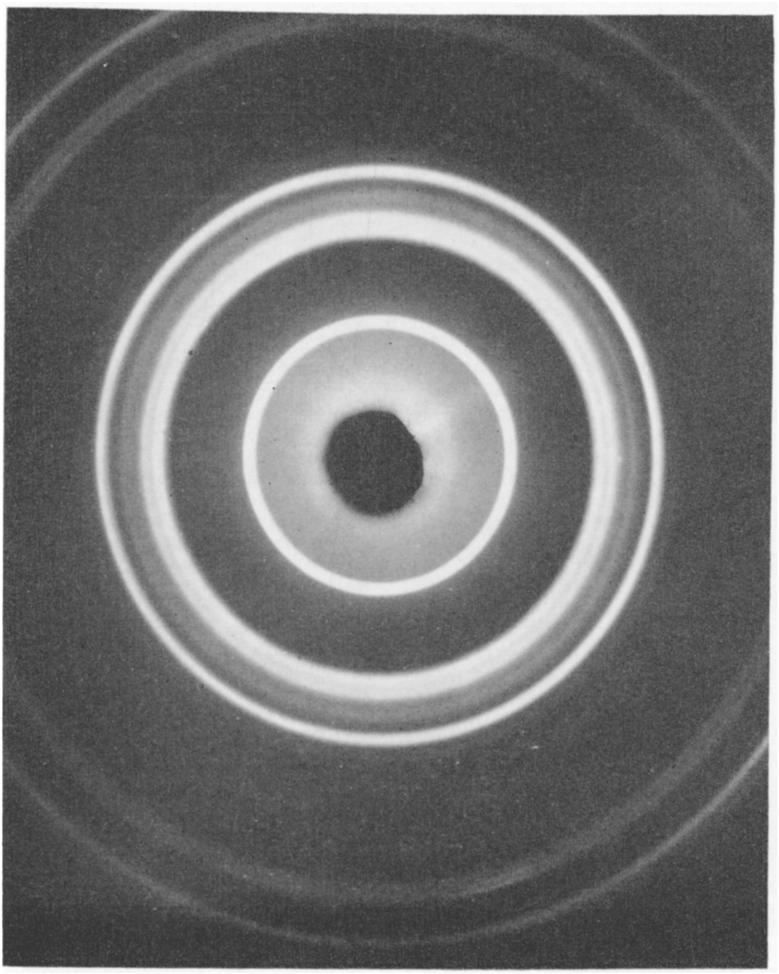
ENGINEERING EXPERIMENT STATION

The Research Engineer

GEORGIA INSTITUTE OF TECHNOLOGY

ATLANTA, GEORGIA

OCTOBER, 1953 - JANUARY, 1954



The Research Engineer

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LIBRARY RESEARCH

The greatest heritage which our civilization has is stored in our libraries. Although many people agree with this thought as it applies to literary work few are aware of the magnitude and value of our technological publications. Especially since the invention of the printing press, the most significant intellectual efforts of the billions of men who have already lived have been recorded. Thus, our libraries present the key to the thoughts and discoveries which have been laboriously developed.

Even in our lifetime, the amount of material being published has increased

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It appears that only about 17,000 persons will be awarded bachelor degrees in scientific and engineering subjects in America this year. Yet, it has been estimated that there is a demand for as many as 30,000 such graduates.

The reason for this shortage is that there aren't enough young people who are qualified and who **want** to study technical subjects. The ambition to study the sciences results partly from inheritance and partly from the student's experiences in his high school classes and laboratories. Teachers who are enthusiastic about the sciences and are well prepared to teach them do much to turn their pupils toward the technical schools.

However, it is commonly observed that high school teachers are required to spend so much of their time in studying courses on teaching methods that they are often unable to properly prepare themselves for their fields of specialization.

If we expect to enroll the number and quality of men and women demanded of our professional schools, it is important that we make it possible for our precollege teachers to be well founded in the sciences.

The University of Delaware has recognized the need for more specialized study by high school instructors and has adopted a new curriculum for its Master of Education Degree for teachers of science in secondary schools. This program departs from conventional degree requirements in that a majority of the class time, in fact four-fifths of it, is devoted to study of the sciences instead of to education subjects. Such a plan of study should go far to provide teachers capable of inspiring a strong desire for science and engineering as professions.

With adequate recognition of the problem by the institutions of higher education and by the school boards, our high school teachers can help to increase the number of students who desire to enroll in engineering and science subjects; thus, they can make it possible for schools like Georgia Tech to train the needed numbers of men and women who do so much to make and keep America great.

BLAKE R. VAN LEER
President, Georgia Institute of Technology

GEORGIA CLAYS

By R. A. Young,* L. A. Woodward,** W. C. Whitley,*** J. D. Walton,† N. E. Poulos,†† Clyde Orr††† and F. Bellinger*†

Clays, particularly kaolin, are the primary mineral asset of Georgia. Yet, very little clay research of any kind has been conducted in the state. This article gives a brief review of the facilities now available at Georgia Tech for clay research and a preliminary report of some of the first investigations.

The magnitude of the kaolin industries in Georgia is well known, as is the fact that the great mass of mined material is shipped to other staates for use as fillers, coatings, pigments, and in ceramics. Also most of the applied research and development is conducted in out-of-state laboratories, notably in the East. In order to obtain basic data, with which to assist the Georgia clay people in the solution of their problems and with which to foster and assist new Georgia clay industries, the Engineering Experiment Station allocated funds to support basic research in this field. This work has been going on for a little over a year. As is usual in undertaking any basic research project, considerable effort was expended initially in determining the problems, developing techniques, and planning the research program.

All of the constituents of a clay influence its behavior, the effect being noticeable sometimes when only small amounts of the constituent are present. The various impurities impart different physical properties. Many, such as the iron oxides, lime, magnesia, sodium, and potassium carbonates, etc., promote fusion, and color is influenced by oxides of iron, titanium, manganese, copper, etc.

