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CERAMIC TECHNOLOGY--FROM POTTER'S WHEEL TO NUCLEATION, A PHILOSOPHY OF CURRICULUM ANALYSIS TO MEET THE NEEDS OF THE SPACE AGE.

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DESCRIPTORS- *INDUSTRIAL EDUCATION, *CURRICULUM RESEARCH, *CURRICULUM DEVELOPMENT, *CERAMICS, CERAMIC TECHNOLOGY,

THE OBJECTIVES OF THIS STUDY WERE TO OBTAIN AND ESTABLISH CURRICULAR COMPONENTS FROM TECHNOLOGICAL RESEARCH AND TO PROJECT THE RESEARCH INTO AN OUTLINE OF ORGANIZED SUBJECT MATTER. THE STUDY IS LIMITED TO AN INVESTIGATION OF SELECTED SCIENTIFIC AND PRACTICAL ELEMENTS OF CERAMIC TECHNOLOGY THAT ARE RECORDED AS RESOURCE REFERENCES. THE DATA WERE SELECTED FROM BIBLIOGRAPHICAL REFERENCES. THE SCOPE AND DIVERSITY OF THE CERAMICS FIELD ARE SHOWN BY ITS CLASSIFICATION OF PRODUCTS--(1) STRUCTURAL CERAMICS, (2) REFRACTORIES, (3) WHITEWARES, (4) VITREOUS ENAMELS, (5) GLASS, (6) ABRASIVES AND CERAMICS TOOLS, (7) CEMENTS, LIME, AND GYPSUM, AND (8) MISCELLANEOUS. THE SUBJECT MATTER OF THE DERIVED CURRICULAR OUTLINE IS DIVIDED INTO THE FOLLOWING SEQUENTIAL ELEMENTS--(1) SCIENTIFIC RESEARCH, (2) ANALYSIS OF CERAMIC MATERIALS AND CLASSIFICATIONS, (3) COMPOSITION AND PREPARATION OF CERAMICS MATERIALS, (4) CERAMIC PROCESSES, AND (5) TESTS OF CERAMIC MATERIALS AND PRODUCTS WHICH INCLUDES DETERMINING TEST PROCEDURES, APPLYING EQUIPMENT AND INSTRUMENTS, DETERMINING TEST CONTROLS, DEVELOPING ADAPTABLE METHODS AND DEVICES, AND DEVICES, AND DESIGNING AND CONSTRUCTING SPECIALIZED EQUIPMENT. A SAMPLE CURRICULAR UNIT, "THE PROBLEM--SLIP CASTING;" IS INCLUDED. THIS IS A REPORT OF A DOCTORAL RESEARCH STUDY, "CERAMIC TECHNOLOGY--A TECHNOLOGICAL RESEARCH AND CURRICULUM ANALYSIS, WITH IMPLICATIONS FOR INDUSTRIAL EDUCATION," SUBMITTED TO OHIO STATE UNIVERSITY AND AVAILABLE AS 61-908 FOR $4.10 ON MICROFILM AND FOR $14.40 AS XEROXED COPY FROM UNIVERSITY MICROFILMS, INC., 300 NORTH ZEEB ROAD, ANN ARBOR, MICHIGAN 48106. (EM)

Ceramic Technology

A CURRICULUM ANALYSIS
WITH IMPLICATIONS FOR INDUSTRIAL EDUCATION

RESEARCH BULLETIN NO.2

VOCATIONAL TRADE AND INDUSTRIAL EDUCATION SERVICES
THE OHIO STATE UNIVERSITY THE STATE DEPARTMENT OF EDUCATION
COLUMBUS, OHIO

CERAMIC TECHNOLOGY:

FROM POTTER'S WHEEL TO NUCLEATION

A philosophy of curriculum analysis to meet the needs of the Space Age.

A report of a Doctoral Research Study by Robert C. Fritz entitled "Ceramic Technology: A Technological Research and Curriculum Analysis, with Implications for Industrial Education." 1960.

Study directed by Dr. Robert M. Reese, Professor of Education, The Ohio State University.

Research Bulletin No. 2

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Preface

This publication provides an overview of a comprehensive research study in the field of Ceramic Technology within the United States. The major purpose of the study was to provide a basis for the development of a curriculum in any one of the several industrial areas of instruction. This may be at the secondary Industrial Arts (general education) level or the high school and post high school skilled occupation and technician level of vocational instruction.

The detailed sections on Composition and Preparation of Ceramic Materials, Processing Methods and Testing Procedures will be particularly useful to a teacher in planning for instruction in ceramics.

Personnel of industry who find a need for a detailed analysis of the ceramics field will also find this bulletin useful.

Acknowledgement is extended to Dr. Robert C. Fritz for summarizing the results of his research study for this bulletin; to Dr. Robert M. Reese, Director of Trade & Industrial Education Service for directing the preparation and editing the material; and to William Berndt and the staff of the Trade & Industrial Instructional Materials Laboratory for the publication of this research bulletin.

Earl Fowler, Supervisor
Trade and Industrial Education

Contents

I. *Introduction*

Since World War II and especially since the advent of the atomic age and "Sputnik", many areas of the economy have been affected by technological and industrial developments. Advances in such fields as electronics, chemistry, and astrophysics are creating shortages of scientists, engineers, technicians, and skilled craftsmen. It is estimated that within the next decade the number of persons employed in professional and subprofessional technical positions may increase about 40 per cent, and the number employed in managerial and highly skilled jobs will increase by 25 per cent or more.[1] At the same time, despite an increase in the total labor force, the number of openings for laborers and unskilled workers will continue to decline.

Because of the emphasis placed on science, considerable interest has been generated in the United States for reevaluation of educational programs. The awareness of the need to disseminate knowledge of the technological and scientific advancements and theories has great implications for Industrial Education in the area of research for new techniques in curriculum development. Research is needed to develop curricula that will exemplify the technology and keep abreast of technological progress. The desired outcomes of such a study is to develop a critical evaluation of subject matter content and to direct the revisions of the curriculum that such an evaluation indicates.

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[1]Bogue, Jesse P. (Editor). American Junior Colleges. Fourth Edition, American Council on Education, 1956. p. 2.

One of the characteristic changes that should be developed in all Industrial Education programs is one reported at the American Vocational Association Conference in 1957 by Robert Jacoby:

> . . .The nature of the method of instruction in most technical courses must be directed toward developing original thinking and diagnosis rather than trial and error application. This necessitates the laboratory method of teaching rather than the job or project type or demonstration-analysis or laboratory workbook method. . . .[2]

To effectuate Jacoby's report, another characteristic change should be implemented. Through the process of delineating the curricular elements of a major technological field and by the extraction of the curricular elements, Industrial Education programs representative of industry, should be developed by the inclusion of technical and scientific knowledge within the occupations. A major field that lends itself to such a research is ceramics. When one considers that ceramic technology is a subject that pertains to several closely integrated sciences and applied sciences, it can readily be seen that research in the field could include the sciences of chemistry, physics, mineralogy, and geology; and in the field of applied science--ceramics, engineering, agriculture, and mining. A consideration of structure, physical properties, origin and occurrence of ceramic minerals is also essential to an understanding of the technology.

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[2]Jacoby, Robert. "An Overview of Technicians Training Through Public Education and Expansion Possibilities Under Federal and State Policies." Presented to the American Vocational Association Convention, Philadelphia, Pa., August 8, 1957.

