoration</td>
<td>46</td>
</tr>
<tr>
<td>9B.</td>
<td>Piercing Decoration</td>
<td>46</td>
</tr>
<tr>
<td>10A.</td>
<td>Impressed Decoration</td>
<td>48</td>
</tr>
<tr>
<td>10B.</td>
<td>Adding Decoration</td>
<td>48</td>
</tr>
<tr>
<td>10C.</td>
<td>Wax Resistance</td>
<td>48</td>
</tr>
<tr>
<td>11A.</td>
<td>Ribbon Tools</td>
<td>64</td>
</tr>
<tr>
<td>11B.</td>
<td>Hole Cutters</td>
<td>64</td>
</tr>
<tr>
<td>11C.</td>
<td>Loop Tools</td>
<td>64</td>
</tr>
<tr>
<td>11D.</td>
<td>Drill Tools</td>
<td>64</td>
</tr>
<tr>
<td>11E.</td>
<td>Sculpture Tools</td>
<td>65</td>
</tr>
<tr>
<td>11F.</td>
<td>Scrapers</td>
<td>65</td>
</tr>
<tr>
<td>11G.</td>
<td>Wood Modeling Tools</td>
<td>65</td>
</tr>
<tr>
<td>Figure</td>
<td>Description</td>
<td>Page</td>
</tr>
<tr>
<td>--------</td>
<td>------------------------------</td>
<td>------</td>
</tr>
<tr>
<td>11H.</td>
<td>Potter ribs</td>
<td>65</td>
</tr>
<tr>
<td>11I.</td>
<td>Raku Tong</td>
<td>66</td>
</tr>
<tr>
<td>11J.</td>
<td>Calipers</td>
<td>66</td>
</tr>
<tr>
<td>11K.</td>
<td>Clean-Up Tools</td>
<td>66</td>
</tr>
</tbody>
</table>
## LIST OF TABLES

<table>
<thead>
<tr>
<th>Table</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Clay Body Formula</td>
<td>16</td>
</tr>
<tr>
<td>2. Summary of Refractory Materials</td>
<td>25</td>
</tr>
<tr>
<td>3. Glaze Formulas</td>
<td>52</td>
</tr>
</tbody>
</table>
ABSTRACT

This paper is an attempt to propose a ceramic art course specifically for Libyan students in The Department of Art, El-Fatah University who pursue their higher education as art majors. What may add to the potentiality of this proposal is that it is the first ever attempted as part of a formal curriculum. It is hoped that it will provide a solid ground for students to benefit from courses as such to open various avenues to this traditionally old, but unfortunately brand new informal education.

The entire course is a combination of theory and practice in ceramics. The emphasis is put evenly on both parts. It is so because no one part can be successful without the other. In other words, each is complimentary to the other, and neither can be denied its contribution to the final outcome of any ceramic work.
CHAPTER I

INTRODUCTION

At the present time a ceramics curriculum does not exist within the Libyan educational system. The college student who wishes to study at the undergraduate level even the rudiments of this growing field must travel to foreign universities. And in the application process he will often discover that he is deficient in prerequisite training for courses at other universities since he has received no precollege background in ceramics. A partial explanation for the lack of formal ceramic training in Libya, where the art of pottery has long been practiced at the popular level, can be found in the fact that there are hardly any persons in the country who are qualified to design and implement the necessary curriculum.

It is the purpose of this paper to propose a curriculum design for a ceramics course at the university level. This design will then serve as the foundation for a full degree program in ceramics at the University of El-Fatah in Tripoli, Libya. The course herein proposed will be structured as a one-hour lecture per week on the technology of material followed by five hours of studio work per week. The emphasis in the model will be on process since the technology has little function if not applied properly.

The need for skilled ceramists in Libya arises from the projected construction in the country of five ceramic factories in the
near future. One of the greatest problems developing nations face is that of supplying the labor required for modern industry. If there is to be real economic progress in the country, skilled as well as unskilled labor must be supplied to the new factories. Certainly, one university course will not provide all the necessary expertise, but this course in addition to other kinds of art design courses, it is hoped, will expand the number of people who can enter management-level positions in the new factories. These people will then be able to train and encourage other students who are interested in ceramics. The development of a full curriculum will be facilitated if a substantial number of Libyan students realize the importance of and fulfillment to be gained from ceramics.

The fact that a trained indigenous population would be better than the importation of foreign skilled labor in order to provide greater national income has been established. It is necessary to consider the financial burden of training people abroad for the new industry. The government must presently send ceramic students to other countries whereas the cost of living is usually much higher than it is in Libya. At the same time the government helps these students with transportation and living expenses as well as college fees. All of these expenses are a tremendous drain on the national economy that a curriculum at the local university could prevent. The funds now being sent abroad could be recycled into the Libyan economy to be used for further development.
Course Curriculum

The proposed curriculum will include these three objectives: 1) to provide information concerning the various properties of the different types of plastic and nonplastic materials; 2) to describe the technology (kilns, tools, etc.) utilized in ceramic production; and 3) to provide instruction in the methods and techniques of ceramic construction and finishing.

Properties of Ceramic Materials

The design of the proposed ceramics course will begin with an overview of ceramic plastic materials, i.e., clays, that provide a historical and geological perspective. This perspective will include a brief statement on the many fields in which clay is being utilized today. Then, the student will learn to classify the different types of clay. Incorporated into the section on clay classification will be a discussion of the chemical properties of different types of clay, e.g., refractoriness, plasticity, etc. Before introducing the student to the physical and chemical analysis of clay, the clay body formula is discussed. This formula is very important to the beginning ceramist because it demonstrates how to mix plastic and nonplastic materials properly in order to achieve more creative affects.

Because clay is composed of many different types of minerals that react in discrete ways to various chemical agents, the ceramist must understand the structure of the clay he is working with. In the section on clay analysis, the student will learn about the new methods of analyzing clay, e.g., the use of petrographic microscopes,
spectrometry, x-ray diffraction, to name a few. Each method will help the student to better understand specific chemical processes that are taking place within the clay under varying conditions. Knowledge of these processes aids the student in deciding what types of clay to mix together and how they should be fired.

When the student has obtained a firm grasp of the elements of the ceramic plastic materials, the nonplastic materials are introduced. These materials, such as alumina, silica, dolomite, grog, and feldspar, fall into two categories: refractory and fluxes. Refractory materials are added to clay to improve heat resistance whereas fluxes provide a crystalline structure inside the clay body that strengthen the clay during firing.

Technology of Ceramic Production

At this point, the student should have mastered the conceptual aspects of ceramics. He is now prepared to learn the techniques involved in producing finished ceramic objects. This part of the curriculum falls into three categories: (1) the techniques of forming objects from clay, (2) decoration, and (3) firing the objects. While learning the forming techniques, e.g., hand building, the student is also beginning to learn which of the various ceramic tools to use in each process. Afterwards, he discovers more tools that will aid him in obtaining different effects such as carving, piercing, or impressing. Once the clay is designed, formed and bisque fired, the glaze must be applied. The student is taught various types of glazing and what will happen to the glaze during firing.
Methods and Techniques

The last phase in the ceramic process, firing, is extremely important in producing a durable object; therefore, it is necessary for the student to learn very carefully each step in sequence. He must remember which temperature is best for each type of clay body as well as the differences of kilns since each type has a certain kind of advantage. In order to correctly control the firing procedure, the student must be thoroughly familiar with individual types of firing and how to execute them. Finally, throughout the firing process it is necessary to teach the student certain safety precautions in order to avoid personal injuries as well as damage to the ceramic object.

Upon completion of this course it is hoped that the students will encourage others to become involved in requesting that a ceramics program begin at El-Fatah University. These students under the supervision of a ceramic specialist can then teach other beginning students. As the demand grows for the new skill, the hiring of foreign instructors will become feasible and the course can then be expanded.
CHAPTER II

CERAMIC PLASTIC MATERIAL

This chapter will discuss the various classifications of ceramic plastic materials, i.e., clay; numerous types of clay; clay properties; preparation of clay; and clay analysis.

Natural Clay

Clay is formed by minerals (silica, alumina, and others) that are derived from decomposed parent rocks such as granite, gneiss, and other feldspathic rocks, as a result of weather action that took place millions of years ago when rocks were exposed to heavy rains and wind. These parent rocks were broken down into mica, quartz, feldspar, and other minerals. After that some of these decomposed minerals were left in place while others were carried away to be deposited deeper within the earth's surface. This latter group turns into a plastic state when mixed with water and becomes durable and hard when exposed to heat. However, this group occupies most of the surface of the earth. Rhodes (1973) and Dickerson (1974) state that deposits of silica and alumina make up about 75 percent of the planet's surface. Clay is characterized by plasticity, strength, color, and high refractoriness, as well as by high durability after firing. Clay is studied on an ongoing basis by experts in the fields of chemistry, geology, mineralogy, soil science, ceramic technology,
pottery, and civil engineering in order to understand its importance to humanity. Clay is a vertebral column of both the ceramics industry and art pottery. As a raw material it can be found in the production of paint, paper, and cosmetics. The uses to which clay may be put depend upon the type of clay. Eight types of clay as well as the two major groups to which they belong will be discussed in this paper.

**Geological Classification**

Geologically, clay can be classified into primary and secondary groups.

**Primary Clay**

Primary clays were formed at their place of origin, i.e., at the same location where the parent rocks originated, rather than at a location where they would have been moved by weather action. The primary clays occur in areas where granite rocks were formed millions of years ago. They can be found in pockets near the earth's surface or deep underground. These clays are characterized by their high refractory or heat-resistant qualities, their lack of impurities such as iron, and their low degree of plasticity.

**Secondary Clay**

Secondary clays, on the other hand, have been transported from the original source by water and settled elsewhere. This kind of transportation gives these clays certain physical properties, such as impurities (which means that some organic as well as other types of materials have been mixed with the clay), and the fact that the clay
particles can be broken down into very fine particles. The secondary clays are very common and can easily be recognized by yellow, green, buff, brown, and grey colors. They are highly plastic, but much less refractory than the primary groups. The two groups of clays then are inversely related with respect to refractory and plastic characteristics.

**Types of Clays**

This section will discuss numerous types of clay: kaolin clay, ball clay, earthenware clay, stone-ware clay, fire clay, bentonite clay, raku clay, slip clay, and local clay. For further information on some common clay analysis, see Appendix A.

**Kaolin Clay**

Kaolin clay, a very common but important clay, takes its names from the Chinese word kao-Lin which means "high ridge" (Norton, 1974 and Dickerson, 1974). The discovery of this clay revolutionized the production of art pottery and industrial ceramics. Kaolin clay can be distinguished by its white color before and after firing. Kaolin is indispensable in all high fire white ware and in the production of pure white porcelain to promote high-fire quality because of its own purity and high refractory qualities. Nevertheless, this type of clay has low plasticity and dry strength which makes it difficult to form if not combined with some more plastic type of clay. Kaolin can be divided into two subcategories: residual and sedimentary. The sedimentary kaolin has less purity than the residual type
as a result of transportation. Besides ceramics kaolin has other important industrial uses, e.g. paper production.

**Ball Clay**

Ball clay, so called because English miners cut it into small balls when they found particles of it during mining excavations, has different characteristics than those of kaolin clay. It has a fine particle size, is high in plasticity, high in shrinkage, and changes in color after firing from dark grey to white, cream, buff, or light grey depending upon the amount of impurities that the clay contains. (The impurities in this type of clay might be iron oxide, calcium oxide, or magnesium oxide.) The vigorous role played by these organic materials is seen clearly when one understands that the clay in a raw state has such a difference in colors as green, brown, or grey, all of which burn away in firing. As a result of excessive shrinkage, ball clay can never be used by itself in order to avoid cracking but is a very important ingredient in all ceramics ware in promoting plasticity, dry strength, high-firing qualities as well as other effects.