Of the many problems needing investigation, it was decided first to concentrate on the viscosity of clay-water suspensions. This is important to the clay industry, as the viscosity of clay in suspension is one of the deciding factors in the ultimate use of the clay. In general, the viscosity of a clay must be high to be suitable for ceramic purposes, and the viscosity must be low to be suitable for paper coating. Large amounts of clay are neither high nor low in viscosity and hence their use is limited. If all of the factors that determine the viscosity of clay-water suspensions could be found and understood, it might be possible to find better uses for this "in between" material.

Attempts have been made to find a reliable method of characterizing the viscosity of a clay-water suspension. This is no easy matter, for a suspension of a single clay, depending on concentration and degree of dispersion, may be Newtonian, thixotropic, or dilatant. Several methods are under investigation. The most promising one is that of characterizing the clay in terms of the per cent solids necessary to give a certain arbitrary viscosity with all measurements made at the same rate of shear.

Although all variables in this problem are not completely settled, a series of crude clays supplied by various producers and described as having a wide range of viscosity values is being examined by various means. These clays are being studied in the chemistry laboratory, the ceramics laboratory, the microscopy laboratory, the x-ray laboratory, and the micromeritics laboratory. The accomplishments in each of these laboratories

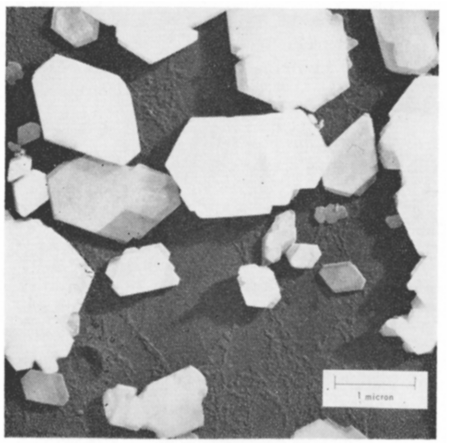

Figure 1. An electron micrograph of kaolin particles.

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are discussed in the pertinent section below. Development of the techniques and collection of data have required the full efforts of the personnel since the inception of this work. A brief review of the data has not shown a simple correlation between viscosity and another variable but it has revealed the need for more precise data in certain areas and additional data to fill in the gaps.

Work in the future will be directed along these lines and, with a more complete knowledge of the composition and characteristics of Georgia kaolins, correlations of properties, uses, and effects may become feasible. The Engineering Experiment Station has developed techniques and is now equipped for the study of clays by means of the following methods and processes:

Electrodialysis
Removal of organic matter
Catalytic activity
Surface area measurements
Optical microscopy
Particle size
Particle size distribution
Particle concentration in liquids and gases
Particle density
Viscosity of clay-water suspensions
Electron microscopy
Electron diffraction
X-ray diffraction
Differential thermal analysis
Fractionation studies
Chemical analysis
Ionic exchange
pH measurements
Spectral photometric measurements
Wettability
Adsorptivity
Grinding characteristics
Sedimentation properties
Filterability

Chemistry Laboratory

The chemical analysis of a clay may give some indication of its behavior or suitability for a given use, but the value of the analysis may be limited because it does not show the exact manner in which the elements are combined, the fineness of the grain, and many other factors which greatly influence the behavior of a clay. For example, the oxides of iron have both a fluxing effect and a coloring effect in the firing of clays. The presence of even a small per cent is often sufficient to produce a noticeable color effect in a fired clay and hence is an injurious constituent of kaolins for certain uses. In such cases it is important to know not only its percentage but also its state of chemical combination, since both factors may have some effect on the clay's behavior. However, the final color and depth of shade depend on many other factors including the particle size, the presence of other minerals which influence color, the temperature of firing, the degree of fusion and the condition of the kiln atmosphere.

Methods have been studied for determination of silicon, iron, titanium, aluminum, phosphorous, calcium and magnesium. The flame photometer is being used to determine sodium and potassium.

A study of the factors influencing the pH of clay-water suspensions is also being made.

Ceramics Laboratory

In the ceramics laboratory, a considerable number of testing procedures have been investigated. These include the determination of particle size distribution with a hydrometer; the measurement of the viscosity of clay-water suspensions with the Brookfield viscosimeter; the preparation of various fractions with gravitational methods and the Sharples centrifuge; and other testing and sample preparation methods.

A temperature-recording, furnace-controller assembly is soon to be put into operation in the ceramics laboratory. This assembly utilizes a proportional-type controller which provides selection of heating rate, holding time at a pre-set temperature and cooling rate. Among the furnaces to be used with this controller is a platinum muffle furnace designed for differential thermal analysis studies. A twin pen recorder and DC amplifier complete the differential thermal analysis equipment.

Work in this laboratory is under way towards a correlation between the calculated stresses developed within a ceramic coating when applied to iron and the thermal and mechanical shock resistance of the coatings. Metals other than iron are to be included in this work. Studies will be made to deter-

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THE PRICE GILBERT LIBRARY

By Dorothy M. Crosland*

For many years Georgia Tech's library building has been inadequate. Often, students could not find a place to study, and many valuable publications were inaccessible and subject to loss by fire. Today, however, the institution can boast one of the most beautiful libraries in the nation, with space for everyone and the entire collection safely stored and readily available to whomever needs it.

The new building which houses the Georgia Tech library collection is a magnificent piece of architecture which stands, commanding the campus, as a symbol of the faith of the institute administration and the Board of Regents in the value of a library. The building is named for the late Justice Sterling Price Gilbert as a tribute to a great Georgian who believed in education in his state.