The field of ceramics offers a diversity of opportunity for exploration and occupations, and it is stimulating enough to maintain a continual attraction by the very fact that crude minerals can be transformed by ceramic manufacturing processes into products of permanence, utility, and beauty. The variety of mineral combinations, the many feasible methods of processing, and the diverse current and possible future applications for ceramic products, insures a continuing interest whether it is in research, education, product design, equipment, raw material processing, purchasing, production control, testing, distribution, sales, or management.

The reason ceramics has advanced so rapidly lies partly in the inherent properties of ceramic materials and partly in their increased exploitation through accelerated research programs. Research activities are continually expanding the accumulation of basic data essential for future developments of increased production of established products, and the development of new products and processes. A. B. Kinzel of Union Carbide and Carbon Corporation predicted further developments in Ceramics.

> Ceramics, long outstanding with respect to temperature and corrosion resistance, are coming into wide use as their strength and toughness are improved. Much remains to be done, but the scientific approach has already resulted in such new ceramics as silicon nitride and various metal silicides, borides, and carbides, not to mention metal ceramics. Potentialities in the field are impressive, and new ceramics promise better furnaces, better chemical plants, better cutting tools, and better jet engines, to mention just a few of the items making for better living.[3]

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[3] "Many Jobs in Many Fields Await the Ceramic Engineer." Reprint from Air Trails Hobbies for Young Men, May, 1955.

The most striking developments have occurred in glass, ceramic coatings, ceramics for electronic uses, and refractories. Much of the progress and the development of new materials has resulted from fundamental studies concerning the nature of ceramic materials; investigations of fine structures of matter--nucleation; research based on crystal structure studies--a new abrasive material; and, investigation of the phenomenon of sintering.

With the new challenge to develop technological and scientific elements within Industrial Education programs, there is a need to investigate new resources and techniques for curriculum development. The philosophy of curriculm analysis for Vocational, Industrial, and Technical Education has to be revised to a more encompassing, realistic view-point cognizant of contemporary and future technological advancements.

II. *Statement of the Problem*

Studies have been made to determine curriculum content and to ascertain the status of Industrial Education in the United States. This study was a departure from the usual research in curriculum development in that it was an attempt to obtain and establish curricular components from a technological research and project the research into an outline of organized subject matter. The principal features of the study are presented as guiding principles.

1. The presentation of a basic philosophical foundation for industrial education that should illustrate its position in education: general and vocational.

2. The presentation of an investigation of the historical significance of ceramics, its nature, and technological development from 12,000 B.C. to the twentieth century that should illustrate the role ceramics has played in past civilizations and future predictions.

3. The presentation of information to illustrate the relationship between ceramics, a major industry, and the economy of the United States that should show the diversity and size of the industry.

4. The presentation of an investigation of technological resource material on ceramics in the United States that should represent the relationship of the sciences to the ceramic industry.

5. The presentation of curricular elements derived from the technological investigation and interpreted in outline form should facilitate comprehension of the scope of the subject matter.

6. The presentation of an illustrative instructional unit in ceramic technology that should be derived from the subject matter outline of selected curricular elements in order to establish a basis for curriculum analysis. The unit should be applicable to vocational industrial education at the technical level utilizing research, experimentation, and the industrial processes of the industry.

Assumptions

It is assumed throughout the study that the ceramic industry has a definite influence upon the economy and the people in the United States; that ceramic technology is advanced by methods of scientific research; and, that there exists within the ceramic technology curricular elements which are applicable to various educational levels. Since most of the major industries are represented at secondary and technical levels, it may be assumed that, as one of the major industries in the United States, ceramic technology should be represented in the curriculum in a form other than fine arts or engineering.

Limitations

The study is limited to an investigation of selected scientific and practical elements of ceramic technology that are recorded as resource references.

An important limitation is the use of literature in the field of ceramics as a primary source of material for the study. It was discovered that there exists numerous technical books and publications on ceramics at the engineering level, and also hobby or how-to-do-it literature; however, there is a paucity of material specifically written for programs at the technical level. Consequently, the material presented is limited to ideas discerned by the writer through personal contacts with many ceramic scientists and engineers in the

industry, and to those ideas derived by logical processes from the technical investigation.

Probably the most important limitation for the investigation of ceramic technology is that it has been restricted to special emphasis on mineral technology, glasses, and coatings (glazes and vitreous enamels). Although the limitation was necessary, the technical aspects of these areas are extensively presented.

The organization of the subject matter, presented in outline form to exemplify ceramic technology, was limited to the technological investigation and to the presentation of selected curricular elements. The elements of the outline were restricted to specific sub-headings that were developed, in sequential order, from the basic fundamental knowledges to the culminating process of testing the properties of ceramic materials and finished products.

The study was further limited to the delineation of the curricular elements into one illustrative unit of instruction which was applicable to the technical level; however, there were implications for other educational levels.

The study was limited to industrial education theories for curriculum development. Consideration was given to the underlying theories of direction and control of the educational processes in determining the content in technical programs through a technological investigation.

Methods and Techniques

The data for the study were selected from bibliographical references: technical; literary; and scientific books, periodicals, and writings. An endeavor was made to examine critically the selected data pertaining to ceramic technology and technical instruction. The statements expressed or implied were extracted from the literature and condensed so as to be applicable to the scope or limitations of the study.

The technical information was written as an overview of selected areas of ceramics; quotations were interpolated to substantiate or express the technical, scientific, and educational factors. The author's parttime employment as a laboratory technician in the Ceramic Division of Battelle's Memorial Research Institute was of immeasurable value to the study. It was through research at Battelle's with materials and scientific procedures that much of the technical scope of the dissertation was developed.

The process of classifying and organizing the subject matter components into an outline of curricular elements reduced their number and permitted a more convenient method for interpretation and analysis. An example was presented to illustrate a unit of instruction for the technical level based on the philosophy of Industrial Education and the selected bibliographical data. The unit was derived from elements of the subject matter, and synthesized into a sequential problematic solution of a unit of instruction for ceramics utilizing bibliographical research techniques, laboratory experimentation, and acceptable standard procedures as prescribed by the ceramic industry.

Industrial Education

Industrial Education is the generic term applied to all types of education related to industry, including general industrial education (industrial arts), vocational industrial education (trade and industrial), and technical education.

A close relationship should exist between industrial arts, trade and industrial and technical education. It becomes apparent that an effective industrial arts program is contributory to a successful trade and industrial program. The first two years of secondary school in which trade and industrial vocational education cannot be taken, permits the student to enroll in industrial arts courses to provide a

means for students to discover their abilities, aptitudes, and interests and thereby to make a more intelligent selection of their vocation.

In each type of program in Trade and Industrial education there is reflected the relationship that exists between these programs and industrial pursuits. It has been commonly accepted that to meet the objectives of Trade and Industrial programs it is necessary that the instruction should be based on an analysis of an occupation or of a particular phase of the occupation. All instructional material should be based on an occupational analysis. The analysis should include an investigation and organization of the occupation and the reducing or dividing of the information into its manipulative skills and technological details. These skills and details are arranged into a logical order to satisfy the particular objectives for the course of instruction.

Because of the difficulty of defining technical education adequately, and in order for technical education to expand and develop, some attempt was made to clarify a basic philosophy. Clarification was attempted by the consideration of a number of characteristics of programs as they have been developed and listed in a paper presented by Robert Jacoby at the American Vocational Association Convention in 1957:

1. Technical education must be different from trade education. Trade education is a curriculum designed to prepare for earning a living in a skilled trade. . . . Technical education differs from trade education by emphasizing definite industrial application of laws of science. . . .