**Earthenware Clay**

Earthenware clay is characterized by its low-fire temperature and its red color. This type of clay is both plentiful and easily identifiable. It contains a high percentage of impurities such as iron and other flux substances which allow it to fuse at low temperatures that range from 800°C to 900°C. These impurities, which make the clay weak and too porous, also give it, in general, a reddish-brown
color in the raw state and light-red to light-brown after firing. It is often used as a raw material in the production of tiles and other types of functional ceramics. Earthenware has great utility for ceramics because of its plasticity and dry strength in addition to the ability to be mixed with other clays in order to manipulate its capacity to resist heat.

Stone-ware Clay

A hardness or stone-like quality after firing is the probable derivation of the name of this type of clay. This type is considered a secondary clay with a natural color of yellow, buff, and grey which turns to a lighter color after firing. It is useful and adaptable to almost any clay body because it has a right plasticity, a good dry property, a middle-range firing, and a sufficiency of flux material. The ceramic artist and industry are attracted to this type of clay because it has a very workable wheel-throwing as well as hand-building mechanical strength and adapts easily to ceramic sculpture. Stoneware articles have a variety of domestic uses, such as tableware, floor tiles, and sewer pipe.

Fire Clay

Fire clay has the ability to resist heat and has a vitrifying point which ranges from 1200°C to 1500°C. It is a primary clay with less plasticity and low amounts of fluxes. Fire clay is very useful in clay structure for promoting high temperature as well as shock resistance. Rhodes (1973) divided this type into two groups: flint
and high alumina clays. Fire clay is an indispensable ingredient for kiln furniture and refractory materials such as fire brick.

Bentonite Clay

Bentonite clay resulted from the ash of volcanic eruptions. It has quite different physical properties from other clays such as high plasticity which makes this clay too sticky so that it cannot be used alone. Bentonite clay is primarily used to ensure the right amount of plasticity and dry strength for any other clay lacking this property.

Raku Clay

Raku clay results from a mixture of any type of plastic clay with a high percentage of nonplastic and refractory material (having the right plasticity and dry strength). Raku clay is used to achieve various effects, such as a low-firing temperature and the prevention of sudden heat or cold shock. According to Finnlynggaard (1973), Chojiro, a Chinese of Korean potter (1615-92) is the first one who made ceramic objects from this type of clay. It later came to be called "Raku". An increasing cost of fuel and materials as well as its unusual color and surface are the main reasons that many ceramic artists have turned to the use of this clay in an attempt to save money and time while achieving a very creative affect at the same time. Raku clay can be prepared from earthenware clay or stoneware clay and the right amount of grog and fire clay or sand.
Slip Clay

Slip clay is a naturally liquid clay made from mixing dry clay and water in the right amounts ranging from 30 to 60 percent of water to the weight of dry clay. This mixture can be made from one type of clay or by mixing with other types of clay or other materials to achieve a different result, such as deflocculation when a percentage of sodium silicate is added to sodium carbonate (see slip-casting) or to function as glazes, by adding fluxes (see fluxes) or different oxides such as iron oxide, cobalt oxide, chrome oxide, manganese oxide, copper oxide, and nickel oxide to achieve colors when used as a coat decoration.

Local Clay

Ghawassem clay and Jeferen clay are both plastic clays. Their natural color before firing ranges from green to yellow and turns light brown after firing, because both contain less than one percent of iron. They are workable either alone or through mixture with other clays. For example, mixing 25 percent from either of these clays with 10 percent ball clay, 12 percent China clay, 21 percent dolomite, and 31.5 percent silica will result in a good clay body that can withstand temperatures above 1140°C. The wet-dry shrinkage of these clays ranges from seven to eight percent. However, most of the local clays contain soluble salt and sometimes its existence can cause problems. According to Memmott (1971) this problem can be resolved by adding 0.5 percent of barium carbonate.
Clay Properties

The following clay properties are discussed in this section: dry strength, dry shrinkage, plasticity, and clay body formula.

Dry Strength

Clay strength is one of the most important dry properties since a sufficient strength will insure the clay article to be carried safely through the firing process. Dry strength is different from clay to clay depending on the clay plate structure. However, Ryan (1978) indicates that dry strength can be improved by the addition of more plastic clay such as ball clay or small amounts of montmorello-mite. Also, the strength can be tested by extruding rods of the plastic material, drying these under specified conditions, then supporting a rod between two knife-edges, and applying an increasing load to the center of the rod until it breaks.

Dry Shrinkage

Clay needs water in order to be plastic. At the same time, it requires the loss of water to become dry. Dry shrinkage is a result of evaporation of water from clay. This evaporation results in a whole decrease in volume; however, the percentage of this shrinkage is different from clay to clay and depends on plasticity and the amount of nonplastic ingredient in the clay. So the shrinkage increases as plasticity increases. The percentage of shrinkage can be expected to range from zero to 20 percent or more. Therefore, excessive shrinkage can cause dry wares to crack and warp. Hence it is very important
to discover the shrinkage percentage of the clay in order to avoid these problems by performing this simple test: pick a piece of plastic clay, make it flat, roll it into a slab with a thickness of approximately one centimeter, mark two notches on the surface of this slab, measure the distance between the two marks, and write it down. Then, take the second measurement after the piece has completely dried, and third measurement after the piece has been fired. The difference between the first and second measurements is the dry shrinkage and the difference between the first and third measurements is the after-fire shrinkage. As Andrews (1928) and Ryan (1978) point out the percentage of shrinkage can be found by following this formula:

\[
\frac{\text{Wet length} - \text{dry length}}{\text{dry length}} \times 100 = \text{percentage of shrinkage}
\]

This formula is called **linear shrinkage**. Dry shrinkage may be determined by taking either linear or volume shrinkage.

**Plasticity**

Plasticity is a major property of clay. It is indispensable to the development of a satisfactory formation. Plasticity is a unique characteristic which gives clay the ability to be squeezed, rolled, pressed and built by hand. It also allows clay to stand up in the throwing process and to hold any shape that is given to it. This property is different in degree from clay to clay. Plasticity has nothing to do with chemical composition, but has to do rather with
physical properties which are directly related to the amount of water which may be added or present in the clay, particle size, and the percentage of organic material and bacteria in the clay. Plasticity is still not completely understood, and it is often difficult to measure and scientifically define this property. There is one fairly simple method of measuring plasticity though (Dickerson, 1974; Memmott, 1971; and Nelson, 1978). A pencil-sized coil of clay can indicate whether clay is plastic or not if the coil is put around the finger without a crack showing. The absence of cracks means that the clay has enough plasticity. On the other hand, there are attempts to improve clay plasticity by adding a high plasticity clay such as bentonite, ensuring the correct moisture, or controlling the presence of nonplastic materials in clay, but Hunt (1974) suggests that "plasticity can be increased by the addition of one-half cup of vinegar, one-half package of yeast, or a can of beer" (p. 35).

Clay Body Formula

Clay body is a mixture of plastic ceramic materials such as clay types and nonplastic ceramic materials such as silica, feldspar, grog, and talc mixed together to achieve different ceramic affects such as color or low- and high-fire temperature. The results (matur­ing temperature, color, shrinkage, absorption rate and workability) from experimentation with different types of clay body formulae for Cone 0.5, Cone 1, Cone 3, Cone 5, Cone 8, and Cone 10 are listed in Table 1 found on page 16.
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<td></td>
<td>25%</td>
<td>20%</td>
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</tr>
</tbody>
</table>

**Kentucky ball clay**

- 25% 18% 25%
- 30% 20% 25%
- 30% 35% 35%
- 25% 25% 20%
- 20% 20% 25%
- 35% 25% 20%
- 30% 20% 25%
- 25% 20% 25%
- 18% 20% 25%
- 25% 30% 30%

**Tennessee ball clay**

- 25% 18% 25%
- 30% 20% 25%
- 30% 35% 35%
- 25% 25% 20%
- 20% 20% 25%
- 35% 25% 20%
- 30% 25% 20%
- 40% 35% 35%
- 50% 60% 70%
- 70% 60% 65%
- 20% 26% 25%
- 13% 12% 11%

**O.M.4. ball clay**

- 30% 20% 25%
- 30% 35% 35%
- 30% 25% 20%
- 20% 20% 25%
- 15% 15% 10%
- 5% 14% 15%
- 35% 35% 40%

**Lincoln fire clay**

- 20% 18% 10%
- 15% 20% 20%
- 10% 18% 10%
- 5% 10% 5%
- 13% 12% 15%
- 10% 10% 15%
- 12% 11% 10%
- 15% 10% 13%

**Ohio stoneware clay**

- 20% 30% 25%
- 30% 25% 20%
- 40% 38% 35%
- 50% 60% 70%
- 70% 60% 65%
- 20% 26% 25%
- 13% 12% 11%

**Ohio red clay**

- 18% 15% 14%
- 12% 12% 15%
- 20% 15% 11%

**E.P. kaolin clay**

- 25% 35% 30%
- 38% 35% 39%
- 30% 25% 20%
- 20% 20% 25%
- 15% 15% 10%
- 5% 14% 15%
- 35% 35% 40%

**Lincoln fire clay**

- 10% 17% 15%
- 10% 10% 5%
- 30% 30% 29%
- 10% 13% 10%
- 10% 13% 15%

**Frit - K.3**

- 18% 15% 14%
- 12% 12% 15%
- 20% 15% 11%

**Fire clay**

- 10% 17% 15%
- 10% 10% 5%
- 30% 30% 29%
- 10% 13% 10%
- 10% 13% 15%

**Talc**

- 10% 17% 15%
- 10% 10% 5%
- 30% 30% 29%
- 10% 13% 10%
- 10% 13% 15%

**Jorden clay**

- 20% 20% 25%
- 22% 20% 25%
- 20% 20% 25%
- 35% 30% 25%

**Bentonite clay**

- 5% 3% 5%

**Cornwall stone**

- 5% 3%

**Nepheline syenite**

- 2% 3%

**Potash feldspar**

- 35% 35% 40%
- 10% 10% 10%

**Fine grog**

- 5% 5% 5%

**Red iron oxide**

- 12% 13% 13%
- 14% 13% 13%

**Total compound**

- 100 100 100
- 100 100 100
- 100 100 100
- 100 100 100
- 100 100 100
- 100 100 100
- 100 100 100
- 100 100 100
- 100 100 100
- 100 100 100
- 100 100 100
- 100 100 100
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- 100 100 100
- 100 100 100
- 100 100 100
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- 100 100 100
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- 100 100 100
- 100 100 100
- 100 100 100

**Shrinkage after firing**

- 3% 1% 0%
- 1% 2% 1%
- 6% 4% 3%
- 4% 4% 5%
- 4% 3% 3%
- 5% 4% 4%
- 5% 5% 3%
- 4% 5% 5%
- 8% 9% 11%
- 10% 11% 11%
- 8% 12% 12%
- 12% 8% 8%

**Opsorbation**

- 18% 17% 19%
- 21% 22% 23%
- 17% 21% 23%
- 18% 18% 17%
- 20% 20% 19%
- 20% 19% 20%
- 18% 17% 17%
- 18% 17% 17%
- 18% 16% 15%
- 4% 4% 4%
- 1% 1% 1%
- 8% 8% 8%
- 6% 5% 4%

**Color after firing**

- light red
- white
- white
- light red
- light red
- light red
- dark brown
- dark gray
- light gray
- light gray

**Workability**

- good
- good
- good
- good
- good
- good
- good
- good
- good
- good
- good
- good
- good

**Texture**

- smooth
- smooth
- smooth
- smooth
- smooth
- smooth
- rough
- smooth
- smooth
- smooth
- smooth
- rough
- smooth
- smooth
Preparing Your Own Clay