The building is an air-conditioned contemporary structure of five floors designed to house approximately 450,000 volumes and seat about 800 people. The north wall, 180 feet by 80 feet, is entirely of glass; the south wall is equally spaced with Roman brick and windows; and the east and west walls are brick. The ground floor has a music room and faculty lounge that may be opened to become one large room that will seat 300 people. The administrative offices and the processing room as well as the staff lounge, the rest rooms, the receiving room, and the only locked area in the building are also located on the first floor. The first and second floors are similar in plan to the third and fourth floors with the even numbered floors forming balconies. The first and third floors have large reading rooms; one will serve primarily the science-technology portion of the library and the other will serve the general studies section. The library is a functional

*Director of Libraries

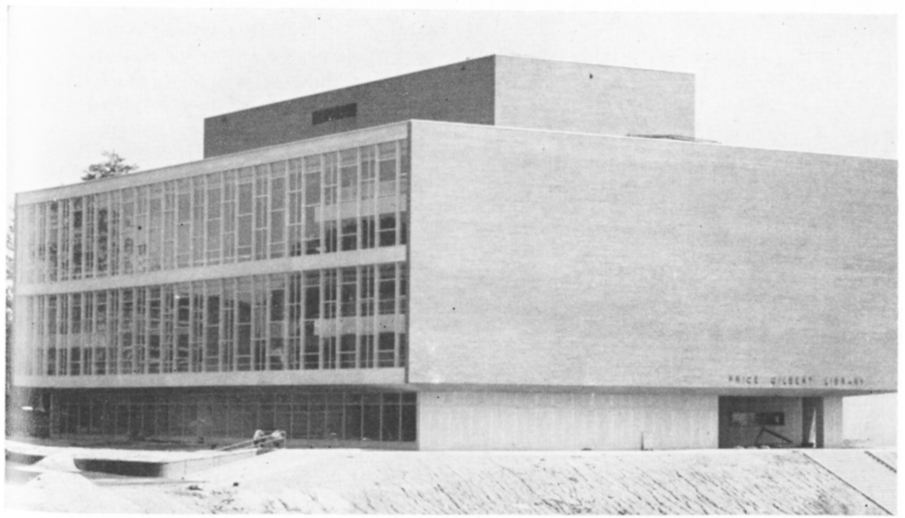

Figure 1. The main reading rooms of the new library are naturally illuminated through the glass wall on the north side of the building.

building, planned for study and comfort. There are 170 individual study tables and 17 carrels on four floors. Comfortable lounge chairs and sofas are also scattered throughout the building. The ceilings above the stacks are low, but because of the 19-foot ceilings of the two large rooms, and because of the manner in which one area has been made to fuse with another, there is a general feeling of spaciousness. Here is a building that will serve well the students, faculty, other staff members and, it is hoped, the engineers and scientists of the state and region.

The dedication of this library will always be remembered as a milestone in the progress of Georgia Tech. For thirty years or more, Georgia Tech has had inadequate physical library facilities. Although a new library building has been on the priority list since 1922, other buildings seemed to take precedence. During World War II, which has been called a scientific war, specific plans to build a new library were undertaken.

The war, with its demands for more highly trained engineers and scientists, had a far reaching effect on Georgia Tech. A new doctoral program in the Graduate School and the expanded research program of the Engineering Experiment Station resulted in heavy demands on the library. It was soon realized that an accredited graduate school is impossible without a good library collection and that scientific research is dependent on a library to supply the materials of knowledge of what has gone before.

Once the needs for a good library were evident, it was decided, in the absence of proper physical facilities, to place the emphasis on building the collection of books to meet the requirements of the undergraduates, the graduate students, the faculty and the other staff members of the academic departments and the Engineering Experiment Station.

Since scientific and technical journals are terrifically expensive Georgia Tech could not have acquired the valuable collection that today is recognized throughout the country without extra appropriations. Fortunately, one of the country's great foundations, the General Education Board, recognized Georgia Tech's need to build its library resources. The members of the Board were aware that the Institution could play an important role in the industrial development of the South and the advanced training of engineers and scientists. The first of several grants for the purchase of materials for graduate work and research was made in December, 1939. Since that date, the General Education Board has been a veritable godmother by granting $97,000 to the library. The Board of Regents, in turn, has allotted $45,000, making a grand total of $142,000 for books, periodicals and society publications for advanced study and research.

Resources

Let us take a few moments to examine the resources which our library now has. The library currently receives 3,701 periodical and serial publications. Of this number, approximately 2,500 are journals, received from all over the world. Reference books and text books are also plentiful, but current periodical literature is the backbone of today's technical libraries. A researcher in science must have the most recent information which is found in journals and often times in so-called unpublished reports.

The library is the central agency for reports arising out of government-industry contracts. These include those reports that are distributed only on the basis of a "need-to-know." Classified reports are housed in a vault in the processing room; unclassified documents are kept in filing cases in the two rooms at the northwest corners of the third and fourth floors and in the locked area on the ground floor. Cards are received for the reports from the Armed Services Technical Information Agency.

Georgia Tech has been designated a depository for technical reports of the following research agencies: Harvard University, Cruft Laboratory; Massachusetts Institute of Technology, Laboratory for Insulation Research; Massachusetts Institute of Technology, Research Laboratory of Electronics; Massachusetts Institute of Technology, Solid-State and Molecular Theory Group; Massachusetts Institute of Technology, Radiation Laboratory; Stanford University, Electronics Research Laboratory; U. S. Atomic Energy Commission; U. S. Army Map Service.

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HEAT TRANSFER TO SLURRIES FLOWING IN PIPES

By CLYDE ORR, JR.*

This article reports one of the first extensive investigations of the heat transfer properties of slurries. It sets forth the procedures by which the heat transfer properties of a variety of slurries may be predicted.

The great body of information dealing with the flow and heat-transfer properties of pure liquids forms an ideal basis from which to examine slurries. It is now generally agreed that, when a liquid flows in a pipe with a mean velocity exceeding a certain value, three zones or types of flow exist simultaneously. Film or streamline flow prevails near the wall, turbulent flow prevails in the core, and between these zones a buffer or intermediate layer exists. Heat leaving the pipe wall must be conducted through the film and into the buffer layer. In the latter, heat is both conducted and transferred by mechanical mixing into the turbulent core comprising the major portion of the liquid.

When these characteristics are properly considered, an average individual coefficient of heat transfer, h, may be obtained. It has been proved that this coefficient is a function of the flow characteristics and the physical properties of the stream. The various factors involved are: the diameter of the pipe, D; the velocity of the liquid, v; the density of the liquid, ρ; the viscosity of the liquid, μ; the heat capacity of the liquid, C_p; and the thermal conductivity of the liquid, k. A treatment of all of these factors according to the principles of dimensional analysis results in the relationship

$$\frac{hD}{k} = a\left(\frac{Dv\rho}{\mu}\right)^{b}\left(\frac{C_p\mu}{k}\right)^{c} \quad , (1)$$

where a, b and c are dimensionless constants which must be evaluated experimentally.