2. Technical education functions most effectively as a program of non-college grade. . .The place or insti-

tution in which technical education is offered is of limited importance as long as the established objectives, principles are not altered. . . .

3. The nature of the method of instruction in most technical courses must be directed toward developing original thinking and diagnosis rather than trial and error application. This necessitates the laboratory method of teaching rather than the job or project type or demonstration-analysis or laboratory workbook method. . . .

4. Technical education offered on a service area basis is sufficiently large to operate efficiently and economically as well as provide a broad and varied curricular program. . . .

5. The technical program can operate as part of a comprehensive vocational education program encompassing a broad curricular program of technical trade and operational levels. . .the states must assume greater responsibility and vision in the development of plans for meeting the needs of all youth and adults for trade and technical education.

6. More attention must be directed to training occupations for girls and women. . . .

7. Technical education must be for the able student. One of the most important obligations is to actively recruit and properly guide youth into technical education who can profit from the instruction. . . .[4]

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[4]Jacoby, Robert. "An Overview of Technicians Training Through Public Education and Expansion Possibilities Under Federal and State Policies." Presented to the American Vocational Association Convention, Philadelphia, Pa., August 8, 1957.

To understand fully the need for the introduction of more technical knowledge in Industrial Education, one must be aware of the changes which have evolved in the industrial economy. There has been tremendous industrial growth and continuous increased use of mechanization, thus requiring labor with technical knowledge to maintain it. In numerous instances, established trades and occupations have disappeared and new and more highly skilled technical fields have emerged. This constant advancement of industrial technology with accompanying new industries, new methods, and new and more sophisticated equipment is placing greater demands upon skilled mechanics and technicians. The economy is based upon a complex and constantly evolving technology; it cannot function without an adequate supply of skilled workers and technicians to keep abreast of the new scientific advances. Therefore, the curriculum planners of Industrial Education should be cognizant of the significant facts concerning (1) current occupational, social, and educational conditions and needs of the nation's citizens; and (2) facilities existing within the nation for serving these needs.

III. *Investigation of Ceramic Technology*

Scope of the Ceramic Industry

The diversity of the ceramic field is comprehensible when the scope of the industry and its classification of products are observed in Figure 1. Ceramic products have been loosely classified as regards raw materials, fabrication methods, character of product, and ware utility. Although it is difficult if not impossible to avoid some overlapping in classifying products, a modification of Wilson's classification is presented in Figure 1.[5] The Figure clearly indicates the extensive scope and diversity of the ceramic field. It is of further interest to review seven of the general methods of manufacture:

1. Those products which are molded in the aqueous plastic condition and which derive their strength from the partial fusion of silicate at high temperatures: structural, whiteware, and refractory.

2. Those products which are heated until they become fluid and are molded in the viscous liquid state. The final strength obtained from cooling: glass.

3. Those pulverized products in which raw materials acquire a latent cementitious property by heating with the addition of water: cements, plasters, and limes.

4. Those raw materials which, sometimes after fusion of sintering and crystallization, are crushed or pulverized and graded into specified grain sizes: abrasives.

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[5]Wilson, Hewitt. Ceramics: Clay Technology. New York: McGraw-Hill Book, Inc., 1927, p. 2.

5. Those minerals which, after mining in massive form, are cut, machined, or shaped into useful products: insulation and diatomaceous earth.

6. Those raw materials or compositions which are applied as coatings to ceramic or metal articles and heated to fuse or sinter the coatings: glazes and vitrified enamels.

7. Those large crystals which are grown from an aqueous solution, from fused powder, by solid state reaction, or by other means: synthetic gems, mica, and other crystals.

It is impossible to define accurately the size of the ceramic industry in the United States. The difficulty is in assembling complete factual data because of the disagreement as to which borderline products are ceramic; however, for the purposes of a statistical analysis, it is evident that the first requirement is a set of well-defined limits for inclusion and exclusion of various branches for collecting data on only ceramic industries. These limits were established by the definition of "ceramics" as adopted by the Research Committee of the American Ceramic Society in 1920.

> In general, the usage of the term by the Greeks may be said to involve two characteristic elements. First, and primarily, a product in whose manufacture a high-temperature treatment is involved; and second and secondarily, a product customarily manufactured entirely or chiefly from raw materials of an earthy (as distinguished from metallic, organic, and so forth) nature. It is also clear that it is these very elements which characterize the significance of the term "ceramics" as it has come to be employed by the American Ceramic Society.

In accordance with this definition, ceramic indus-

Structural Ceramics
- Brick - paving, common
- Tile - facing, structural, drain, roof, wall, floor
- Terra Cotta
- Insulation - acoustical, thermal
- Structural - glass, porcelain enamel
- Flue lining

Refractories
- Fireclays
- Refractory mortars
- Silica, aluminous, chromite, magnesia, zirconia, mullite, kyanite & sellimanite
- Insulating
- Cermets
- Refractory ceramic coating
- Special oxide, carbide, nitride, etc.
- Carbon and graphite

Whitewares
- Porcelain, china, semi-vitreous ware, earthenware, stoneware, etc.
- Nuclear ceramics
- Semi-conductors and resistors
- Electrical insulation and dielectrics
- Chemical wares
- Filtering media

Vitreous Enamels
- Household
- Sanitary, medical, chemical, electrical
- Refractory coatings
- Structural, advertising ware and signs

Glass
- Household and art glass, structural
- Lighting, electrical, optical, photosensitive
- Fiber, mechanical, chemical
- Container (bottles)
- Ceramic glazes
- Vitreous enamels
- Agricultural frits

Abrasives and Ceramic Tools and Dies
- Silicon carbide
- Aluminous
- Silica and porcelain

Cements, Lime, and Gypsum
- Portland cement
- Calcium aluminate cement
- Magnesia, silicate, dental cements
- Special cements
- Building, agricultural, and chemical lime
- Calcined gypsum products

Miscellaneous
- Cermets
- Cerganics
- Slag and rock wool
- Mineral-glass composites
- Asbestos products
- Synthetic gems

SOURCE: DERIVED FROM WILSON, CERAMICS: CLAY TECHNOLOGY

FIGURE 1 CERAMIC PRODUCT CLASSIFICATION

tries may be properly defined and described as those industries which manufacture products by the action of heat on raw materials, most of which are of an earthy nature, while the constituents of these raw materials, the chemical element silicon together with its oxide and the compounds occupies a predominant position.[6]

Nature of the Ceramic Industry

The numerous ceramic materials and products applied to industry is extensive. Many industrial areas could not subsist without ceramic refractory materials. Through constant research in ceramics refractory materials, important to the metal industries, have become paramount in the development of missiles, satellites, and nuclear advances. Refractories are also necessary in the processing of cements, limes, and other ceramic materials, as well as linings of boilers and furnaces. These and other requirements, make it understandable as to why ceramic refactory materials are so essential to modern industry.

Electronic ceramics is the fastest growing industry in the United States according to Deem and Sullivan[7]; it includes transitors in communications and other electronic controls and operations, and the ferrites in the field of computers. Ceramic parts composed of alumina meet many of the demands of high-powered, high-frequency, and high-temperature electronic equipment. There appears to be no limit

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[6]"Report of Committee on Classification and Nomenclature," American Ceramic Society Bulletin, Vol. 24, 1, 1945. p. 536.