Replacing preformed clay can be done by digging and preparing your own clay. To dig and prepare your own clay does not require very complicated equipment, and it is an easy and interesting way to learn a basic ceramic procedure. The first step, i.e., looking for a good location of a continuous clay source, can be accomplished by looking over geological maps that show clay locations or by observing the exposed strata in road excavations and valley edges. Colors and crack patterns make clay easy to identify. The second step is to dig a sufficient amount of clay. The third step is to test the quality of the clay in a laboratory, if one is available. Remove coarse impurities, such as organic materials and stones like limestone (CaCO₃) and gypsum (CaSO₄·2H₂O) from small amounts of clay because they cause problems during the firing process. Bauleke (1977) observed that gypsum can endanger the clay with breakage during firing and calcite can cause bits of clay to break off after firing. Dry the clay in the sun, grind it, screen it through a screen (30 to 60 mesh), mix it homogeneously with the right amount of water, knead it, roll it into a slab about 10 by 5 centimeters and one centimeter thick, allow it to dry, and fire it until very hard. Look at the color of the clay because color will help to classify the clay into high, middle or low for firing processes. For example, nearly white and light colors are more refractory, which means that the clay can be fired over 1200°C. Some clays which contain calcium carbonate must be fired at lower temperatures inspite of their light color. Buff, cream, and grey
colors can be fired in a middle range from 1100°C to 1200°C. Red and brown-colored clay should be fired in the lower range of 900°C to 1100°C. After the test to determine whether it stands alone or needs to be mixed with other clays or materials (see "Clay Body Formula") to achieve the intended purpose, the final step is to prepare a sufficient amount for the present project by determining which type of clay to use. There are various methods of mixing clay, such as dry mixing, slip mixing and plastic-state mixing. If the clay is already in a workable form, it can be prepared by following these steps. Fill several containers with clay, add enough warm water to cover all the clay, then let this mixture sink for a minimum of one week, adding water when necessary. Water will break the clay particles into fine particles. A day later the mixture should be stirred to form a slip which will enable the clay to pass through a sieve (60 mesh) in order to remove foreign materials. Then, let excess water evaporate or pour off the water. Later pour the mixture over dry plaster plates or on canvas exposed to the sun in order to dispose of the moisture. After several hours, the clay will be ready for mixing together manually or by machine. Finally, it should be divided into suitable amounts and placed in tied plastic bags for storage.

Clay Analysis

Clay is seldom found pure; it is mixed with different types of minerals. These minerals have an affect on clay properties, so that it is important for the ceramist to be aware of clay analysis and some methods which are used for this purpose in order to achieve the
intended form. Among the many techniques used to identify minerals of a given material complex, electron microscope and x-ray diffraction are the most recent and most efficient and accurate methods applied to this purpose. Petrographic microscope, electron diffraction, thermal analysis, and infrared spectrometry are other techniques that are used in mineral analysis and minerological composition.

Electron Microscope

The electron microscope, a combination of lenses for creating magnified images of minute objects, provides information about the size, shape, and structure of materials in which there is a degree of organization such as clay particles. Similar to visible light, a beam of electrons is refracted when it passes from one area to another having a different density of magnetic lines of force.

X-ray Diffraction

Minerals of the soil, and especially those constituted of the clay faction, determine both the physical and the chemical properties of soil. An understanding of these mineral properties is essential to a meaningful evaluation of clay in relation to classification and engineering properties. One method of analysis used is x-ray diffraction which identifies minerals and determines their properties in polycomponent systems. Crystalline structures are characterized by a systematic and periodic arrangement of atoms or ions in a three-dimensional way. The distances between planes of atoms specific to each crystal characterize the crystalline species. The phenomenon
of x-ray diffraction involves the scattering of x-rays by atoms of a crystal and the reinforcement of scattered rays in definite directions away from the crystal. Per Bragg's law ($N\lambda = 2d \sin \theta$), reinforcement of scattered rays is quantitatively related to the distance $d$ of the separation of atomic planes, Fig. 1. Since no two minerals have exactly the same interatomic distances in three dimensions, the angles at which diffraction occurs will be distinctive for a particular mineral. The interatomic distances within a mineral crystal then

![Diagram of diffraction from crystal planes](image)

Figure 1. Diffraction from crystal planes according to Bragg's law $N\lambda = 2d \sin \theta$.

- $\lambda$ = wavelength
- $d$ = interplanes spacing
results in a unique manner of diffraction maxima which serves to identify that mineral. The value of 2θ is available directly from the chart of a direct-recording x-ray spectrometer. In the event that several crystal species are present in the sample to be analyzed, each component species registers its own diffraction maxima independently on a photographic film or plate that is geometrically so placed in relation to the sample as to allow determination of the angle of diffraction and subsequent calculation of the interatomic spacing of d. To ensure detection of mineral species in clay samples by means of x-ray diffraction analysis, the concentration of individual species is distinctly advantageous. Removal of flocculating and aggregate-cementing agents, such as alkaline earth carbonates, organic matter, oxides and hydroxy-oxides of iron, oxides of manganese, amorphous silica and alumina should be accomplished in order to obtain efficient dispersion of clay particles prior to size fractionation in order to improve the x-ray diffraction quality of segregation samples. The intensity of diffraction from a particular mineral is a function of its concentration, crystal size, and crystal perfection. Fine particles are characterized by yielding weaker diffraction intensities than do larger particles. Accordingly, it is especially important that samples be separated according to size and analyzed separately. Qualitative identification of minerals may be accomplished by either a direct comparison of diffraction patterns of unknown samples of minerals with a pattern obtained from known mineral samples or by measurement of diffraction-spacing and comparison with known spacing.
of standard minerals. The Hanawalt tables (1938) or the STM card files are available references for mineral species identification.

In order to determine the concentration of minerals in a sample being analyzed, the intensities of diffraction must be related to the number of corresponding diffraction planes which aids in estimating quantitatively present minerals.

The principle factors that influence diffraction intensities in addition to the aforementioned findings and concentrations are particle size, crystal perfection, chemical composition, variations in sample packing, crystal orientation, and amorphous substances.
Most ceramic objects are made of a mixture of plastic materials and nonplastic materials. There are a variety of nonplastic materials, and these materials have varying effects on the clay and glazes when added to the clay body. The most important effect is to render objects either more or less heat-resistant. Thus, nonplastic materials can be divided into two major groupings, fluxes and refractories, according to the type of heat-resistance effect produced.

**Flux Materials**

Flux is a substance which decreases the fusion temperature point. In other words, it is a material usually added to a clay body in order to enable it to fuse more readily during firing. The flux material forms a kind of glass which connects articles thereby strengthening the body of the substance when it is fired at normal temperature. Some clay bodies already contain enough natural flux to ensure the formation of the glass substance. There are the five basic fluxes: 1) Feldspars are an important group of minerals used as flux because they form glass if heated to a sufficient temperature either together or with other types of substances. Worrall (1969) reports that the most effective fluxes are those that contain the alkali oxide (Na₂O, K₂O, or L₂O), lime (CaO) and magnesium (MgO).
For the ceramic industry the most important are:

a) Potash feldspar = (orthoclase) $\text{KALSi}_3\text{O}_8$.

b) Soda feldspar = (albite) $\text{NaALSi}_3\text{O}_8$.

c) Lime feldspar = (anorthite) $\text{CaAL}_2\text{Si}_2\text{O}_8$.

2) Nepheline syenite is also used as a flux. 3) Cornwall stone is very common England. Norton (1974) states that this flux is a partially decomposed pegmatite containing albite, orthoclase, and small amounts of kaolin and flourides. 4) Bone ash is ground calcined animal bones that is used as a flux in clay body and glazes. 5) Talc is an insoluble mineral that works very actively as a flux for ceramic objects and as a source of magnesium for clay bodies.

**Refractory Materials**

Refractory materials are used in the construction of kilns, kiln furniture, and different types of ceramic objects because of their ability to withstand high temperatures without loss or deformation. The most common refractory materials are alumina, silica, grog, and fire clay. Ryan (1978) has written a summary about other refractories, their formulae type, and melting points. (See Table 2 on page 25.)
Table 2  
Summary of Refractory Materials  

<table>
<thead>
<tr>
<th>Material</th>
<th>Type</th>
<th>Approximate Melting Point</th>
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<tbody>
<tr>
<td>Silica SiO₂</td>
<td>Acid</td>
<td>1710°C</td>
</tr>
<tr>
<td>Clay Al₂O₃·2SiO₂·H₂O</td>
<td></td>
<td>1710°C</td>
</tr>
<tr>
<td>Alumina Al₂O₃</td>
<td></td>
<td>2050°C</td>
</tr>
<tr>
<td>Mullite 3 Al₂O₃·2SiO₂</td>
<td>Neutral</td>
<td>1810°C</td>
</tr>
<tr>
<td>Graphite</td>
<td></td>
<td>3700°C</td>
</tr>
<tr>
<td>Chromium oxide Cr₂O₃</td>
<td></td>
<td>2430°C</td>
</tr>
<tr>
<td>Zirconium oxide 2rO₂</td>
<td></td>
<td>2720°C</td>
</tr>
<tr>
<td>Magnesium oxide MgO</td>
<td>Basic</td>
<td>2800°C</td>
</tr>
<tr>
<td>Calcium oxide CaO</td>
<td></td>
<td>2570°C</td>
</tr>
<tr>
<td>Barium oxide BAO</td>
<td></td>
<td>1920°C</td>
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CHAPTER IV

TECHNIQUES OF CLAY FORMATION

From the earliest time potters have used different methods such as coil, slab, throwing, and molding to afford expression in clay. In this short explanation of different methods, details about every method will not be provided because every person should speak his own language with the clay in order to express himself most effectively.

Hand Building

This section presents two types of hand building, the coil method and the slab method, as well as illustrations of both methods.

Coil Method

The coil method has been used since antiquity to build any desirable form. It is a very simple and useful method for large pieces. Coiling provides a wide range for creative ability. To construct a coil-built form, these requisite steps should be followed:

1) Choose a piece of plastic clay and roll it with a rolling pin or flatten it by hand into a suitable thickness in order to use it as a base for the projected form.
2) Select another piece of clay and roll it backwards and forwards with the full plane of the hands to form a satisfactory thickness and length of coil.

3) Score the edge of the surface of the base and moisten it with slip clay.

4) Attach the first coil to the edge of the surface of the base and slightly push it down and join it carefully to the base.

5) Place the second coil on the top of the first coil and with a molded tool or your finger, join the second to the first from inside.

6) Add six or seven coils, slightly on the outside or inside in the same way as before to make the form grow larger or narrower.

7) Determine the desired texture for the surface of the form and allow the form to dry.

(See Figure 2.)

Slab Method

The slab method is an interesting and flexible technique for sculpture, because objects can be constructed with a minimum of effort while construction of a variety of forms is possible. To construct a form with the slab technique a design should be drawn, a sufficient amount of plastic clay selected, and the place where the slab will be rolled covered with fabric in order to avoid the clay's sticking to the surface. Working with this technique is not difficult and can be performed by rolling the plastic clay into the right thickness using either a rolling pin or a slab roller machine. Cut the slab into the
Figure 2. Coil Building
number of pieces needed for the desired design, allow them to dry until they are able to stand without collapsing, score the edges that are to be joined together, wet these edges with slip clay, then join them together carefully to form the sculpture. Do not forget to reinforce the corners with coils to prevent their breaking apart. For a large slab construction it is preferable to roll silk screen on one side of the slab. (See Figure 3.)

Throwing on the Potter's Wheel

Throwing is the method of producing symmetrical hollow forms. This type of construction should be done on a potter's wheel. Moreover, throwing on the wheel is rather difficult for the beginner because it requires a high degree of skill. Thus a great deal of practice is necessary for success with this technique. As Hamilton (1974) states, there is no one way to throw, because these processes have been used at least since the third millennium, B.C. Each thrower then must develop his own method, but there are still standard steps to be followed. The throwing process can be successfully accomplished by concentrating on these steps:

1) Choose the required amount of plastic clay.

2) Knead it thoroughly to avoid trapped air and shape it into a ball form.

3) Place the ball of clay in the center of the wheel head.

4) Place your hands around the clay and apply pressure on it until you feel that the clay is steady and well balanced.
Figure 3. Slab Building
Figure 3. Slab Building—Continued
5) Make an opening in the clay with your fingers for a thick, short clay wall.