For liquids under conditions of turbulent flow and not having viscosities greater than twice that of water, it has been found that Equation 1 may be used with a having a value of 0.023, b having a value of 0.8 and c having a value of 0.4 if the liquid is being heated or 0.3 if the liquid is being cooled. Regardless of whether the liquid is being heated or cooled, the properties of the liquid are to be evaluated at its average bulk temperature.

None of the variables of Equation 1 except viscosity change markedly with temperature. However, the viscosity of relatively viscous liquids may vary sufficiently between the wall film and the turbulent region to require a modification of the equation. Several suggestions have been offered. For example, the use of Equation 1 with a and b having values of 0.023 and 0.8, respectively, with c having a value of 1/3 and with all properties evaluated at the film temperature, has been suggested. Evaluating the film temperature presents difficulties, however. It has been found that this equation is satisfactorily approximated and its use is made more convenient if the ratio, raised to the 0.14 power, of the liquid viscosity at the bulk temperature to the liquid viscosity at the temperature of the inner surface of the pipe wall, μ_w, is incorporated, provided all other terms are evaluated at the bulk temperature and the constant a is given the value of 0.027. The resulting equation is

$$\frac{hD}{k} = 0.027\left(\frac{Dv\rho}{\mu}\right)^{0.8}\left(\frac{C_p\mu}{k}\right)^{1/3}\left(\frac{\mu}{\mu_w}\right)^{0.14} \quad . (2)$$

The use of Equation 2 is not recommended when the Reynolds number, $\frac{Dv\rho}{\mu}$, is less than 10,000.

Equation 2, being applicable to all liquids within the limits outlined above, will be employed in the discussions that follow. Indeed, it will be shown to describe the heat-transfer properties of slurries over a quite considerable range of concentrations. A large part of

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this report is concerned with showing how to evaluate the parameters comprising Equation 2 for the case of slurries.

The investigation was divided into three rather distinct phases: (1) study of the thermal conductivity of slurries, (2) study of the viscosity characteristics of slurrie, and (3) the heat-transfer investigation proper.

Thermal Conductivity

As is well known, the thermal field in a two-phase system is analogous to the electrical field in a similar system. The equation describing electrical fields has been developed by Maxwell and subsequent investigators; it may be written in analogous form for the thermal field as

$$k_s = k_L\left[\frac{2k_L + k_p - 2x_v(k_L - k_p)}{2k_L + k_p + x_v(k_L - k_p)}\right], \quad (3)$$

where k_s, k_p and k_L refer to the thermal conductivities of the slurry, the solid particles and the liquid, respectively, and x_v is the volume fraction of solids composing the slurry.

When this equation was checked with data from the literature involving bituminous compounds with quartz sand and aniline gum with quartz sand, agreement was found. While these limited data indicated that Equation 3 possessed considerable merit, it was deemed advisable to test it experimentally under more stringent conditions. Since water was of most interest as the liquid phase, some means was sought by which water could be used and, at the same time, the settling out of the solid material prevented. This latter requirement was met by using a very dilute gel instead of pure water. The error introduced by so doing was small.

The apparatus used to measure thermal conductivity is shown in Figure 1. It consisted of two chambers which could be main-

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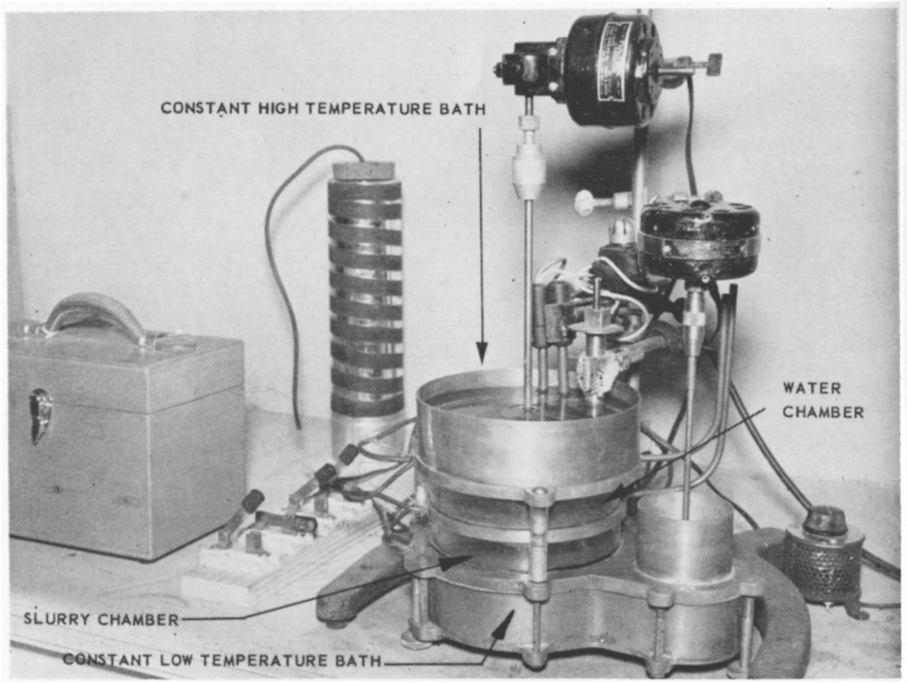

Figure 1. This apparatus was designed at Georgia Tech to measure the thermal conductivity of slurries.

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GEORGIA CLAYS

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mine the factors responsible for the crystallization of cristobalite in ceramic coatings. Cristobalite is one of the crystalline phases of silica (SiO_2), and exists in two forms, "X" below 220° C and "B" above this temperature. The conversion from "X" to "B" cristobalite results in a linear expansion of about one per cent at 220° C. Experiments have shown that the presence of cristobalite in an enamel greatly reduces the stress developed within the enamel. The stresses developed within an enamel are proportional to the thickness and firing temperature of the coating, thus very thin coatings have been necessary for high temperature application. By the use of cristobalite, thicker coatings, providing a greater degree of thermal insulation, should be possible.