[7]Deem, Betty and John D. Sullivan. "Ceramic Statistics." American Ceramic Society Bulletin, Vol. 39, 2, 1960.

to the size and shape in which alumina can be fabricated. Many parts are produced to precise tolerances such as vacuum tube envelopes, coil forms, and other high-frequency products.

The list of glass products for industrial use is almost endless. In every field of science and industry, glass has an important role. In regard to new developments in glass products, H. E. Simpson, of Alfred University, comments as follows:

> Continued research with photo-chemical glass has produced a new process of chemical machining. . . . Pieces can be produced by this process which are so intricate that their manufacture by mechanical means would be impossible. New glasses are being developed that will transmit or retard radiations of specific frequencies. Glasses of improved faculties for the absorption of infrared and ultraviolet rays have been produced as well as glasses capable of absorbing slow neutrons. . . .[8]

The final machining of highly finished products by new abrasive tools has attained dimensions never thought possible with the use of metal tools. Many other major industrial operations vital to manufacturing are performed with the use of these artificial abrasives. Although fifty years ago the only hard abrasive available was emery--a natural form of impure alumina--today, there exists many manufactured grinding materials possessing great hardness. One of the more recent developments has been the ceramic-tipped tools.

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[8]Shute, R. W. and B. W. King. "Engineering for Increased Glass Production," Industrial Engineering Chemistry. Vol. 46, 1, 1954. p. 174.

A projection into the future of ceramics would reveal significant advances in nuclear energy experiments. Consequently, ceramic products should increase in importance as the trend continues toward higher temperature applications for electrical and electronic currents. Dr. Edward Teller, a leading scientist in the development of hydrogen devices, had the following to say about the future use of ceramics in the nuclear field:

> High-temperature resistance ceramics are playing an increasingly important role in the planning of the nuclear reactors of the future. A thorough understanding of these materials will be needed in order to engineer the energy supply for the coming decades.[9]

Hydrogen fusion may become a source of low cost power through the use of alumina. Alumina, because of its properties of density and strength is to be used as the ceramic material for the reactor changer. Other new uses for alumina are being developed.

Melting points have become a major factor to be considered in the future development potential of new materials in high refractory processes. The temperature chart Figure 2, illustrates how the utilization of pure compounds, many very scarce materials, make it practical to use higher temperature materials as compared to present-day commercial refractories. Presently, the only practical possibility of achieving temperatures above 5,000° F. is with graphite in a controlled atmosphere. M. Jack Snyder, Project Engineer, Battelle Memorial Institute has the following to say about the future of refractories:

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[9]Ceramic Education Committee. For Career Opportunities Explore The Wonder World Of Ceramics. Columbus, Ohio: American Ceramic Society.

> Although new high-melting compounds undoubtedly will be discovered, it is highly unlikely that they will be composed of the more abundant elements, and accordingly these new compounds also are likely to be unavailable in the quantities needed for refractory application even at a high price. . . It is likely that some expedient such as cooling the walls, use of the reactants as the container, or levitation would be employed in developing the process and be adapted to commercial operation.[10]

The development of new high-temperature chemical processes requires an associated development of new materials. Snyder proposes a number of ideas that require new materials such as processing ozone from oxygen, direct synthesis of cyanogen from carbon and nitrogen, and additional production of products by thermal decomposition.

As to the future developments in the glass industry, there should be greater conversion to adapt the combination of gas and electric heating for melting furnaces. It has been reported by ceramists that the output of furnaces already in use should, when converted, increase production from 30 to 50 per cent. A few predictions in glass research are for the future development of a large mirror to produce a temperature of 5,000° F. from the sun's rays; malleable glass that can be worked like plastic, but still resistant to heat; light-weight glass for construction; glass cements; and glass-coated bearings for engines.

Equally diversified products are forecast in the ceramic areas of abrasives, the laboratory development of a man-made material with greater hardness than diamond; cements, plaster, limes, extending the longevity of concrete by new developments in cements; insulation, using newly

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[10]Snyder, M. Jack. "Ceramic Materials for High-Temperature Applications in the Chemical Process Industries." Chemical Engineering Progress. November, 1958.

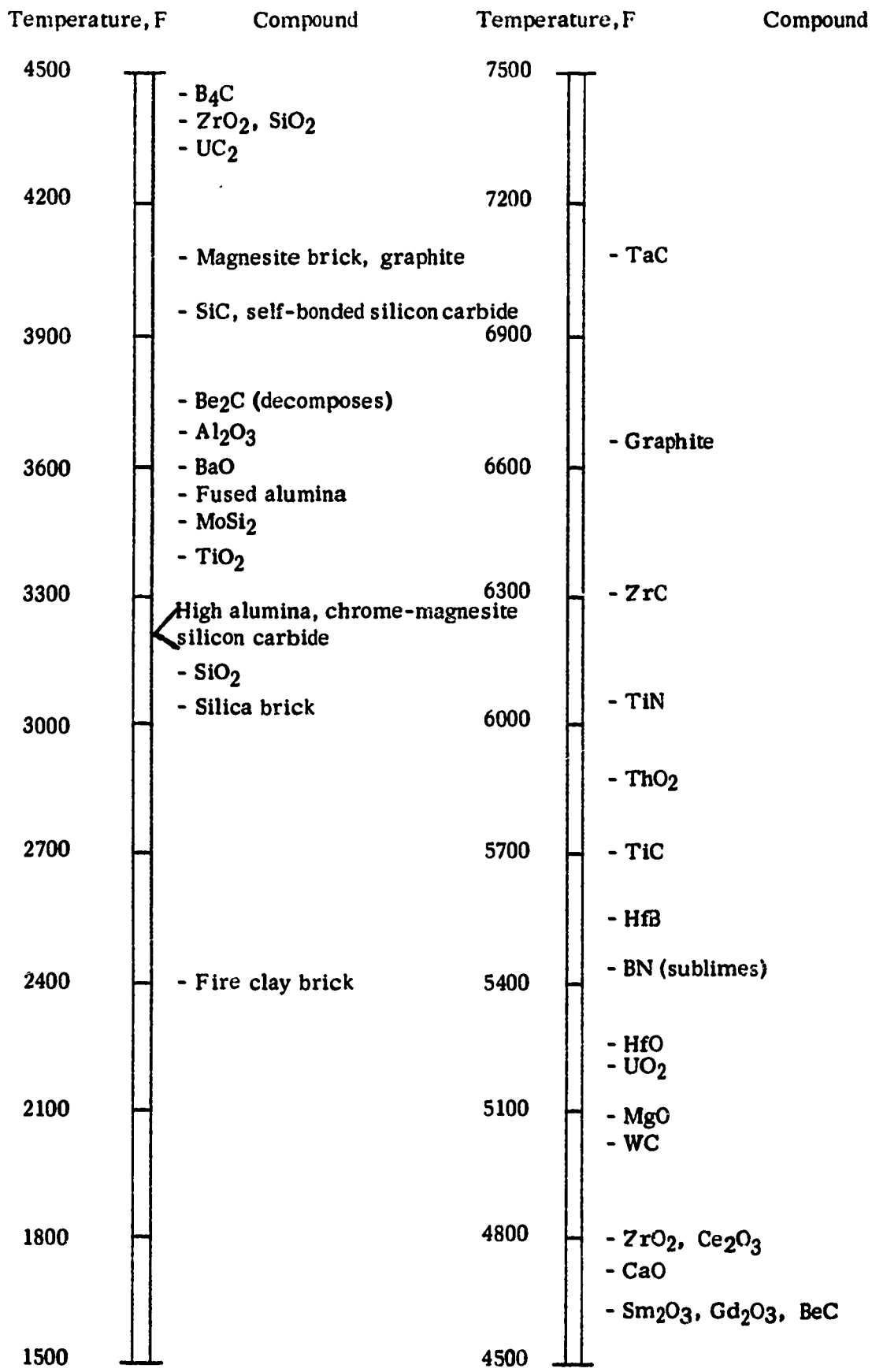
developed theories; ad infinitum.