6) Place one hand inside and the other on the outside of the object and squeeze the clay walls between your fingers to raise the walls to a satisfactory height and thickness.

7) Press gently with your fingers from inside and outside the clay until the desired object has been formed.

8) Cut the base with a metal wire and leave the form until it becomes leather-hard, then trim the rim and the base.

(See Figure 4.)

Molding

Molding is another way to produce or reproduce various ceramic objects. There are four major types of molding: plaster, hump, press and newspaper. The hump mold and press mold are not very complicated, but the plaster mold can be very involved so the following description will emphasize that type.

Plaster Mold

To make a plaster-casting mold, the figure should be modeled from a preselected design. Then, the model should be placed on the plaster slab with a pencil-mark outline through the center of the model. Decide how many pieces will be needed for the mold in order to avoid undercutting since it will be impossible to remove the model from the mold without some distortion. The separation lines should be made earlier, and along these separation lines a clay wall about
Figure 4. Throw Building
Figure 4. Throw Building—Continued
three centimeters high should be set so the separating walls are now all in place. The casting box is set around the edges of the plaster slab and clay walls. Press the clay, pushing the walls tightly against the sides of the casting box. The part of the model to be done first should be sprayed with oil. Prepare a pan of plaster, spoon the plaster into the corners and on the top of one part of the model, then pour plaster on that part until the plaster reaches the end of the casting box and clay walls. Level the top of the plaster with a paint scraper and let the plaster set. After the plaster hardens, move to another side of the model which will make connection with the plaster, remove the clay wall between the two sides, and trim the shoulder of the plaster to a smooth surface. In the plaster shoulder dig out two or three key-holes, spray that part, and plaster the shoulder. Apply the plaster on the top of that part in the same way. Continue with the same procedure until all the parts have been finished. Remove the casting box, turn the mold upside down, trim the plaster shoulder, and dig out three or four key-holes. At least one hole, and perhaps another, should be left through which slip clay will be poured into the mold. This can be done by setting one or more clay coils on the top of model in the places where the hole should be. The last piece of mold will be held in place. Finally, the pieces should be separated and the model carefully removed. With soft plaster fill in any holes and scrape the inside surface with sandpaper until it is smooth. Put all the pieces together again by fastening them with a heavy rubber band to make the mold ready for pouring. Pour slip clay
into the mold and remove the clay when it has dried to a plastic con-
dition (see Slip Casting and Figure 5).

Hump Mold

The hump mold is a one-piece mold and can be made from plaster, plastic, or stone. When the mold is ready, a slab of plastic clay is dropped over it, then pressed to conform to the mold. Any decoration can be placed on that surface. When the clay is leather-hard the excess clay should be cut and the edges should be trimmed.

Press Mold

The press mold is very widely used in industry, especially for large shapes. It is also easily adapted to small-scale production. First make a model from clay. With a clay slab build the required height and then leave a space around the model. Pour plaster over the model and allow the plaster to dry. Remove the clay model and leave the plaster mold until it becomes dry. Prepare some plastic clay and press it into the (negative space) of the mold. Trim off any excess clay with a knife, and remove the clay when it becomes leather-hard. (See Figure 6.)

Newspaper Mold

Newspaper can replace plaster in molding. The advantages of using this material are the decrease in expenses, less time consumed in performing the operation, and the ease of production. The first step in this procedure is to create or choose a preformed model from clay or some other material. Prepare an adhesive substance by mixing
Figure 5. Plaster Molding
Figure 6. Press Molding
a suitable amount of wheat flour and water, heating until the substance gains the consistency of glue. In order to prevent the paper from sticking to the model surface, the model should be sprayed with oil. Small pieces of papers (10 x 15 cm) are moistened with the prepared adhesive substance and applied to the model surface. This process is then repeated until the desired thickness (two millimeters) is obtained. The mold is sun- or oven-dried. When the paper is dry enough the mold is cut into one or more pieces to separate it from the model. Finally, the cut pieces are reapplied in order to reset the model. The clay preparation is achieved by wedging, kneading, and rolling it into a desirable slab thickness. It is then cut into a small slab. Slabs are applied adjacent to each other along the surface of the paper mold until the complete set is attained. It is advisable to set the edges of the slabs with slip clay in order to reinforce the joints. The surface should then be patted until smooth. Finally, allow the set to dry. (See Figure 7.)

**Slip-Casting**

A slip is a mixture of clay and water used for pouring into molds in the mass production of ceramic objects. During this process the water which is in the slip is gradually absorbed through the porous mold leaving a layer of clay which gradually builds up over the entire internal wall surface of the mold. If a hollow cast is desired the slip should be left in the mold until the desired thickness is achieved, then the excess slip should be poured out. The mold must be left until it is dry enough to remove easily.
Figure 7. Newspaper Molding
Figure 7. Newspaper Molding—Continued
To achieve a successful casting some points should be considered. Keep in mind that an ordinary mixture of clay and water does not behave like a true liquid because, as Cowely (1978) points out, the individual clay particles have a static electrical charge that makes them stick and draw together in groups or flocks. Clay particles, if not vigorously stirred, will settle down; then clay suspension may appear very viscous and not give a good casting. In this situation, clay slip needs a chemical treatment to achieve deflocculation in order to keep clay particles separated from one another. This can be achieved by adding substances such as sodium silicate and sodium carbonate. These substances may be used singly, but are frequently used together. The percentage of these substances should range from 0.3 percent to one percent of the clay weight. The effects of these substances are different from clay to clay so it is important to test the affect of these substances. Deflocculation substances have a disadvantage that many people ignore. As Worrall (1956) reports, these substances affect the mold, in that it may not last too long and must be changed from time to time. The final point to be made is that the mold will leave marks and other rough spots on the surface of the ware which should be smoothed out carefully during the leather-hard stage with a damp sponge.
CHAPTER V

DECORATION AND TOOLS

The term decoration can be applied to anything that is added to, applied to, or cut off from the surface of the object in order to achieve richness of the surface, movement, light and shadow, variation of texture, lines, tone, color, or specific shapes. The decoration methods vary from culture to culture and from person to person depending upon different visual experiences, creativity and wealth of design vocabulary. Some of the basic methods of decoration will be described in this section.

Marble Decoration

Marble decoration has been used by many ceramic artists to affect the texture of marble after the article is bisque-fired. This technique is not difficult, and needs only clays with two or more contrasting colors that are slow dried to avoid cracking and underfiring problems. The clays should be cut into slices, stacking up the contrasting sliced colors of clays, then wedged and kneaded in preparation for forming. This process can also be accomplished by rolling a slab from clay of one color, cutting slices with different colors, then putting these slices on the surface of the slab and rolling this mass into the desired thickness of slab before forming. On the other hand, an inlaid technique can be used to give the same
texture by making the form from one clay color then, while in the leather stage, carving the surface, filling the carving with one or more contrasting clay colors, allowing it to become leather-hard, and scraping the surface. (See Figure 8.)

**Carved Decoration**

Carved decoration has a long history dating back thousands of years. The carving technique is very attractive because it gives the surface a contrast of dark and light. However, this technique requires special tools and takes a great deal of time to perform. The effect can be achieved by carving either lines of different width and depth, or negative and positive areas, or even both when the form is in the stage suitable for carving. (See Figure 9.)

**Piercing Decoration**

Piercing decoration is different from the others in that it involves making small holes in the form. This technique requires skill in design as well as patience. Piercing may affect the function of the form if it was intended for carrying liquids, nevertheless, the advantage of this type of decoration lies in the fact that it provides the form with a uniquely graceful and beautiful look. The technique was famous and very popular several centuries ago when the Islamic ceramists used it to make a mesh in the main opening of containers for drinking water in order to keep out any impurities and to allow for a slow flow when pouring water. Later, the same technique was applied to decorate other forms such as bowls and for
Figure 8. Marble Decoration
Figure 9. Carved and Piercing Decoration
A. Carved       B. Piercing
lattice work on houses or mosques in order to achieve an intricate network of tiny holes. For success in working with this technique, the clay should be in a leathery stage for easy cutting. If the clay is too hard, the piercing may cause cracks; on the other hand, if the clay is too soft the cut may not be clean; thus, the form could be destroyed. Moreover, care should be taken that the walls are not too thick. Sharp cutting tools are always preferable in the piercing process. (See Figure 9.)

Impressed Decoration

People, animals, and plants leaving imprint traces in the sand or mud may have led ancient ceramists to apply imprinted decoration on ceramic forms. The technique of pressing objects into clay is very easy to accomplish and has a wealth of possibilities. Special tools or skills are not required for this technique. Instead, one uses materials with different textures such as fabrics, plant leaves, shells, or anything that will stamp a pattern in the clay. These materials should be harder than the soft clay in order to leave a firm impression on the clay. Pressing the materials on with a rolling pin will make a better impression. (See Figure 10.)

Adding Decoration

Adding decoration is another very interesting technique and is performed by making a design on the surface of the clay form while adding separate clay elements according to the design, e.g., applying clay coils or slabs to the surface of the clay form. Each piece can be
Figure 10. Impressed, Adding and Wax Resistance Decoration

A. Impressed
B. Adding
C. Wax Resistance
firmly pressed so that it will adhere to the surface. This type of technique has two major prerequisites: first, the area to be decorated should be coated with slip clay in order to ensure that the coils or slabs adhere to the surface, and, secondly, the form should be soft rather than leather-hard in order to prevent the clay from separating when the additions are being made. (See Figure 10.)

Decal Decoration

A decal is a type of printed transfer that is used as a decoration for ceramic objects. The decal is printed on specially prepared paper to form films that can be transferred when the paper is soaked in water and the paper releases the image onto the ceramic surface. Actually, this technique is as simple as passing a low-fire Engobe (China painting) through a silk screen onto ceramic decal paper sheets and coating them with a clear burning ceramic varnish. Kaplan (1975) states that during a subsequent low temperature firing, the varnish film burns off while the China-painted image fuses with the glaze and becomes an integral part of the surface.

Wax-Resistance Decoration

Wax resist is basically a paraffin wax or beeswax which is treated by heat to form a liquid. This liquid is then applied over the surface of the object as free brush work or according to a drawn design. The function of this liquid is to prevent any slip, glaze or oxide colorants from adhering to waxed areas, but rather to untreated surfaces in order to achieve a contrast in color between the
body of the article and the glaze applied. Wax resist can be applied to ceramic objects in various stages: leather-hard, bisque, unfired glazed surfaces. For efficient work wax should be kept in a liquid form during use. Wax resist does not have any affect on the objects since it burns away in the firing. For the same function, latex rubber can be used because it is easy to apply and peel off; mistakes are easier to correct. (See Figure 10.)

Engobe Decoration

Engobe is a solution of clay and water or fluxes such as feldspar and water. To achieve variation in color different percentages of metallic oxides are added. This solution has widespread use as coat decoration for clay forms in order to change the color of the form or part of it. Engobe can be applied to clay objects in various stages, such as wet, leather-hard, dry, and bisque. But in the dry and bisque stage the engobe sometimes peels away from the surface of the body because of the difference in shrinkage rates. However, Shafer (1976) and Nelson (1978) suggest that a solution for this problem is to reduce the amount of clay and replace it with calcined clay, feldspars, silica, and fluxes. Hamilton (1974) describes three essential qualities for an engobe: 1) it must shrink during drying at the same rate as the form to which it is applied, 2) it must expand and contract at the same rate as the form during the firing cycle, and, 3) it must be of the desired color and texture. For successful work with engobe, it is preferrable to use the same clay body in the
solution and make the coat neither thin nor thick. Engobe is very attractive if it is covered by a transparent or semitransparent glaze, or applied over glaze.

**Glaze Decoration**

Glaze in general is a combination of substances such as silica, fluxes, oxides, and alumina. Silica forms a glass, fluxes aids melting, and alumina holds the glass in place. All these substances, if they are applied to clay forms and treated by heat until a sufficient temperature is reached, will give a glass coat over the surface of the form. The glazed surface is appealing to the ceramist to be used as a decorative element. In addition, it helps render ceramic articles impervious to water and makes them easier to clean. For formulas on glaze composition see Table 3. Also see Appendix B for ceramic raw materials.