Microscopy Laboratory

A group of crude clays, described by producers as having a wide range of viscosities, have been fractionated and electron micrographs prepared. These clays are now being studied in detail by the personnel participating in the project. The study was undertaken to determine the relationship, if any, between particle shape and commercial use. The results are not as clear-cut as desired, but general trends have been noted. The smaller particles (up to about 2 microns) for papercoating clays occur as well formed crystal plates. Because of fractionation during processing, few particles larger than two microns were found; those seen were, in general, cylindrical laminated "stacks" of mosaics of the crystal plates.

Filler clays, as might be expected from their intended use, contain relatively fewer particles having a definite crystal structure but resemble the coating clays with, of course, more of the above-two-micron particles. This again probably is due to methods of processing.

Those clays described as intended for use in refractories are all considerably different from the coating clays. The smallest particles (below 0.5 microns) have moderately good plate-like crystal form, but with increasing size the pieces are more accurately described as being irregular sheets of material with only much smaller crystal forms being noted as making up the sheets. The above-two-micron pieces are not cylindrical "stacks" but irregular pieces with no distinguishing characteristics.

Those clays that are used as ceramic clays seem to be somewhat mixed in form. Most resemble the refractory clays, but some seem to grade into the coating type clay.

X-Ray Laboratory

X-ray diffraction has long been recognized as one means of identifying clay minerals and as the principal means of determining their crystal structures. With the increasing interest in and understanding of imperfect structures, x-ray diffraction is becoming ever more valuable in the study of clays. It affords a means of measuring the size of the crystallites which comprise the particles, and thus is capable of yielding valuable information about the structure of the particles. It affords a means of comparing the orientability of clays. Orientation gives an indication of shape, and may also be a variable affecting viscosity.

Probably of most interest is the fact that x-ray diffraction affords a means for studying certain of the imperfections within the clay crystals. These imperfections would be expected to influence the macroscopic physical properties of the clay.

Some effort has been devoted to understanding and measuring one imperfection which seems to occur commonly in kaolinite. It is called "nb/3 shifting" and arises from the fact that adjacent layers of kaolinite may fit together equally well in any of three symmetrical positions along the one axis of the unit cell, but only one of these positions allows the aluminum atoms to be aligned through successive layers. The misalignment, i.e., "nb/3 shifting," affects the various lines in the diffraction pattern differently. It is theoretically possible to derive a quantitative relationship between the amount of

"nb/3 shifting" and the measured effects on the diffraction pattern.[1,2]

Several photographic methods combined with recording on film strips or on charts are available for showing this shift. It has been found that the greater dispersion and resolution and the more accurate and readily measurable registration of intensities and line profiles make the x-ray Geiger-counter diffractometer* more generally suitable than any one type of x-ray camera. In many cases the diffractometer will yield information not obtainable with film techniques, although at times the converse may be true.

Clays in which the particle shape is generally plate-like, or needle-like, such as kaolinite and halloysite respectively, will readily orient to some degree upon handling. Unless this orientation is controlled, preferably either by making it truly random or by maximizing the preferred orientation, the intensities recorded in the diffraction pattern will be without significance. A method for preparing samples for the diffractometer has been developed and tested. This method is a modification of a technique described by McCreery[3]. It employs his sifting technique but differs in that a constant volume of sifted material is used and the operation takes a little less time.

Johns[4], in a study of the mineralogy of clays, concluded that increasing nb/3 shifts in kaolinite was accompanied by an increasing "C" dimension (for kaolinite the "C" dimension is the thickness) of the crystallites, as though the presence of nb/3 shifts gave added strength to the interlayer bonds. This was found not to be true here. In the seven samples most studied there was no apparent correlation between amount of nb/3 shifting and "C" dimension. A possible reason for the differing observations of Johns and ourselves may be found in the fact that Johns had only one sample of Georgia clay. Since it was from Georgia he accepted it as "well crystallized," and certainly it was in comparison to his other samples. We, on the other hand, have investigated a range of nb/3 shifting within Georgia clays.

*Diffractometer is a new term recommended by the International Union of Crystallography for this instrument, which in the past has been called an "x-ray Geiger-counter spectrometer."

An effort has been made to find correlations between the various measured factors, and combinations thereof, for the electrodialyzed clays. The electrodialyzed form was selected for intensive analysis because it was felt that this form represented a nearly reproducible condition. The data on seven samples for pH and viscosity at 20 per cent solids (viscosity measured with a Brookfield viscosimeter, spindle #2 at 30 rpm) were selected more or less arbitrarily for detailed study.

For six of the clay samples, an apparent correlation was found of hydrogen-ion concentration with degree of nb/3 shifting and "C" dimension of the crystallites, taken together. The correlation may be explained by making two specific assumptions. The first assumption is that the particles of the six clays have roughly the same shape so that their specific surfaces would vary inversely with any single dimension, in this case the "C" dimension of the crystallites. The second assumption is that an increase of nb/3 shifts means an increase of possible cation sites per unit surface area. On this basis one would expect the H ion concentration to be inversely related to the "C" dimension of the crystallites and directly related to the amount of nb/3 shifting. This analysis depends in turn upon the observations and theory that, as absorbed cations are displaced by H ions in electrodialysis, the pH of the clay slip decreases to an end point that is a constant for a particular clay.

The amount of nb/3 shifting is observed by noting the ratio of two peak heights in the diffraction pattern. The quantitative relation of this ratio to the amount of shifting is not known at this time. Because of the uncertainty about this ratio and because the errors involved in measuring are fairly large, while the number of samples was small, it is not possible at this time to derive any specific functions relating the hydrogen ion concentration (or pH) to the crystallite size and nb/3 shifts. However, if further investigation, involving many more samples, still indicates the correlation suggested by the present data, it would seem to be both possible and feasible to derive the functional relationship of these three factors. Such a derivation would require calculating the relation

of nb/3 shifting to the observed peak ratio; this calculation is theoretically possible.