Analyses Of The Technological Investigation

The investigation of the technological research was presented as an analyses of selected subject matter that was considered to be representative of ceramic technology. The research of the technological material and its presentation required decisions that were difficult to make; therefore, the selection presented were only those the writer believed to be pertinent to the study. Certain areas of the study were substantiated through the utilization of charts, figures, and tables. Unquestionably, many of the areas discussed could involve major experimentation and research by specialists; this was not the purpose of the analyses. The purpose being the presentation of basic technological information for breadth rather than depth of scope. If additional knowledge is needed, the many bibliographical references are available. Undoubtedly, additional references are needed to expand research and experimentation in the ceramic field. The analyses can be logically divided into three groupings: Analysis of Ceramic Technology, Analysis of Manufacturing and Processing, Analysis of Production Processes.

Analysis of the Ceramic Technology

The analysis of ceramic technology is primarily concerned with selected fundamental information pertaining to the technology of minerals and materials of the ceramic industry. The technology involves selected basic knowledge in geology, mineralogy, and to the possible origin and mineralogical composition of ceramic materials. The technology is also concerned with selected chemical and physical reactions as related to crystal chemistry and physical state reactions involving scientific phenomena that have definite affects upon the preparation and processing of ceramic materials.



Source: Snyder, "Ceramic Materials for High-Temperature Applications in the Chemical Process Industries."

FIGURE 2 UPPER OPERATING TEMPERATURES OF COMMERCIAL CERAMICS AND MELTING POINTS OF PURE COMPOUNDS

A brief outline of the analysis of the selected knowledge includes:

- Ceramic Mineral Analysis
  - Classification of minerals
  - Elements of crystal chemistry
- Origin and Occurrence of Ceramic Minerals
  - Ceramic geology and minerals
  - Formation of clays
  - Chemical constitution of clay minerals
- Properties of ceramic materials
  - Texture
  - Homogeneity
  - Porosity
  - Permeability
  - Strength and allied properties
- Rheological phenomena
  - Elements of colloidal chemistry
  - Fundamentals of plasticity
- Physio-chemical reaction between ceramic materials
  - Changes effected by water-hydration
  - Chemical components of ceramic materials
  - Plastic materials
  - Non-plastic materials

Analysis of Manufacturing and Processing

The analysis of manufacturing and processing is primarily concerned with the preparation, composition, calculation, and batching of ceramic materials into enamels, bodies, and coatings. The calculation of most ceramic bodies and coatings involves similar steps and methods of expressing formulas and recipes. The raw materials used are similar except in the degree of refinements, therefore, the same consideration is given to their classification.

A brief outline of the analysis would include the following:

Preparation of raw materials
- Mining methods

Composition and calculation of ceramic products
- Empirical formula
- Equivalent weight
- Batch calculation-compounding
- Substitution
- Triaxial diagram
- Blending

Preparation of ceramic bodies
- Clay
- Glazes
- Glasses
- Vitreous enamels
- Methods of preparation

Analysis of Production Processes

The analysis of production processes is primarily concerned with the various methods of forming ceramic materials, methods of drying, decorative techniques, and thermo-chemical reactions that occur during the firing process. There is also a discussion of a number of properties and tests that are utilized by the ceramic industry.

A brief outline of the analysis would include the following information:

Forming methods
- Plastic forming
- Casting process
- Pressure forming
- Glass forming

Drying products
- Drying rate
- Drying systems

Design development

Decorative Processes
- Glaze application

Firing and Settings
- Firing
- Heat and temperature
- Temperature measurement and control
- Types of kiln
- Kiln design principles
- Firing changes and defects in clays
- Firing changes and defects in glazes
- Firing changes and defects in vitreous enamels
- Firing changes and defects in glass

Thermal chemical reactions
- Equilibrium diagrams
- Eutectics and related phenomena
- Liquid and/or solid state reaction
- Vitrification, porosity, and absorption
- Properties and tests of ceramic material

IV. *Organization of the Subject Matter - Curricular Elements*

This part of the study is an analysis of the technological material presented in Chapter III. From the analyses, a selection of basic curricular el ıents was organized into a compilation of pertinent subject matter. The subject matter is in no way a specific curriculum proposal for a level of training, but rather a selection of basic learning elements discernible to the writer that may be applicable to the various educational levels. However, a specific proposal for one unit of instruction for the technical level derived from the following curricular elements is presented in Chapter V.

Although scientific knowledge has accumulated throughout the centuries to lay the foundation for modern research techniques, it has only been in the last half century that new applications have been discovered as well as new atomic theories developed. Through scientific research, dynamic changes have been initiated in the ceramic industry.

The field of research in ceramic technology is so large that it has taken many years to understand and substantiate the basic principles involved. The major problem has been the difficulties experienced in obtaining pure substances, the general insolubility and apparent inertness of most ceramic materials at temperatures below a dull-red heat, and the need for the development of testing and recording the constitution and properties of materials and products.

At present, many important fundamental principles need further investigation in areas such as colloidal phenomena, distribution of water in drying products, and the effects of

temperature on ceramic materials. There has been a substantial accumulation of research recorded which has caused changes to take place in many phases of manufacturing processes in the ceramic industry.

The following abbreviated outlines are concerned with an introduction to research techniques and procedures, and application of these techniques and procedures as they apply to selected areas in ceramics. The subject matter, represented in the outlines, is divided into the following sequential elements of the technological research: Scientific Research, Analysis of Ceramic Materials and Classifications, Composition and Preparation of Ceramic Materials, Ceramic Processes, and Tests of Ceramic Materials and Products.

Scientific Research

This section is organized to represent an orientation to ceramic technology and its place in the American economy. Introduction to research techniques and a selected listings of various basic working laws as they apply to the ceramic technology are presented in the outline. The physical and chemical reactions that are inherent in ceramic materials and the method of measurement and control of them are also suggested. The basic fundamental knowledge requisite to technological research are presented as suggested elements throughout the curricular outlines.

I. Nature of Ceramics
   - A. Orientation
     1. Terminology
     2. Scope of Industry
   - B. Orientation to Occupational Field
     1. Technological: technical, engineering
     2. Supervisory
     3. Sales

4. Designing

II. Introduction to Research
- A. Language of research
  1. Centigrade vs. Fahrenheit
  2. Inches vs. Centimeters
  3. C. g. s. -- Centimeters, grams, seconds
- B. Basic Working Laws
  1. Electricity and Electronics--Ohm's law, voltage, resistance, etc.
  2. Optics--optical systems
  3. Physical Chemistry--gas laws, atomic and molecular weights, valences, etc.
- C. Methods and Devices
  1. Temperature Measurements--thermometers, pyrometers, thermocouples, potentiometers
  2. Temperature Control

III. Development of Scientific Procedures
- A. Procedures in Experiments
  1. Standardization with controlled variables
  2. Experimental
- B. Record Keeping
  1. Procedure change
  2. Process specifications
  3. Reporting
- C. Measurements
- D. Investigation of Published Research

IV. Application to Ceramic Technology
- A. Elements of Crystal Chemistry
  1. Classification
  2. Crystal Structure
  3. Mineral Structures
  4. Identification of Minerals

B. Rheological Phenomena
   1. Properties of Solid-liquid Systems
   2. Ion Exchange--flocculation, deflocculation
   3. Colloids--theories
C. Chemical Constitution of Ceramic Minerals
   1. Acids, Bases, and Salts
   2. Chemical Constitution of Materials
D. Crystalline and Glassy State of Matter
   1. Glass Structure and Composition
   2. Phase Rule and Equilibrium Diagrams
E. Physico-Chemical Reactions
   1. Factors Influencing Chemical Reaction
   2. Phase Conditions

Analysis of Ceramic Materials and Classifications

The fundamental curricular elements pertinent to research techniques have been presented in abbreviated form. Concomitantly, the assimulation of sufficient knowledge of the ceramic technology is necessary in the area of physical and chemical properties of raw materials and finished products. Such a technical investigation illustrates the importance of raw material control to mechanization.