**Transparent Glaze**

Transparent glaze is a smooth, shiny coat of glass through which all material beneath it can be seen.

**Matt Glaze**

Matt glaze is a smooth surface with neither shine nor transparency due to the presence of undissolved particles which obstruct light from passing through. This glaze can be prepared either by introducing zinc, calcium, barium or titanium or by increasing the content of both alumina and silica. Nelson (1978) states that matt glaze can be formed either by adding an excess of alumina or by
<table>
<thead>
<tr>
<th>Glaze Raw Materials</th>
<th>Matt</th>
<th>Crystal</th>
<th>Reduction</th>
<th>Raku</th>
<th>Ash</th>
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<tr>
<td></td>
<td>Cone 9-10</td>
<td>Cone 9-10</td>
<td>Cone 9-10</td>
<td>Cone 04-05</td>
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<td>2</td>
<td>1</td>
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<td>3%</td>
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<td>Zinc oxide</td>
<td>9%</td>
<td>11%</td>
<td>23%</td>
<td>26.40%</td>
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<tr>
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<td>50%</td>
<td>5%</td>
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<td></td>
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<td>56%</td>
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<td>50.23%</td>
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*Add percentage of metallic oxides for color.
substituting barium carbonate for some of the flux in the glaze. Dickerson (1974), Fraser (1974), Norton (1970), and Ruscoe (1974) define this type of glaze as a crystalline glaze although the crystals are not largely formed.

Colorant Glaze

Colorant Glaze refers to various colors and tones that can be achieved in glaze by the addition of metallic oxides such as iron, manganese, chromium, cobalt, copper, nickel, etc., to the dry weight of glaze. There is no relation between the color of glaze before firing and after firing, but for successful color different tests should be made to determine the exact percentage of oxides. Ruscoe (1974) lists a summary of the minimum and the maximum percentages of oxides as follows:

1) Antimony oxide (Sb$_2$O$_3$) gives weak whites . . . 10-20%

2) Antimoniate of lead (pb$_3$ (SbO$_4$)) in lead glazes gives naples yellow at temperature up to 1050°C . . . . . . . . 5-10%

3) Chromium oxide (Cr$_2$O$_3$) produces an opaque green coloration which is rather changeable, i.e., yellow and red in some lead-type glazes, and pink when in combination with tin . . . . . . . . 1-3%

4) Cobalt carbonate (COCO$_3$) and cobalt oxide (CO$_3$CO$_4$), the most powerful of pigments, gives blue and in the presence of magnesium, the color becomes purple. It does not burn away . . . . . . .0.5-2%

5) Copper carbonate (COCO$_3$) and copper oxide (CuO) in lead glazes yields grass green; in alkaline glazes the carbonate gives
turquoise and blue. When reduced in a suitable glaze copper-reds will ensue. Fluxing ........................................ 1-5%

6) Inlmenite (ferrous titanate) \((\text{FeO}.\text{TiO}_2)\) gives iron coloration and areas of spots and specks ........................................ 1-7%

7) Iron Compounds are used in many forms: ferric oxide \((\text{Fe}_2\text{O}_3)\), ferrous oxide \((\text{FeO})\), ferroso-ferric oxide \((\text{Fe}_3\text{O}_4)\), and others. A wide range of colors are produced from iron, according to the nature of the glaze used and the method of firing. When oxidation firing takes place, warm creams, yellows, red-browns and blacks emerge. In reduction firings, the warm colors become cool, and celadon greens and blues are possible ........................................ 1-10%

8) Iron chromate \((\text{Fe}_2\text{O}_3\text{Cr}_2\text{O}_3)\) produces grey .................. 1-3%

9) Manganese carbonate \((\text{MnCO}_3)\) and manganese oxide \((\text{MnO}_2)\) give brown in lead glazes and purple in alkaline glazes. When mixed with cobalt a violet color will develop. Fluxing ........................................ 2-10%

10) Nickle oxide \((\text{NiO})\) colors tend to be dull and uncertain grey is usually produced ........................................ 1-3%

11) Potassium bichromate \((\text{K}_2\text{Cr}_2\text{O}_7)\) is used to produce orange and red in lead glazes \((900^\circ\text{C})\). It is soluble and used as frit. 1-10%

12) Rutile \((\text{TiO}_2)\), a colorant which does not dissolve, gives brown specks and streaks. It is a titanium-bearing iron ........................................ 2-10%

13) Titanium oxide \((\text{TiO}_2)\) gives whites and cream ........................................ 5-10%

14) Tin oxide \((\text{SnO}_2)\), the much-used opacifier from ancient times, gives soft snowy whites, semi-opaque at 5% and opaque at 10%.
15) Uranium oxide \((U_3O_8)\) depleted is used to give flame-colored oranges to reds in soft lead glazes \ldots 2-7\%.

16) Vanadium pentoxide \((V_2O_5)\), depending on the nature of the glaze and the temperature and firing conditions can produce a variety of colors such as yellow with tin, blue-grey to black of reduced..5-10%.

17) Zirconium oxide \((ZrO_2)\) compounds give white opacity. It is refractory but extra amounts are required \ldots . up to 15%.

18) Cadmium and selenium are used to produce orange and red glazes at low temperatures, 980 - 1080°C. The colors are fugitive if over-fired and it is usual to buy prepared glazes.

Overglaze

Overglazes are low-fire, prepared colors such as enamals and china paints, applied on the top of glaze surface in various ways. These colors then fuse and become durable over the glaze of objects as a result of heat treatment. Overglazing technique opens the way for a wide range of low temperature colors. For a powdered color mixture, oil or turpentine are usually used as a medium.

Frit Glaze

Frit glaze is a melted combination of raw glaze materials which are usually added to the glaze. Frit as it is defined by Rhodes (1973) is a glass which has been melted, quenched, and ground to a powder ready to add as an ingredient to glazes or enamels. The necessity for using frit is to obtain certain valuable alkaline oxides in an insoluble form and to avoid poisonous oxides such as lead.
When lead oxide is fritted with sufficient quantities of other oxides, it becomes less toxic (Rhodes, 1973). Ruscoe (1974) adds that further advantages are the lower temperature at which soluble materials may be incorporated into the glaze in melting or preparation.

Ash Glaze

Wood, plants, vegetable, and volcanic ash are the main source of ash glaze, since this ash is very rich in the essential components used in making glazes. Rhodes (1973), Ruscoe (1974) and Nelson (1978) report that the chemical analysis of ash demonstrates a content of silica, alumina, potash, iron oxide, lime and magnesia, which are all useful for glaze. In order to achieve a successful glaze, different tests should be performed. Mellon (1980) indicates that ashes vary in their chemistry. For example, grasses, small shrubs and plants contain more silica while trees have more calcium, therefore different types of ashes will produce varying results. Moreover other materials such as feldspar or nepheline syenite should be added to give the glaze substance and flux. Before mixing the ingredients for ash glaze the ash should be passed through a 60 or 80 mesh screen. Ash glaze usually requires high temperature in order to melt. This requirement may be a result of a silica presence.

Raku Glaze

Raku glaze is not basically different from other glazes except that bright colors can be achieved at low temperatures as a result of the presence of a high percentage of fluxes. This type of glaze is
able to withstand rapid firing and sudden cooling, so that the whole process can be finished in a short period of time, perhaps less than an hour. Color can be obtained by addition of metallic oxides to the basic glaze. Unpredictable colors can also be achieved as a result of a reduction atmosphere which can be accomplished by placing the red-hot glazed object in a container of saw dust or newspaper. Raku objects are less water tight.

Salt Glaze

Salt glaze produces a thin coat of glaze over the surface of clay objects. Rhodes (1973) and Shafer (1976) indicate that this process originated in Germany. This type of glaze can be done by introducing salt into the kiln through small openings in the kiln when the mature temperature has been reached. This operation can be repeated until a desirable glaze thickness is obtained. On the other hand, sea water also gives a successful salt glaze when the sea water is dripped in the firebox (Sydenham, 1980). As a result of heat, salt rapidly turns into a vapor and sodium reacts with silica to form this type of glaze. This reaction was briefly described by Lawrence (1972) as follows:

1) \[2NaCL + 2H_2O \rightarrow 2NaOH + 2HCL\]

The salt reacts with the water vapor present in the kiln atmosphere to form sodium hydroxide and hydrochloric acid fumes which are given off in the surrounding atmosphere.
2) \[ 4 \text{NaOH} + \text{heat} \rightarrow 2\text{Na}_2\text{O} + 2\text{H}_2\text{O} \]

The sodium hydroxide formed in reaction to the kiln temperature decomposes to form sodium oxide (\(\text{Na}_2\text{O}\)), and water vapor which evolved.

3) \[ 2\text{Na}_2\text{O} + \text{XAL}_2\text{O}_3 \cdot \text{SiO}_2 \rightarrow 2\text{Na}_2\text{O} \cdot \text{XAL}_2\text{O}_3 \cdot \text{XSiO}_2 \]

The sodium oxide reacts with the surface of the clay ware to form a sodium alumina silicate glaze. Salt glazing can be done in any type of kiln except the electric kiln since salt affects the kiln elements. Nelson (1978) adds that salt also coats the whole interior of the kiln which makes the kiln unsuitable for bisque and other types of glazes. Color in salt glaze, as Lawrence (1972) and Nelson (1978) point out, can be produced by applying coloring slip to the ware by mixing metallic coloring chlorides or body stains.

Crystal Glaze

Crystal glaze is similar to others except that during the cooling phase of the firing cycle, portions of the glaze separate from the batch in an orderly manner to form crystals or ice-like structures on the surface (Conrad, 1980; Snair, 1975). Crystal formation, as described by Conrad, occurs in two steps: first, the atoms arrange themselves to form a unit cell or nucleus and then additional groups of atoms attach to the nucleus to increase its size thus creating the crystalline form. The basic crystal glaze consists of silica glass, fluxes, and crystal formers (such as zinc for high temperatures and chrome or uranium for low temperatures). Other metallic oxides are
added for cooling and glaze stabilization. Rhodes (1973) indicated that the presence of alumina largely prevents the glaze from crystallizing as it cools and he suggested that alumina in the composition of crystal glaze should be drastically reduced to less than 0.1 molecular equivalent. Ruscoe (1974) added that glaze composition should have little or no alumina and a large proportion of zinc introduced with soda, lead and boron as fluxes. Additional oxides that give a high saturation of crystal forming agents such as titanium oxide, Rutile, and vanadium oxide as well as those providing color and tint crystals such as iron, copper, or cobalt are recommended in the composition. The high content of zinc oxide and the presence of rutile or titania were proven to form the development of crystals (Rhodes, 1973). Conrad indicated also that each crystal glaze composition has a different time and temperature cycle that determine the rate and the size of crystal growth. He mentioned that high soda content glazes develop crystals more readily than do potash or calcium-base glazes. Manganese or iron in small amounts (less than 2%) help promote large crystals. Ten to 35% in a zinc silicate crystalline type are favorable.

The cooling procedure as well as the time allowed for crystalline growth are key factors. The slower the cooling of the kiln after reaching maturity and the more time allowed for crystalline growth, the larger and more plentiful the crystals are (Ruscoe, 1974 and Conrad, 1980). Because the firing cycle is a key factor, Norton (1956) suggested the following firing cycle: heat to 1275°C in one hour and hold for a half hour, cool suddenly to 1100°C and hold for one to
four hours to allow crystals formation, and then cool to room temperature.

In order to achieve the correct result, the crystals must be extremely fluid, and some way of separating the piece from the glaze puddle or the base must be found. Stilts, a soft cookie of clay which may be cut away, or use of a carefully fitted clay ring cemented to the base of the ware and freed by gently tapping with a chisel after firing could lead to the achievement of proper crystal glazes (Snair, 1975).