While it has not been possible to find any consistant correlation of pH, crystallite size and nb/3 shifting with the viscosity of these samples, it is felt that such a correlation could have been masked here by impurities in the samples. Small amounts of bentonite and halloysite are particularly suspect in this respect. Further information about the shapes of the particles is not available. Some information on shape might be obtained from x-ray measurements of orientability. The orientation would be induced by depositing clay samples on a flat surface through evaporation of a clay-water suspension.

Micromeritics Laboratory

The Micromeritics Laboratory (micromeritics stems from two Greek words which are combined to mean small particles) offers a wide variety of research facilities, some of which are unique in the South, to the clay industry of Georgia.

Analytical measurements for which facilities are maintained include average particle size, particle size distribution, specific surface area (both external surface area and the internal surface area presented by the walls of cracks along grain boundaries, capillary pores, etc.), particle concentration in either liquids or gases and particle density. General facilities are also available for investigations of the adsorptivity, wettability, catalytic activity, optical properties and grinding characteristics of solid powders; the viscosity, the sedimentation properties and the filterabiltiy of slurries; the nature and hazards of atmospheric pollution by dusts; and other related properties. Much of the apparatus available in this laboratory has been designed and erected especially for the work here. One of the two adsorption apparatus is shown in Figure 2.

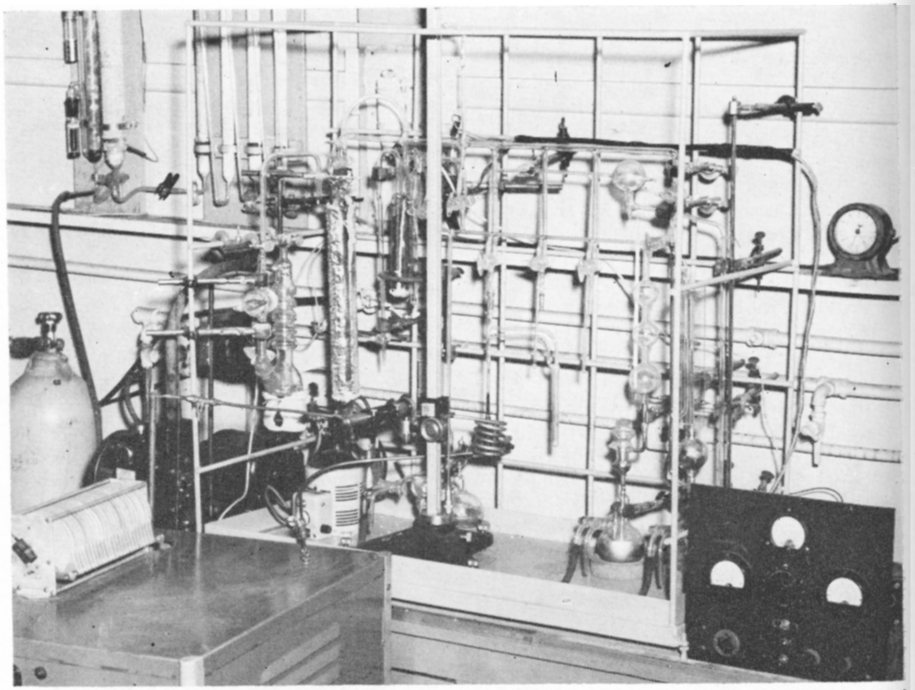

Figure 2. This adsorption apparatus for measuring surface area, adsorptivity, etc., is one of the important instruments used in studying clays.

The work in this laboratory has resulted in a continued series of articles of interest to the clay industry. While most of the articles are prepared on the basis of "fine-particles" in general, some are based specifically on clays. As examples:

"A Rapid Liquid-Phase Adsorption Method for the Determination of the Surface Areas of Clays." Orr, C., Jr. and Bankston, P. T., *J. Amer. Cer. Soc. 56*, 58-60 (1952).

"Co-Current Turbulent-Flow of Air and Water Clay Suspensions in Horizontal Pipes." Ward, H. C., and DallaValle, J. M., soon to be published in *Chem. Engr. Progress.*

* * * * *

The Engineering Experiment Station now has adequate personnel, equipment and techniques for basic and applied research on clays. Data have been collected on a variety of types of clays from Georgia, and existing correlations between their physical, chemical and usage properties are being investigated. There is a very apparent need for more precise data on refined samples in order to obtain a basic understanding of clay, its variables and its behavior. It is planned that separate articles dealing with specific phases of this work will be published in appropriate journals in the future.

It is our desire that the clay industries of Georgia and of this region avail themselves of our facilities and background in this field to assist them in solving their problems and increasing the uses of Georgia clays.

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2. A. J. C. Wilson, **X-Ray Optics**, Methuen & Co., Ltd., London (1949), Chapter V, VI.
3. George L. McCreery, **J. Am. Ceram. Soc. 32**, 141-6 (1949).
4. W. D. Johns, **The Mineralogy of Flint Clays and Associated Fire-Clays**, Thesis, University of Illinois (1952).

THE PRICE GILBERT LIBRARY

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Recently the library was asked to be a depository for the research publications of the Rand Corporation of Santa Monica, California. Supplementing these reports, there are many series which are purchased or received on exchange. Among these are the Lecture Notes of the Institute for Fluid Dynamics and Applied Mathematics at the University of Maryland and the dissertations of the Swiss Federal Institute of Technology at Zurich, Switzerland.

Since May 1946, the library has received copies of U. S. patents; it is hoped that before too many years patents back to 1925 may be acquired. The library subscribes to the most important patent journals of Canada, England, Germany, France and Australia. A complete collection of the *Official Gazette of the United States Patent Office* and a long run of the *Abridged British Patent Specifications* are in the collection. Patents play an important role in applied scientific research. Since 1946, patent lawyers, research workers and would-be inventors throughout the Southeast have made use of the patent specifications.

The library is among the important university and research libraries participating in the Farmington Plan for the acquisition of foreign publications. The Tech library receives copies of all items in the field of textile engineering which are published in countries participating in the plan. Graduate students have found the textile collection strong in chemistry and design.