This section is an abbreviated outline of an analysis of subject matter about the properties of "raw" materials as to their identification and methods of preparation. The classification of products is also presented to characterize and identify ceramic products.

I. Ceramic Materials
   A. Definition
   B. Origin & Occurrence of Clays & Ceramic Materials
      1. Ceramic Geology

2. Classification
3. Characteristics

C. Mineralogical Composition
1. Formation of Minerals
2. Crystallography

D. Physical Structure

E. Identification

F. Physical State
1. Solid
2. Pastes
3. Slips
4. State of Aggregation
5. Alteration

G. Properties of Ceramic Materials
1. Color
2. Hardness
3. Strength
4. Elasticity
5. Fired Properties

II. Preparation of Raw Materials.
A. Mining Methods
B. Disintegration
C. Size Classification
1. Screening
2. Milling
D. Treatment
1. Washing
2. Blunging
E. Controls for Uniformity

Composition and Preparation of Ceramic Materials

The physical and chemical properties of raw and prepared materials have been presented; therefore, this section is concerned with the composition and calculation of ceramic

bodies and coverings which constitutes the next important phase of ceramic technology. The determining factors of the properties of ceramic products are formulated at this time. The numerous theories and phenomena included in the technology are considered as they are applied to technical formulas. This section includes those elements involved in the formulation, batching, and processing of ceramic materials as they apply to ceramic bodies and coatings.

I. Composition and Calculation of Bodies & Coatings
   A. Constitution
      1. Bases
      2. Neutrals
      3. Acids
   B. Method of Expressing Composition
      1. Molecular Weights
      2. Empirical Formula
      3. Formula Weight
      4. Equivalent Weight
      5. Batch Formula Weight
   C. Formulation of Ceramic Bodies and Coatings
      1. Phase Equilibrium Diagrams
      2. Charts
      3. Triaxial
      4. Substitution
      5. Fundamentals of Color Formation
   D. Classification of Ceramic Bodies & Coatings
      1. Salt Glaze
      2. Raw-lead or Leadless
      3. Bristol
      4. Feldspathic
      5. Fritted
      6. Earthenware, Stoneware, Porcelain
      7. Transparent, Opaque, Matt, Gloss, Color
      8. Ground and Cover Coat

E. Physical Properties
   1. Thermal Expansion
   2. Density
   3. Elasticity
   4. Tensile Strength
   5. Hardness
   6. Thermal Conductivity
   7. Compressive Strength
   8. Viscosity
   9. Coefficient of Expansion
   10. Adherence
   11. Surface Factors

II. Preparation of Ceramic Materials
   A. Clay Bodies
   B. Glazes, Glasses, Vitreous Enamels
   C. Processes
      1. Wedging
      2. Blunging
      3. Pugging--De-Airing
      4. Milling
      5. Filter Pressing
      6. Magnetic Separating
      7. Screening
      8. Mixing
      9. Chemical Treatment--Bleaching
      10. Coloring
      11. Grinding
      12. Deflocculating
      13. Fritting
      14. Flocculating
      15. Calcining
   D. Product Control
   E. Product Preparation
      1. Chemical Cleaning of Metal
      2. Pickling
      3. Acid Washes

Ceramic Processes

The preceding sections include a presentation in sequential order of the fundamental considerations of ceramic materials and their preparation. The preparation and control of materials are the major determinants for the requisite method of fabrication; therefore, this section constitutes those elements of processing methods and their implications for production techniques. Elements of drying and decoration are presented with related techniques applicable to the forming, decorating, and drying of ceramic products. These curricular elements lead to the completion of processing raw materials into finished products; this culmination of the ceramic processes is represented as selected elements of firing and setting, including the elements of measurement and control of thermo-chemical reactions. As a result of extensive research into various phenomena and control of materials and fabricating processes, the ceramic industry has adopted new methods of automotion and mechanization.

I. Processing Methods
   - A. Plastic Forming
     1. Hand Molding--pinch, coil, slab
     2. Wheel Throwing
     3. Jiggering
     4. Pressure Forming--die, hot, ram
     5. Extrusion--pub-mill, auger, hydraulic, injection
   - B. Casting
     1. Slip Casting--solid, drain
     2. Fusion Casting
   - C. Pressure Die Forming
     1. Dry Pressing
     2. Damp Pressing
     3. Sinter Pressing
     4. Hot Molding (Resin)

D. Special Forming
   1. Grinding
   2. Turning
   3. Repressing
   4. Drop Molding
   5. Vibrating
   6. Fluid Pressure
   7. Coating
E. Glass Forming Processes
   1. Rolling
   2. Molding
   3. Drawing
   4. Casting
   5. Mechanical Glassworking
   6. Pressing
   7. Blowing
   8. Hand Shaping
   9. Lamp Working

II. Production Techniques
   A. Application of Techniques
      1. Plaster Molds and Dies
      2. Slips-preparation, uses
      3. Binders & Lubricants
      4. Special Processes-cementitious bonding, nucleation, cermets
   B. Elements of Drying
      1. Surface Evaporation
      2. Drying Shrinkage
      3. Dry Strength
      4. Vaporization
      5. Defects in drying
   C. Application of Drying Method
      1. Drying Systems
      2. Classification--intermittent, continuous
      3. Controls

III. Elements of Ceramic Design

A. Controlling Factors

1. Ceramic Materials
2. Decorating Materials
3. Firing Conditions
4. Composition--bodies, coverings, glasses

B. Decorative Processes

1. Selected Processes for Greenware
2. Selected Processes for Bisqueware
3. Selected Processes for Glazes--stencil, decalcomania, silk screen, etc.
4. Selected Processes for Glass--cutting, grinding, etching, polishing, etc.

C. Color Formation

1. Stains
2. Overglaze
3. Underglaze
4. Lusters
5. Oxides of Metal

D. Die Design

E. Defects

IV. Elements of Firing and Setting

A. Thermo-chemical Reactions and Changes

1. Thermodynamics of Reactions
2. Equilibrium Diagrams--Interpretation
3. Solid-State Reactions
4. Pyrochemical Measurements
5. Chemical Change Inversions
6. Thermal Behavior of Ceramic Material
7. Sintering and Recrystallization
8. Nucleation
9. Devitrification of Glass
10. Vitrification, Porosity, Adsorption

11. Eutectics and Related Phenomena
12. Physical Changes
13. Effects of Heat, Temperature, Combination, Radiation, and Time

B. Fundamentals of Kiln Design and Construction
1. Principles of Design
2. Temperature Measurement
3. Controllers and Devices
4. Fuels

C. Setting

Tests of Ceramic Material and Products

It is through the study of the preceding outlines that this section is possible because through research, experimentation, and scientific reporting, standard procedures have been established. The establishment of these standard procedures has resulted in advanced research, standardization of products, and a standardized nomenclature for communication purposes.