Reduction Glaze

Reduction glaze is another type of glaze which can be achieved in reduction atmospheres either by overloading the kiln chamber with carbon gas and cutting down the intake of air or by keeping the air rate the same and increasing the gas input and closing the dampers to force back into the kiln chamber the exhaust gases which contain unburnt carbon, thus creating a reducing condition (Grazio, 1972). Under reduction firing atmospheres, excess hot free carbon seeks out and combines with oxygen from any available source such as unstable oxides contained in glaze materials. Changes in color and sometimes in texture of glazes occur under these conditions (Dickerson, 1974; Fraser, 1974; Nelson, 1978; and Sanders, 1974). Iron and copper oxides which have the least stability are transformed under reduction atmospheres into jade green colors produced under oxidation. Cool colors of grey, grey green, blue green and olive green are the colors resulting from the reduction of iron oxide from ferric ($\text{Fe}_2\text{O}_3$) to
ferrous iron (FeO) (Dickerson, 1974; Ruscoe, 1974). Colors like green, turquoise and aqua from copper, bright yellow from uranium and vanadium, grape purple from manganese are not possible under reduction conditions (Rhodes, 1973). Brisson (1980) indicated that the best red colors are obtained by using less than one percent (0.3 - 0.5%) copper in a fluid alkaline base glaze fired no higher than ortan cone 9. Other oxides, such as alumina, silica, calcium, barium and potassium are stable oxides and they are not affected by reduction atmosphere, as far as color and texture of glazes are concerned (Rhodes, 1973). Hence, reduction glazes produce that unique color known as copper red or ox blood, peach bloom or flambe'-like celodon. The length of reduction and the exact temperature at which to start will essentially be determined by how the glaze reacts as well as by the type of result desired. Davis (1980) indicated that the richness of the glaze is dependent upon various factors such as thickness of glaze, kiln atmospheric condition (oxidizing or reducing), placing of wares, juxtaposition of wares, design of the kiln and the length of firing. Brown and Norton (1956) stated that the thickness of glaze has a considerable effect on the quality of the red. They indicated that glaze should be thick enough to prevent complete oxidation and thin enough to produce the proper amount of chromaphores. They suggest two-tenths of a millimeter as a satisfactory thickness of glaze.
Glaze Application

Glaze can be applied over the surface of ceramic articles in different ways. Some of the primary methods are spraying, pouring, dipping, and painting.

Spraying

This method is used very commonly in ceramics mass production and is the only method which requires a great deal of equipment such as an air compressor, air gun, spraying booth and a fan-extractor since some glazes contain poisons which may endanger health. However, in order to obtain success the glaze should be passed through a 60-mesh screen and be fluid before use. Spraying usually wastes more glaze than the other types of application. Spraying also requires the air-brush gun to be cleaned after spraying.

Dipping

The simplest method of application can be done by dipping a ware into a sufficient amount of glaze for several seconds and then withdrawing it. Ruscoe (1974) mentions that three things should be considered in this method: the thickness or density of the glaze liquid, the porosity of the bisque, and the length of time for dipping.

Pouring

In this method the glaze should be poured inside the ware if the ware is hollow and then the ware should be emptied. Finally, the glaze is poured over the surface. This method is very simple and more efficient.
Painting

This technique is very useful on a small scale since the main device for this technique is a brush which requires skill and more time. In this method the glaze is brushed over the surface with a wide brush or small brush and with the same thickness. Several coats of glaze should be applied when using this method.

Tools

Many different kinds of tools are required in ceramics, but there are some tools that are used constantly in working with clay. A general description of these basic kinds of ceramic tools will be provided here. For example, in order to achieve a clean surface or carving small details, clean-up and detail-carving tools are very helpful. In operating the potter's wheel, scrapers, potter's ribs, sgraffito, and loop tools aid in shaping, carving, smoothing, trimming and removing the excess amount of clay from the wheel. These tools are easy to manipulate. Calipers, on the other hand, as well as other tools that are used to measure the thickness and diameter of the thrown forms require great care to ensure exactness. Hole cutters, drills, and lace tools are employed to form a clean hole or lacework designs. Wood modeling and ribbon tools are for sculpting in ceramics. Steel Raku tongs are used to handle raku ware during the firing process. (See Figure 11.)
Figure 11. Tools

A. Ribbon Tools    C. Loop Tools
B. Hole Cutters    D. Drill Tools
Figure 11. Tools

E. Sculpture Tools  G. Wood Modeling Tools
F. Scrapers       H. Potter Ribs
Figure 11. Tools
I. Raku Tong  J. Calipers
K. Clean-Up Tools
CHAPTER VI

KILNS AND FIRING

When clay objects have been designed, shaped, and air dried, firing is then needed to finish the process and give them adequate strength and hardness. The kiln is the tool used for the firing of ceramic wares. Hamilton (1974) defined the kiln as the ceramist's major item of equipment identified by the fuel which is burned to create the necessary heat, the temperature attained, and the size of the firing chamber. He indicates four types of kilns: electric, gas, oil and solid fuel kilns. Dickerson (1974) defined kilns as either insulated boxes within which heat is generated or chambers into which heat is drawn by draught.

Types of Kilns

The types of kilns which will be discussed in this section are electric, gas, oil fired, solid fuel, and solar kilns.

Electric Kilns

The most common type of kiln found in ceramic studies is the intermittent electric kiln (Counts, 1973; Hamilton, 1974). As described by Dickerson, electric kilns have no internal combustion of fuel in them and they are not fitted with dampers or chimney systems. Heat is generated from coiled electric elements of kanthal. Dickerson added that they are safe, free of smoke and noxious fumes, and
they are easily operated. This is in agreement with Counts (1973) who indicated that electric kilns are in a sense error-proof but less challenging than some of the other types. On the other hand, electric kilns are expensive and large ones do not fire well, particularly towards the center where radiant heat does not penetrate. Dickerson further indicated that, from an aesthetic point of view, the most serious disadvantage of electric kilns is their naturally oxidizing atmosphere. Attempts to achieve reduction necessitates either major, expensive modifications to the kiln (replacing the elements with silicon carbide rods) and methods and techniques of firing which accelerate the rate of element wear. According to Hamilton (1974) an electric kiln usually takes the form of a brick-lined steel box with a door in either the top (top-loading), or the side (front-loading). He added that it is simple to manufacture, install and operate. Firing temperatures are limited to the ones recommended by the manufacturer to sustain the life of the elements and to reduce the time required to reach top temperatures.

Gas Kilns

Gas kilns are more economical to operate than electric kilns and provide a variety of atmospheric conditions within the firing chamber over a wide range of temperatures (Hamilton, 1974). As compared to electric kilns, gas kilns do not suffer if reduction firing conditions are induced. The gas kilns most commonly designed today are known as down-draught and up-draught kilns.
When dampers and secondary air vents are fully opened, complete burning of gas is obtained and the firing is said to be oxidizing. When dampers are partly closed and secondary air vents are shut, reducing conditions are in effect and minerals in the clay will tend to form oxygen-depleted molecules.

Oil-Fired and Solid-Fuel Kilns

Oil-fired and solid-fuel kilns are of similar design to gas burning types. They are drip-fed or air-blown (Hamilton, 1974). These kilns have the advantage of being comparatively cheap to build, suffering no diminution of performance with size increase, and having lower maintenance costs (Dickerson, 1974). Both reducing and oxidizing atmospheres are available. On the other hand, fuel-burning kilns lack the convenience of electric kilns and require elaborate smoke and fume-dispersal systems and need experienced operators to be precisely fired (Dickerson, 1974).

Solar Kilns

The future use of solar energy for kiln-firing appears very promising. Kujundzie (1976) constructed a small experimental solar kiln. It was simply made of plywood with a sliding back running between a couple of wooden rails and two wingnut bolts in order to precisely focus the sunlight that was being collected. A year later he introduced the Fresnel Compound lens to concentrate the power of the sun into the area where the kiln is placed. Kujundzie stated that the best results were obtained during the longer days of late
spring or summer when the sun was almost directly overhead. He indicated that only a short period of the day would be effective for producing temperatures high enough to melt low-fluxing glazes such as Cone 04, 1940°F. He finally demonstrated that a larger kiln may be constructed using two or four collector lenses in a battery that yield greater amounts of useful heat at higher temperatures.

Kiln Design and Construction

The basic structure of each kiln is carefully designed to provide adequate strength, to withstand being jostled about and at the same time, to prevent its being clumsy and excessively heavy (Fraser, 1971). There are several factors determining the choice, planning, design, and construction of kilns. Fraser classified these into five major factors: the approximate size of the kiln required, the maximum temperature to which the kiln will be fired, difficulty of access to the kiln site, electricity consumption and existing electricity supply, and the space in which the kiln will be situated. Gregory (1977) established a set of steps to be followed when planning a kiln project. He stated that the first consideration is the use to which the kiln will be put, the kind of pottery to be produced, the size of the kiln, available space, safety of the site from the possible hazard of fire or its being bothered by neighbors. A second step is to decide what kind of fuel is to be used.

Generally, as stated by Dickerson (1974), kiln style is based on typical Roman-British design but a few minor modifications have been incorporated. The kiln consists mainly of two distinct parts:
1) a permanent lower level, and 2) the dome. Nelson (1978) stated that early kilns consisted of a fire-box and a connecting chamber with a vertical chimney vent dug into the side of a clay bank, hence the name bank kiln. He also added that during the Greek and Roman eras the typical kiln continued to be a rounded, dome-shaped design of moderate size. Because heat travels directly upward from the firebox through the ware and finally out the chimney vent above, the plan is termed an updraft design (Nelson, 1978).

Great advances in kiln design and construction were accomplished in Europe during the industrial revolution. It was not until after 1710 that the first porcelain was produced in Europe, and, by about 1800, kilns were in service in European factories which were the equals of Chinese factories (Nelson, 1978; Rhodes, 1968). Unlike the Middle East, China had numerous deposits of high firing clays, both stoneware and fireclay, as well as kaolin. To ensure even temperature, the kiln was divided into separate chambers with the major firebox at the base but with an individual firebox for each chamber (Nelson, 1978). Koreans and Japanese used a long, tube-like kiln where flame and heat are deflected by the wall of saggers upward and downward through the stacked ware and these kilns are downdraft type designs (Nelson, 1978). Hence, several changes were made in kiln design to fit and accommodate the recent conditions and requirements. Ancient kiln types are still in use today, but a few modifications have been introduced to accommodate new fuels, new materials, and, in the case of industry, the need for expanded and efficient
large-scale production. Improved refractories, better arrangement for the circulation of heat and the introduction of coal for fuel enabled the attainment of higher temperatures. The development of cast-iron grates for fuel-burning brought about a considerable improvement (Rhodes, 1968). Nelson (1978) stated that the most significant change of kiln design in recent times was due to the development of a new source of power, electricity. Electric kilns have played a large part in the current popularity of ceramics because they are simple and safe to operate, and comparatively portable.

Fuels

The availability of fuel and the advantages each has to offer would determine the choice of kiln design.

Wood

In order to use wood as a source of heat, thinner pieces should be selected since energy is released faster than it is with thick logs. To obtain the required temperature with wood, the fire mouth must be fed with wood at a steady rate (Gregory, 1977).

Oil

When using oil, care should be taken to prevent slagging in the firebox caused by oil flame. The adjustment of air and oil is of great importance to obtain the optimum use of fuel. According to Gregory (1977), oil provides controlled results from oxidation to reduction; a rapid advance of heat can be achieved relatively easily once the kiln is warmed up and the fire mouth is hot.
Coal and Coke

The lack of reliance on electricity for power constitutes one of the major advantages of solid fuel-fired kilns along with the bonus of their ability to fire both oxidized and reduced processes (Gregory, 1977). Coal and coke are sources of heat used for large kilns but they are rather inconvenient because they require a greater deal of storage space and maintenance since they generate much dirt.

Gas

Gas is a relatively safe and simple way of firing. Oxidation and reduction can be controlled easily and a very slow or fast flame can be developed by either turning up or down the gas supply.

Olive Oil Cake

As a source of heat, olive oil cake is also satisfactory in kiln firing. It provides a very viable alternative source of fuel for firing that is less expensive than some of the other types.