In aeronautics, the library has complete files of the more important journals of the United States and many foreign countries. The library subscribes to the cards of the Pacific Aeronautical Library of the Institute of Aeronautical Sciences. It also has the *Catalog of German and Japanese Air Technical Documents* issued by the Air Material Command, Wright Field, Ohio.

No one library can hope to have all the resources necessary for research, but most materials not available at Georgia Tech are available through interlibrary loans either as

originals, photostats, or microfilm copies. Through the *Union List of Serials*, *Union Catalogs*, and bibliographies of holding libraries in certain fields or regions, materials can be located for borrowing.

Services Rendered

The South cannot boast the large libraries that other parts of the country have, but rapid strides are being made to keep up with Southern industrial development. Libraries are as vital to the growth of research as laboratories, classrooms and offices. For this reason the resources of the Georgia Tech library are made available not only to students and workers at Georgia Tech but also to various industrial concerns throughout the South.

During the past decade many industrial research institutes have been established in the Southeast. These and the large government agencies currently doing millions of dollars worth of research, have increased the interlibrary-loan activities of the Georgia Tech library by heavy borrowing from its collection. Sometimes, as in the case of the Air University, the requests are tapered off as the agency libraries are expanded. The heaviest borrowers have been the following libraries:

Carbide & Carbon Chemicals Company, Oak Ridge, Tennessee
Redstone Arsenal, Huntsville, Alabama
Arnold Engineering Development Center, Tullahoma, Tennessee
Southern Research Institute, Birmingham, Alabama
U. S. Department of Agriculture, Washington, D. C.
Communicable Disease Center, U. S. Public Health Service, Atlanta, Georgia
West Point Manufacturing Company, Shawmut, Alabama
Lockheed Aircraft Corporation, Marietta, Georgia
E. I. duPont de Nemours Company, Savannah River Project, Augusta, Georgia

Figure 2. Large reading rooms are located on the first and third floors of the library.

These are only a few of the agencies that have found the Tech library valuable to their research programs. Loans of library materials on a smaller scale have been made in the past year to the following agencies, industrial firms, research institutes:

Argonne National Laboratory, Lemont, Illinois
Babcock and Wilcox Company, Alliance, Ohio
C. F. Braum and Company, Engineers, Alhambra, California
California Company, New Orleans, Louisiana
Callaway Mills, LaGrange, Georgia
Chemical Products Corporation, Cartersville, Georgia
Consolidated Vultee Aircraft Corporation, Fort Worth, Texas
Coca-Cola Company, Atlanta, Georgia
Coos Bay Lumber Company, Coos Bay, Oregon
Corn Products Refining Company, Argo, Illinois
Dow Chemical Company, Freeport, Texas
Esso Laboratories, Baton Rouge, Louisiana
General Foods Corporation, Hoboken, New Jersey
General Motors Institute, Flint, Michigan
Institute of Textile Technology, Charlottesville, Virginia
Girdler Corporation, Louisville, Kentucky
Hudson Pulp and Paper Corporation, Palatka, Florida
International Minerals and Chemical Corporation, Mulberry, Florida
Lowndes County Engineers, Haynesville, Alabama
Magnolia Petroleum Company, Dallas, Texas
Minute Maid Corporation, Plymouth, Florida
Monsanto Chemical Company, Texas City, Texas and Springfield, Massachusetts
Oak Ridge National Laboratories, Oak Ridge, Tennessee
Radiation Research Corporation, West Palm Beach, Florida
Rohm and Haas Company, Huntsville, Alabama
Redstone Arsenal, Huntsville, Alabama
Reynolds Metals Company, Sheffield, Alabama
Shell Development Company, Houston, Texas
Sperry Gyroscope Company, Great Neck, Long Island, New York
Standard Oil and Gas Company, Tulsa, Oklahoma
Tennessee Copper Company, Copperhill, Tennessee

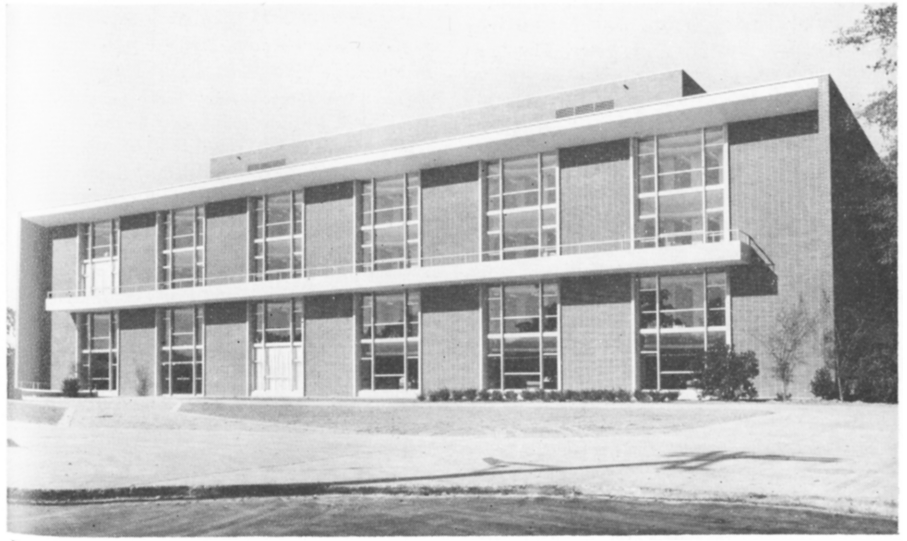

Figure 3. The library's south wall provides light for the staff work areas and stacks. A balcony on the third floor serves as an outdoor lounge and study area.

Tennessee Corporation, Research Laboratory, College Park, Georgia
Tennessee Eastman Company, Kingsport, Tennessee
Texas Company, Beacon Laboratories, Beacon, New York
U. S. Army Chemical Center, Maryland
U. S. Navy Electronics Laboratory, San Diego, California
U. S. Waterways Experiment Station, Vicksburg, Mississippi

There were four industrial organizations engaged in research for the national defense program which together borrowed 728 items during the school year 1952-53. Four private industries were loaned 382 items. These last four are: Carbide and Carbon Chemicals Company, Oak Ridge, Tennessee; Arnold Engineering Development Center, Tullahoma, Tennessee; Lockheed Aircraft Corporation, Marietta, Georgia; and Rohm and Haas Company, Huntsville, Alabama.