The following subject matter is concerned with the testing procedures that have been accepted as standards by the ceramic industries. Test samples are prepared, formed, dried, and fired within the standards so that variables for testing may be held constant. This is essential for one test or standard may be dependent on the preceding sample. Just as raw materials are essential to finished products, adequate testing procedures used concomitantly throughout all processing are necessary if standards are to be maintained.

One of the many challenges to the researcher, especially when it is out of the realm of standard procedures and into the field of creative thinking, is the area of ceramic technology for design and construction of specialized equipment requisite to experimentation and research.

I. Determination of Test Procedures

A. Clay Materials

1. Representative Sampling
2. Clay Trials
3. Testing--slaking, water of plasticity, shrinkage
4. Dry Strength
5. Temperature
6. Particle Size
7. True Specific Gravity
8. Firing Behavior-fired properties
9. Fired Strength Tests
10. Effects of Heat--thermal shock, porosity
11. Chemical Analysis

B. Glasses

1. Chemical Properties--durability
2. Mechanical--tensile, impact, thermal
3. Optical Properties--Snell's law, dispersion, transmission
4. Electrical Properties
5. Thermal Properties
6. High-temperature Glass--viscosity, annealing

C. Vitreous Enamels

1. Thermal Properties--fusibility, fusion, optical, physical, chemical

D. Refractories

1. Physical and Mechanical Properties

II. Application of Equipment and Instruments

A. Chemical Laboratory Ware
B. Standard Analytical Scales
C. Tyler Standard Sieve Series
D. Specification for a Sieving Test

1. Apparatus
2. Sampling

3. Preparation of Sample
4. Procedure--dry or wet screening
5. Method of Reporting Results

E. Specialized Equipment--mills, mixer, microscope, etc.

F. Measuring Devices--pyrometers, controller potentiometers, etc.

G. Ceramic Equipment--kilns, driers, ovens, etc.

III. Determination of Test Controls

A. Investigation of Literature--books, periodicals, etc.

B. Hypothesis of Experiment
1. Theory
2. Variables
3. Measurements

C. Procedure
1. Variable Constants and Changes
2. Measuring Devices
3. Anticipated Results
4. Equipment Design

D. Recording
1. Record of Hypothesis
2. Record of Procedure
3. Record of Variable
4. Record of Equipment
5. End Results

IV. Development of Adaptable Methods and Devices

A. Temperature Measurements
1. Method
2. Devices

B. Controls
1. Basic Principles
2. Method of Automatic Control
3. Controllers

V. Design and Construction of Specialized Equipment

A. Experimental Kilns

1. Construction Principles
2. Special Features
3. Measurement and Control

B. Specialized Equipment

Note: Each experiment requires the construction of some special equipment, which is usually not purchasable, along with standard equipment such as chemical glass ware, measuring devices, and controllers. The experiment controls the type and method of construction.

The outline as presented is by no means intended to be a complete study of ceramic technology for changes in the field are constantly being affected. Research in manufacturing processes, according to Kingery, has caused many changes in the ceramic industry. He lists a number of factors that have been important in effecting these changes:

> First of all, there has been a substantial increase in ceramic research and its general dissemination.
>
> Secondly, users of special ceramic materials have become sufficiently concerned with special properties to undertake ceramic research. . . .
>
> Thirdly, rapidly growing electrical, electronic, aeronautical, atomic energy, and other industries have found that developing ceramics with improved properties is essential to technical progress.
>
> Fourthly, increased automotion and mechanization have been necessary to maintain economic production--and this has required better control of processes.

> Finally, increased realization that statistical quality control can be applied to ceramic processes with substantial advantages has led to a desire for better control of ceramic processes. In general, as theoretical understanding of the factors affecting ceramic processes becomes available, improved utilization of automation and statistical quality control can be achieved--which leads to further study of the principles underlying actual processes.[11]

In summary, the organization of the subject matter in the form of an outline of curricular elements has been presented. These elements were extracted from the resource material from which selected elements can be organized and presented at various educational levels.

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[11]Kingery, W. D. (ed.). Ceramic Fabrication Processes. New York: John Wiley and Sons, Inc., 1958. p. 1

V. *Application of Ceramic Technology to Industrial Education*

A systematic presentation and analysis of American ceramic technology was previously developed. Specifically, an investigation was presented, as a technological research, of the highly complex nature of the principal divisions in ceramic technology. An organizational treatment of the subject matter, presented in outline form, was derived from an analysis of the technological research. The organization of the subject matter is not proposed as a curriculum outline for a specific program, but rather as as prototype for future use of this method for curriculum development by extracting the basic curricular components for arrangement in a course of study applicable to the objectives of specific educational programs.

The introduction included a review of the nature and foundations of the American educational system, with special reference to Industrial Education: industrial arts, vocational and industrial, trade and technical. The curricular unit (The Problem: Slip Casting) is limited to the technical aspects of ceramic technology and the implications for enrichment of industrial education curricula, with an illustration of a curricular unit derived and extracted from components of the subject matter outline. Just as resource studies are requisite to the development of curriculum guides, so are the guides (outlines) essential to sound application of the curricular elements to the educational level.

The approach to ceramic technology should be one that stimulates and challenges the creative capacities or potentialities of the students. It is through the individual's own experiences that real learning takes place. The objectives involved in the application of ceramic technology to industrial

education are to encourage the student to think creatively; to stimulate his interest in the subject by research of literature which pertains to the new learning areas; to require his experimentation with the possible methods for solving the problem; to require his reporting of the results of the problem in a systematic and scientific manner; and finally, to require an evaluation of his results based upon his written procedures and final product.

Implications for Industrial Education

The following unit of instruction in ceramic technology, slip casting, and the method of presentation are selected from the Curricular Elements, to demonstrate how units may be derived from the curricular elements into a teaching unit with breadth and depth. The unit is a prototype for the technical level of vocational education; however, similar units may be derived appropriate to the various educational levels. Selected units may be made comprehensible to the secondary or elementary levels, or enriched with "theory" to the level of ceramic engineers. The unit should be designed to fulfill the objectives requisite to the specific level for which the proposal is made.

The unit of instruction, slip casting, was selected because it is a basic forming process in the ceramic industry by which many shapes and sizes can be mass produced. The process of slip casting includes so many areas of the ceramic technology that study of this one unit alone could touch on a majority of the sciences involved in the subject matter. In addition, the evolution of the process is typical of the historical developments in ceramic processes.

The primary purpose for the outlines in the previous chapter makes it possible for the instructor to be cognizant of the scope of the ceramic technology when he determines which elements to use in the specific units of instruction. Furthermore, the outline serves as a readily understood

source for the units of instruction which are inherent in the ceramic technology. To illustrate the possibilities for the use of the outline, a consideration of the approach to the first manipulative procedure listed for the problem, "to design a ceramic article for production," might require bibliographical research and laboratory experimentation by the students in such areas as follows: bibliographical research would include investigation as to product use, design and decorative processes; laboratory experimentation would include such areas as model considerations by sketching and planning; and determining the method of application for the decorative process.