Rubber

Car tires have been used by many popular Libyan potters as a source of heat in kilns, particularly in bisque firing under reducing atmospheres.

Kiln Building Materials

Refractory Materials

Refractory materials are essential elements for kiln performance and should be well selected for the wellbeing of fired ware.
Solid fire bricks, common bricks, hot face insulating bricks, constables are the refractory materials commonly employed in kiln building.

Firebricks with their advantageous properties (density, strength, refractoriness, resistance to cracking and spalling, resistance to acids and slags, and exact sizing) have long been used in kiln construction and ceramic work (Rhodes, 1968). Sandstone is the only natural mineral besides clay that can be used for kiln building. Soft or insulating firebricks are a more recent development and they are designed specifically for greater heat retention. They are made from clay, diatomaceous or fuller's earth. Counts stated that K-23 and G-23 refractory bricks, soft, lightweight insulating materials can withstand temperatures up to 2300°F. Gregory indicates that the better the quality of bricks, the longer working life of kilns and it is worth the initial expense for the time saved in repairs.

The two types of bricks used generally in construction of kilns are refractory bricks and refractory insulation bricks (Fraser, 1971). The former are fairly dense and comparatively heavy in weight. They absorb heat quickly and are used in positions where heat loss is not quite so important. Fraser added that these types of bricks can not be used in electric kilns and the bricks used for the manufacture of electric kilns are normally of the refractory insulation type. Gregory stated that for a salt kiln, high alumina and low iron brick with a relatively hard face is advantageous, however. Highly siliceous firebricks attract more sodium than those with a
high alumina content. He added that solid firebricks soak up heat and take longer to cool than high temperature insulating bricks.

The desirable properties of any firebrick are the strength, good refraction and ability to withstand heat. Gregory suggested that hot face insulating bricks made from fireclay and kaolin, mixed with air in thick slip can be used for interior wall building because of their better insulating qualities. Another advantage is that the kiln construction is much lighter in weight. However, having soft composition, these chip and spall easily, breaking down faster than solid firebricks do (Gregory, 1977). He also stated that for better insulation of kilns and less fuel waste, 70 parts of vermiculite plus 15 parts of ball clay in addition to sodium silicates were recommended to be trowled over the whole chamber. Since vermiculite is not very refractory to be used near the hot face, three parts of sawdust, one part of fire clay plus one part ball clay as well as sodium silicate could be used for this purpose.

Asbestos board or asbestos plaster, fiberglass or feldspathic wool, ground charcoal and aluminum foil are additional materials besides vermiculite and firebricks used as kiln insulators (Rhodes, 1968).

According to the melting point of elements given in the periodic table, there are mainly seven types of substances with high refractoriness. These are oxides, carbides, nitrides, silicides, sulphides, borides, and simple elements (Rhodes, 1968). The most refractory oxide, thoride (ThO₂), has a melting point of just over 3000°C.
Carbon is the most refractory element. The most refractory of all known substances are hafnium and tantalum carbides with a melting point of around 4000°C (Rhodes, 1968). However, such substances as carbides, nitrides, silicides, borides, sulphides and most single elements being oxidized when facing high temperatures and air, have a severely restricted use unless they are suitably protected or used for very short-term application. Silicon carbide is somewhat of an exception to this and can be used as a refractory material because when it begins to oxidize at high temperatures, a glaze of silica is formed on its surface giving it a protection from further oxidation (Rhodes, 1968). Al₂O₃, MgO, BeO, ZnO₂ and ThO₂ are being considered useful refractory materials for temperatures in excess of 1800°C. Pure kaoline or kaolinite clay (Al₂O₃, 2 SiO₂, 2 H₂O) has a melting point of 1785°C and it is the most available and useful refractory material (Rhodes, 1968). Rhodes added that no matter how pure clays are, their melting points are below that figure (1785°C) because of impurities like iron and traces of alkali and other oxides in addition to alumina and silica. Rhodes suggested that the firings of 1000°C or more require more refractory bricks made of fireclay or kaolin.

Firebricks, although they are the most suitable insulating materials being used, may fail in two ways: melting or deformation from excessive heat or corrosion due to material coming into contact with them, cracking or spalling and crumbling from fatigue due to
repeated heating and cooling which loosens the bond between particles thus diminishing the bricks' strength and stability (Rhodes, 1968).

**Heat Transfer**

As far as heat transfer and retention are concerned, insulating materials and wall thickness are the key to kiln manipulation. Heat is transferred either by conduction or convection or radiation, particularly by convection and radiation through the interior of the kiln. Heat transferred by conduction through a barrier is a function of several factors such as the area of the conducting surface (the larger the area the greater the amount of heat that is carried), the thickness of conducting material, the difference of temperature between the two sides of the conducting solid, and the time allowed for heat transfer and the nature of the material (Rhodes, 1968). He added that for extended firing, thick walls might be desirable. For most potters, a 9-inch kiln wall of hard firebrick is adequate and a wall 4½ inches thick may be sufficient if K-23 or K-26 insulating bricks are used.

**Kiln Stacking**

Wares being placed inside the kiln prior to firing is referred to as kiln stacking. This is of great importance for a successful firing and wares should be placed wisely and carefully. Kiln furniture should be checked after each firing and any loose particles of kiln wash lightly brushed away. Spots of glaze sticking to the shelves must be chipped or ground away and the area painted over with
a new layer of wash (equal amounts of kaolin and silica mixed with water until a lump-free paste is formed). This practice of checking for debris in the kiln should be performed on a regular basis (Counts, 1973; Dickerson, 1974; and Rhodes, 1968).

Kiln shelves and props are usually made from sillimanite or a mixture of refractory materials similar to sillimanite (Rhodes, 1968). Some potters make their own kiln shelves from refractory clay such as fire clay and grog mixture. Large heavy pieces may need a platform under them to prevent warping, and a thin layer of kiln wash or silica sand which should be placed between the platform and the shelf to prevent the platform from sticking to the shelf. Damp wares may explode or crack as a result of steam pressure built up inside them when firing begins. Counts suggested that for economy in bisque firing, potters should place as many pieces as they safely can in the kiln since pots are not going to be fired to maturity. Pots are stacked in columns, rim to rim, bottom to bottom, or one inside another as long as delicate parts are safe from stress.

**Firing**

The types of firing which will be discussed in this section are as follows: bisque, glaze, salt, crystalline, luster glaze, oxidation and reduction.

**Bisque Firing**

There are mainly two firing phases: bisque and glaze. The object of the former is to ensure that during the early stages of
firing, the water vapor is chemically held inside the clay ware, which is then converted into steam and allowed to escape from the kiln very easily. This is called the water-soaking period (Counts, 1973). Counts added that the heat is allowed to build up slowly through what is known as the silica-inversion period at around 1000°F. The rate of temperature increase is governed by several factors, the most important of which are the relation of input to loss and the design of the kiln as it affects circulation and heat transfer (Rhodes, 1968).

Rhodes stated that periodic kiln, from an engineering point of view, must be regarded as a very inefficient machine because so little of the heat energy expended is used in heating the ware itself. Norton (1956) established the heat balance in the most efficient kiln as follows:

- useful heat applied to the ware 20%
- heat lost in cooling 18%
- heat lost through the flue 36%
- heat lost through walls and crown 18%
- heat used in vaporizing moisture 8%
- heat stored in walls and crown 14%
- incomplete combustion of fuel 6%

The input capacity of the burners determines the quantity of heat necessary to increase temperature. Burners must generate and transmit to the kiln more heat than is being stored or lost (Rhodes, 1968). Fraser indicated that the rate of temperature increase should be slow and no greater than 100 degrees per hour for thinner pieces of
pottery, while for thicker wares this rate should be much slower (50 - 70° per hour). He added that the brick work lining the interior of the kiln will be glowing noticeably when the temperature is up to 650 - 700°C. At this point the kiln can be switched to its high setting to finish off the firing for terracotta and earthenware types of clay. For stoneware clays that contain a comparatively high amount of carbon, particularly those with a fireclay content, it is suitable for the temperature to be kept at a medium setting for another hour before switching it to the high setting (Fraser, 1971). The process of firing ceramics ordinarily involves gradually heating the kiln up to the degree needed to accomplish the desired results, then cooling it again gradually to room temperature (Rhodes, 1968). A proper firing cycle or schedule of advancing and reducing temperature is determined by the nature of the wares fired and the changes desired in them. Slow cooling is also desirable to prevent damage to the ware from shock and sudden contraction (Rhodes, 1968). Irregularity of heating can be damaging to the glazes and cause pyrometric cones to give an inaccurate indication of the end-point of firing.

When pots are taken from the kiln, they should be closely examined. A greyish color indicates the probability of the remains of organic matter inside the pots, in which case, the temperature increase of future bisque firing should be retarded by leaving the kiln at its medium setting for a longer period of time (Fraser, 1971). If cracking occurs one possible cause is steam pressure building up
inside the ware thus causing it to rupture. In this case the kiln must be allowed to remain at its low setting for a longer period of time in future firings (Fraser, 1971), or the ware should be dried longer.

Glaze Firing

Depending on the type of glaze fired and the final temperature desired, the final temperature may be followed by a soak in order to provide a satisfactory glaze surface (Hamilton, 1974). Too much soaking will cause the glaze to become liquid and melt or it may also produce glassy glazes when matt glazes are desired. Once the top temperature is reached, it is essential to cool the glaze satisfactorily. If the glaze is to be matt finished, it will be necessary to cool it slowly in order to induce devitrification of the glaze (Hamilton, 1974). A decrease in temperature at the rate of 50°C per hour is suitable. For a satisfactory glaze surface, the glaze may be cooled at the normal rate of 100°C per hour when it falls below the hardening point which is usually 200°C below its maturity temperature (Hamilton, 1974). Dickerson stated that the rate of temperature rise should be cut back as the maturation temperature of the glaze approaches to allow fusion to take place within it. He added that during the last few degrees the temperature rise should be as slow as possible to allow gases to escape from the glaze and for it to run smoothly. He suggested that when maturation temperature is reached, the kiln should be maintained at that temperature level.
for at least one hour to ensure the healing of the mars in the glaze caused by the release of volatile gases. This is in accordance with the findings of Fraser (1971).

Salt Firing

Salt firing, an international technique in the repertoire of ceramic practitioners, was invented in the German Rhineland during the early part of the 15th century and developed into one of the most pervasive styles during the 16th and 17th centuries (Dickerson, 1974). Once a kiln is used for salt glazing it cannot be used for other types of firing without the effects of salt vapor occurring. Salt firing has a wide temperature potential and should be explored. Salt firing, as indicated by Rhodes, should be performed in a downdraft kiln built from hard firebrick. Before the first firing is set, the kiln should be washed over with aluminum oxide to prevent excessive building of salt glaze on the inside of the kiln. Rhodes added that an ample flue and chimney are required to carry off the unpleasant and dangerous vapors.

Crystalline and Luster-Glaze Firing

Both crystalline and luster firing require special treatment in cooling (Rhodes, 1968). For crystalline glazes, it is necessary to hold the kiln at a certain temperature during the cooling cycle to allow the crystals to form in the glaze. Luster glazes are reduced during the cooling cycle. For a good luster, the reduction has to be quite heavy and the damper should be kept almost closed. Electric
kilns have been most successful for nonreduction luster surfaces. As far as firing is concerned, electric kilns have been successfully used and they are very convenient because the temperature control is easy (Rhodes, 1968).

Fraser advises that before any kiln is put into use, it should be fired slowly to a temperature no higher than 100 to 200°C below the maximum firing temperature for which it was designed. This gentle firing drives away moisture within the brickwork and the kiln is then ready to be put into full service.

Oxidation and Reduction Firing

A reduction atmosphere as defined by Fraser results when the kiln atmosphere becomes overloaded with carbon. Cushing (1976) reported that for the past thirty years, reduction firing swept the whole United States and every exhibition and every craft store was flooded with subdued brown, muted greys, grey-greens and brown-blacks, the glaze colors resulting from reduction firing. Cushing stated that reduction firing is considered the enemy of the ceramic industry, because it is less reliable, less predictable, less controllable and filled with constant hazards. Oxidation, on the other hand, has several advantages. Cushing indicated that at the firing range of Cone 4, 5, and 6, the most obvious benefit is an economic one. Oxidation is faster than the long, slow soaking fires of reduction. The lack of soot and smoke of reduction wastes as well as its fuel pollution in the atmosphere are other advantages of oxidation firing. Oxidation does not require gas or oil, wood or coal fuels and can be
successfully performed in electric kilns, which is an ecological gain (Cushing, 1976). Cushing mentions another consideration which concerns clays and clay bodies. He indicated that cone 4, 5, 6 firing range, is a perfect range in which to combine the advantage of stoneware with all the advantages of earthenware. Cone 4, 5, 6 is the point at which real density and hardness begins to develop in stoneware clays, ball clays, most fireclays and the plastic kaolins.

Rhodes reported that many kilns that fire with gas and oil function well in reduction but will not fire oxidized wares such as lead-glazed pots without flashing and partial reduction. Hamilton reported that various atmospheres have an important effect on glaze and body colors and textures. As a general rule, a neutral to light reduction gives a good color and texture. Heavy reduction involves waste of fuels usually by heating the advance of temperature or can even result in a loss of temperature.

Under reduction firing, green copper oxide loses some of its oxygen and becomes red copper oxide resulting in the beautiful Sang de boeuf or ox blood, similarly red iron-oxide becomes black iron-oxide which produces a grey-green color known as celadon (Fraser, 1971). Fraser added that kanthal elements used in most electric kilns and for all those kilns fired over a temperature of 1150°C are covered with a protective oxide layer serving to seal off the metal element itself from harmful gases. During a reduction firing this protective coating begins to reduce its thickness until eventually it disappears. Restoration of this coating can be obtained
through oxidation firing. If there is any evidence of this reduction effect, an oxidizing firing must be carried out to restore the protective oxide layer to normal thickness.

In the early stages of firing (750 - 900°C), reduction will cause deposits of some carbon in the clay that is being fired, the so-called body reduction, and this may produce a brown or orange color in stoneware clays. Too much reduction at this stage may cause bloating or cracking, especially if the later stage of firing is rapid (Rhodes, 1968). Heavier reduction toward the end of firing may be beneficial by soaking, which favors the development of celadon and copper red glaze colors. Reduction firing may be damaging to the firebrick of the kiln especially if the brick contains considerable iron. However, reduction firing offers results which cannot be achieved through other methods of firing and requires continuous exploration.

Temperature Control

It is of great importance in the manipulation of the firing cycle to control temperature for the well-being of wares being produced. There are basically two methods of controlling a kiln firing: by means of pyrometers and by the use of pyroscopes such as Staffordshire Cones which are often referred to as pyrometric cones (Fraser, 1971). Pyrometers measure temperature whereas pyroscopes measure heat work. Pyroscopes, as described by Fraser, are indicators made of ceramic mixtures based on silicates the chemical nature of which is such that they don't have definite melting points, but they do have
a temperature range. Within this range the process of glass formation (vitrification) takes place. When a sufficient degree of vitrification occurs, the pyroscope can no longer support itself and bends or collapses. It should be noted and carefully understood that other factors can influence the temperature at which cones collapse. In a strongly reducing atmosphere, it is possible for a chemical reaction to take place that results in a hard refractory skin being formed on the outside of the cone which may then stand quite upright and the indication of temperature is no longer accurate (Fraser, 1971). Fraser suggests placing the cones in some definite order, e.g. from left-to-right in order of increasing fusion point so that the cone on the extreme right will be the last to go down.

Rhodes (1968) indicates that the color of the kiln interior is a good indication of its temperature, varying from a dull cherry red as the color that first appears to almost white heat as it reaches high fire. The draw trial has been widely used as a temperature indicator but because of quick cooling, the color of draw trials is usually indicative of what the glazed ware will be like because of the rapidity of cooling. The fusion of glaze is precisely revealed, however. The change in the pottery being fired is indicated rather than that of the temperature (Rhodes, 1968). Rhodes adds that pyrometric cones invented by the German ceramist, Herman Segar, have the advantage of measuring both the effect of temperature and the length of firing on the ware in the kiln. He stated if firing is slow, the effect of the longer time causes the cones to soften at a lower
temperature. The ceramist is enabled by the use of pyrometers to control the advance of temperature with due regard to critical points where the firing should proceed slowly, such as the stage of firing from 570 to 600°C, the stage when quartz is changing from alpha to beta form (Rhodes, 1968). Pyrometers are also used in gauging the cooling of the kiln. Optical pyrometers and total radiation pyrometers have been developed for extremely high temperature measurement (Rhodes, 1968). Bullers rings and Holdscroft bars are other devices employed to control temperature and kiln firing (Fraser, 1971). Fraser mentions an important fact related to the placing of pyrometers in the kiln. He indicates that pyrometers must not be positioned where they are subject to radiant heat, draught or dampness, and the surrounding temperature should not exceed 35°C. They must also be checked with a spirit level to ensure that they have been mounted in a perfectly level position. For end points of pyrometric cones see Appendix C.

**Kiln Cooling**

Kiln cooling should be carefully and precisely achieved in order to conform to the type of wares being fired. If the kiln takes too long to cool to 750°C, the surface of glassy glaze is likely to be comparatively dull, evidence of devitrification. On the other hand, slow cooling is suitable to obtain the best results from matt glazes (Fraser, 1971). Sudden entry of cool air when the kiln is switched off may cause cracking of pots as well as kiln shelves. From the range of 750°C to room temperature, cooling as slow as possible is
beneficial and particularly while the kiln temperature passes the quartz and cristobalite inversion points (Fraser, 1971).

**Safety Precautions**

When firing earthenware, terracotta, etc., it is generally better to fire the bisque fire to a higher temperature than that of the glaze because, in the production of stoneware or porcelain where the clay ware is fired to about 900 - 1100°C and the glazed ware to 1250 - 1300°C, the ware during the glaze firing will continue to shrink once the temperature increases above bisque firing temperature. Kiln furniture must be dry before being subjected to the normal firing schedule in order to prevent any cracking due to escaping steam (Fraser, 1971). Crazing, peeling, cut glaze, dunting, cracking, devitrification, matt glazes that become glassy, blow out, sulphuring, blistering, dull underglaze colors, dull on glaze colors, inaccurate pyrometer readings are some of the major pottery faults that are caused by incorrect firing procedures, incorrect materials or ignorance on the part of the potter. To overcome these problems, potters should determine what is the probable cause of the process, then adjust procedures accordingly. Many pottery faults are often wrongly attributed to an inaccurate heat treatment in the kiln (Fraser, 1971).

Rhodes (1968) stated that kilns need not be fire hazards. Obviously kilns need to be built in ways that totally preclude the possibility of collapse during firing. The chimney and the manner in which it passes through the roof or other parts of buildings should be safely designed because most fires have been reported to start
from kiln firing because of faulty construction of the flashing around the chimney. Rhodes added that it is advisable to have a shut-off valve of the gas line at some distance from the kiln as well as to maintain a sizable fire extinguisher in the room. Ventilation, or protection from escaping gases, is another consideration. Personal safety precautions such as not wearing loose clothing or scarves that catch fire easily, should be taken when working around kilns.

Environmental quality, such as the prevention of air pollution, is yet another consideration. Colson (1975) indicated that no matter what the location is, a number of common sense rules should be observed before the construction of kilns of any considerable size are attempted. Becoming familiar with zoning regulations may be a good place to begin. Colson considers the following points as rules or guides to kiln construction:

1) Do not install a kiln near inflammable vapors of explosive mixtures.

2) Loss of pressure between gas regulator and kiln should not exceed 0.5 inches of water column pressure.

3) Kilns located inside buildings or confined areas must have a source of ventilation from the outside; normally a draft-hood is required.

4) Gas must be odorized.

There are also several other considerations that are important for the safety of the kiln and surrounding areas. Pollution is certainly a complex problem. Pollution laws require that industries
install auxiliary burners which will eliminate carbon or residue in the stack. One alternative is to design a double-chamber kiln. In this design, the primary heat source is in the high-temperature heat chamber, and this heat is then passed through a secondary chamber attached to the first which is used to fire pottery at a lower temperature. The secondary chamber functions as an auxiliary burner chamber, using heat that would otherwise disperse into the atmosphere (Colson, 1975). The second chamber is relatively free from reduction by the time excess heat leaves its flue opening. Salt vaporization from the kiln flues is much more harmful as a pollutant than carbon because it is composed of sodium chloride and hydrochloric acid which are highly damaging to the surrounding environment as well as to the kiln operator. Recent experiments that have used substitute ingredients to create the same effect as salt vapor have been successful. Methane was found to be a clean organic fuel and virtually pollution-free. It has a very high carbon content which provides necessary heat to fire a stoneware kiln to desired temperature. Alternatives to produce methane in huge quantities are presently being sought (Colson, 1975). Lawrence (1972) indicated that the following principles apply to smoke-free combustion of all types of fuels: a proper air-to-fuel ratio, an adequate mixing of air and fuel at the proper time, sufficient ignition temperatures in combustible gases, adequate furnace volume to allow time for burning, proper fire-box setting height, and finally the three Ts of combustion: temperature (1200 - 1400°F),
turbulence (as much as possible), and time. Smokeless firing requires sufficient oxygen for complete combustion.
CHAPTER VII

CONCLUSION

With this note on safety and environmental concerns the introductory course in ceramics concludes. It is hoped that the student has obtained a firm grasp on the composition of materials as well as the application of ceramic techniques. If the student understands how different elements and compounds react with each other under varying conditions and which implements, temperature, measuring devices or glazes to use, he or she will be able to create more exactly the ceramic form desired. And, it is often this act of creation that is the ultimate goal of the ceramist: whether for aesthetic or functional purposes, the ceramist's idea is transmitted into a durable clay form.

With the introduction of this course into the general curriculum of the University of El-Fatah comes the first step toward a full art curriculum there. Currently there are no courses offered in ceramics and it is hoped that this course can begin the development of a ceramic department at El-Fatah, for the philosophy and basic methodology of ceramics area applies to all of the artistic media, and could be a starting point for opening a fine arts college.

92
APPENDIX A

ANALYSIS OF COMMON CLAYS AND CHEMICALS
<table>
<thead>
<tr>
<th>Material</th>
<th>SiO₂</th>
<th>Al₂O₃</th>
<th>Fe₂O₃</th>
<th>TiO₂</th>
<th>CaO</th>
<th>MgO</th>
<th>K₂O</th>
<th>Na₂O</th>
<th>Li₂O</th>
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<td>18.3</td>
<td>6.3</td>
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<td>0.5</td>
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<td>1.2</td>
<td></td>
<td>6.4</td>
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<td>29.9</td>
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<td>0.5</td>
<td>0.6</td>
<td>1.0</td>
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<td>0.3</td>
<td>0.3</td>
<td>0.3</td>
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<td></td>
<td></td>
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<td>0.5</td>
<td>1.5</td>
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<td>0.4</td>
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<td>0.4</td>
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a plus 5 percent flourine.

APPENDIX B

TABLE OF CERAMIC RAW MATERIALS
## TABLE OF CERAMIC RAW MATERIALS *

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<th>Eq. Wt.</th>
<th>Remarks</th>
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<td>Antimoniate of lead</td>
<td>Pb$_3$(SbO$_4$)$_2$</td>
<td>993</td>
<td>Yellow</td>
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<tr>
<td>Anatase</td>
<td>TiO$_2$</td>
<td>80</td>
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<td>BaO</td>
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<td>Image</td>
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APPENDIX C

END POINTS OF ORTON PYROMETRIC CONES
### APPENDIX C

**END POINTS OF ORTON PYROMETRIC CONES**

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SELECTED BIBLIOGRAPHY