The unit of instruction was organized to add breadth and depth of knowledge about slip casting in the ceramic technology. The emphasis is upon individual research and experimentation in determining a solution for the problem through the use of techniques such as investigation of literature, experimentation in scientific procedures, application of the investigation and experimentation in solving the problem, and an evaluation of the problem through accurate recording and reporting. The writer believes that the length of time assigned to any one problem is determined by the scope of the problem. However, a single unit may be organized in such a manner as to involve as much time for research as would be required by two or more problems.

The Problem: Slip Casting

To investigate the technique of slip casting as a production process through the utilization of basic principles involving design, calculations, compounding, material preparation, measurements, controls, constructions, testing, and production of a ceramic product.

Manipulative Procedures

The procedure should facilitate the development of a

challenging, problem solving learning situation. Since the purpose of the problem is to develop the student's experience and knowledge in ceramic technology, the instructor's role should be to advise and counsel; to require individual review of the literature; to suggest new research sources pertaining to the problem; to assist in interpreting the results of the experiment; to encourage further experimentation. The instructor should make judicious use of such methods as: demonstration and discussion; visitation--to industry and museums; and teaching aids--films, slides, displays, mock-ups, charts, and diagrams.

Each of the following selected procedures involves research or experimentation in order to successfully complete the unit. Many of the points listed are dependent upon the student's results from his investigation for the preceding point.

1. To design a ceramic article for production.

2. To construct a model.

3. To construct a case and block mold.

4. To construct a casting mold.

5. To calculate, batch, and prepare a casting slip body.

6. To make necessary tests for porperties of the body and make necessary adjustments.

7. To cast and dry ceramic product.

8. To make necessary tests to determine quality of the unfired product.

9. To bisque fire product and make necessary tests to determine fired properties of product.

10. To calculate, batch, and prepare glaze.

11. To test fire glaze on body.

12. To apply glaze and/or decoration to product.

13. To glost fire the ceramic product.

14. To test finished product and evaluate findings.

15. To report recorded results.

Bibliographical Research

The successful conclusion of the problem is often dependent upon the student's accumulated knowledge acquired from the various research techniques. Today, there are many reports, bulletins, and scientific writings published on most phases of the ceramic industry. A review of the literature aids in developing the student's background in the new learning area requisite to experimentation with the materials. The following are selected research areas of slip casting:

Product investigation--purpose: home, industrial.

Decorative process investigation--plastic, greenware, underglaze, overglaze.

Body composition--materials, plastic, non-plastic, temperature range, classification properties.

Rheological phenomena--colloid, base exchange, plasticity, suspension, electrolytes, viscosity, specific gravity.

Glaze composition--temperature range, classification properties, gloss, matt, transparent, opaque, color, fritted, leaded, alkali, Bristol, leadless.

Plaster of Paris--density, strength, absorption, water-plastic ratio, burning, saturation.

Property tests (unfired)--porosity, shrinkage, warpage, adjustments.

Drying of ceramic bodies--elements of drying, methods, infrared, humidity control, air velocity, temperature.

Testing raw materials--grain size, contamination, calcination.

Fired qualities of ceramic bodies and coverings--thermal behavior, eutectics, phase diagrams, densification, vitrification, porosity, absorption.

Investigation of defects--pinholes, crazing, spalling, cracking, crawling, and others.

Measurements and controls--thermocouples, thermometers, potentiometers, milliameter.

Investigation of recording techniques and reporting.

Laboratory Experimentation

Because record keeping and reporting are of key importance to technicians, it should be stressed throughout the unit that it is necessary for the student to maintain accurate and complete records; otherwise, a true evaluation of his problem is not possible. This section on experimentation includes the resolving of solutions from the research that are applicable to the manipulative procedures.

Calculation of ceramic body--earthenware, stoneware, porcelain, terra cotta, non-plastic.

Compound slip--viscosity, electrolyte, specific gravity, release, flocculation, deflocculation.

Form test pieces--dry, test shrinkage, warpage, porosity.

Test fire--temperature range, absorption, shrinkage, thermal analysis, density, vitrification.

Plaster--water ratio, strength, density, absorption.

Calculate and batch glaze--substitution, blending, opacity, color, milling time, liquid contents, fritting, testing, specific gravity, viscosity.

Glaze application--effects of method, thickness, effects of application.

Properties and uniformity of raw materials--sieving, grinding, milling calcining.

Method of clay preparation--blunging, screening, properties, effects of method.

Thermal behavior of ceramic materials--thermal analysis (thermograms), temperature measurement and control, microscopic examination.

Effect of water and electrolyte on plaster of Paris molds--saturation, drying, sulphating, calcium deposits.

Control of production determined by records.

Record keeping and reporting.

Materials

Ceramic raw materials include many complex compounds and reagents that are practically in unlimited supply. However, reactions involving these materials are often difficult to predict because complex compounds do not remain constant at high temperatures. Analyses and research of these ceramic material reactions are available for reference, as well as information on product properties that are helpful in solving other ceramic problems. The following is a list of materials that may be used for the "Slip Casting" problem; however, there are available many other materials and combinations of materials that a student may want to consider.

Clays	Metal Oxides:
Feldspars	Calcium
Silica	Zinc
Alkalies	Tin
Fluorspar	Lead
Borax and Borates	Manganese
Plaster of Paris	Barium
Electrolytes	Chromium
Bentonite	Cobalt
Kaolin	Copper
Sizing	Ferric
Nepheline Syenite	Magnesium
	Nickel

Tools and Equipment

It may be seen from the list below, that technical ceramics involves many specialized tools and equipment; those listed are standard manufactured equipment. There are many occasions, however, in which they are used in combination

with one another; at other times, they are adapted to the specific problem and additional equipment and tools are designed and constructed. Some problems require the use of a special kiln, oven, or method of method of measurement and temperature control in order to solve the problem. The following list is only suggestive of the type needed for this problem. Other problems may require more or less sophisticated tools and equipment.

Blunger	Scales	Chemicals
Filter press	Viscosimeter	Voltage Controller
Blender	Recorder	Controller
Grinder	Servo Unit	Microscope
Mill	Potentiometer	Drier or Oven
Mixer	Thermocouple	Thermometer
Pug Mill	Sieves	Assorted Hand Tools
Auger	Millimeter	

Individual research and the application of basic scientific knowledge are the essential factors in the study of ceramic technology. This basic technique once developed may be applied to most areas of ceramic research.

The problem, slip casting, a basic ceramic forming process, was presented to illustrate the procedure for selecting curricular elements from the subject matter outline and organizing them into an instructional unit for industrial education. Although the unit was designed for the technical level, similar units may be derived that are appropriate for, and comprehensible to, other educational programs. The selected unit is delimited by the objectives representative of a particular program. The inclusion of research and experimentation extends the problem beyond the usual project approach of curriculum organization; it could include a theoretical problem implemented and solved on paper. With the wealth of subject matter presented in the outline, an enriched technical or general program may be developed.

Conclusions

Considerable interest has been generated in the need for improvement of curriculum development in the United States, especially since the advent of the atomic age and "Sputnik." Numerous studies have been made to determine curriculum content and to ascertain the status of industrial education in the United States. This study was a departure from the usual research in curriculum development in that it was an attempt to obtain curricular components from a technological research and project it into an outline of organized subject matter.

The conclusions are based on the postulate that the contemporary society in the United States has developed into one that is basically technological, and that educational institutions should reflect this technology through the objectives of the various programs. The conclusions, therefore, reflect the dynamic technological advancements and a need to develop a curriculum to reflect these changes in industrial education programs.