* * * * *

Now, after many years, Georgia Tech has adequate library facilities for its expanded graduate school and research program. It still remains for the library to find ways and means to continue building its resources and technically trained staff in order to expand with the institution and with the industrial growth of the South.

HEAT TRANSFER TO SLURRIES

Continued from Page 8

tained at constant but different temperatures. These chambers were separated by two other chambers into which the slurry of unknown conductivity and a liquid of known conductivity, i.e., water, could be placed. The walls of the middle conductivity chambers and other connecting parts were made of lucite, a material having a thermal conductivity somewhat less than that of water. The horizontal elements of each chamber, as well as all parts of the two constant-temperature chambers, were made of brass, a high conductivity material. Each lucite wall was sealed to the brass plate immediately under it. Thermocouples were installed just under the surface of each plate forming a part of the conductivity chamber. When this apparatus was externally insulated, heat flowed from the higher-temperature chamber through the two middle chambers to the lower-temperature chamber.

The slurry to be tested was prepared by dissolving two per cent by weight of agar in heated, distilled water and then adding the desired quantity of dried solid powder. As soon as the resulting gel became sufficiently rigid to prevent sedimentation, the material was carefully poured into the lower conductivity chamber of the apparatus, distilled water was poured into the upper conductivity chamber, the entire device was fastened into a single unit with lucite connectors and then was wrapped with insulating cloth. The constant-temperature chambers above and below the chambers through which heat was to flow were brought to different temperatures and the apparatus was allowed to come to temperature equilibrium. After equilibrium was attained, as indicated by temperature constancy, the temperatures were recorded and the vertical dimensions of the conductivity chambers were measured. These varied somewhat due to the use of different gaskets. It should be explained that the slurry was always placed in the lower, and consequently cooler, conductivity chamber in order that there would be no chance of melting the gel. It was found experimentally that temperatures only slightly exceeding room temperature were best for the heated bath; higher temperatures tended to cause bubble formation under the upper plate of the liquid conductivity chamber.

Heat flowing downward from the higher temperature bath to the lower temperature bath passed through both the liquid of known conductivity and through the suspension of unknown conductivity. When steady-state flow was reached, the thermal conductivity of the

slurry was readily obtained by the following relation:

$$K_s = K_L\left(\frac{\triangle t_L}{\triangle t_s}\right)\left(\frac{L_s}{L_L}\right), \qquad (4)$$

where $\triangle t_L$ is the temperature drop in the liquid chamber, $\triangle t_s$ is the temperature drop in the slurry chamber, L_s is the vertical spacing between the top and bottom of the slurry chamber and L_L is the equivalent dimension of the liquid chamber. Experimental data were obtained for a number of systems, and the results indicated satisfactory agreement with Equation 3 in every case.

While the apparatus and technique were not elaborate, it was concluded that Equation 3 could be relied upon to give the conductivity of slurries for use in the correlation of heat-transfer data.

The results of this investigation indicate that (1) a very large increase in thermal conductivity cannot be obtained by selecting a filler or solid phase of high thermal conductivity and (2) to a first approximation, thermal conductivity is independent of the degree of dispersion of the filler.

Viscosity

A fluid is said to be Newtonian when its viscosity is independent of the rate of shear. Liquids and dilute slurries are approximately Newtonian in character. Concentrated slurries, on the other hand, are often non-Newtonian, i.e., their viscosities vary not only with temperature, as do the viscosities of all materials, but also with the rate of shear and, in extreme cases, with the duration of shear.

A number of years ago it was found that the fluidity, i.e., the reciprocal of viscosity, was essentially a linear function of the solid concentration of a slurry at low concentrations. If the curve of a plot of fluidity versus solid concentrations were extrapolated, a fluidity of zero was indicated at a rather low concentration. The solid concentration at "zero fluidity" was found to be independent of temperature. Consequently, the suspension fluidity could be expressed by the linear equation

$$\phi_s = \phi_L\left(1 - \frac{x_v}{x_{vo}}\right), \qquad (5)$$

where ϕ_s and ϕ_L represent the fluidity of the slurry and pure liquid, respectively, and x_{vo} is the volume fraction solids in a slurry having an indicated zero fluidity. In terms of viscosities, Equation 5 becomes

$$\mu_s = \mu_L\left(\frac{1}{1 - \frac{x_v}{x_{vo}}}\right). \qquad (6)$$

Equation 6, if the volume of x_{vo} is known, expresses the viscosities of relatively dilute suspensions with considerable accuracy. Some of the suspensions used in the heat-transfer phase of the investigation to be described later had a solid concentration greater than the indicated "zero fluidity" concentration, however. Logically, a fluidity of zero (or an infinite viscosity) can occur only when the concentration is such that each individual particle is in contact on all sides with other particles, in other words, when it is in a bed. Consequently, this line of attack was pursued.

Measuring the apparent viscosities of most suspensions is complicated by the fact that agitation must be provided to maintain the suspension. The problem therefore is to provide a suitable, temperature-controlled, measuring device having a stirring mechanism which does not greatly interfere with the measurement.

The main component of the apparatus which was developed was a commercial Saybolt viscosimeter which was altered in several ways; the resulting instrument is shown in Figure 2. The liquid chamber, with its drain line and orifice, was replaced. In this new component, a capillary tube replaced the orifice, and the flow-controlling valve was built inside the fluid chamber. Sealing the flow from above the capillary was necessary since, otherwise, the capillary would plug with sediment. The capillary was surrounded with another tube through which the thermostatically-controlled liquid, oil, was passed. The normal oil bath stirring system of the viscosimeter was modified to the extent of using a propeller of greater pitch to produce the necessary flow in the capillary jacket. Agitation of the slurry was accomplished by means of two, oppositely rotating, multi-paddle stirrers. The stirrers were located in relation to the orifice so that relatively quiescent slurry entered the capillary. The

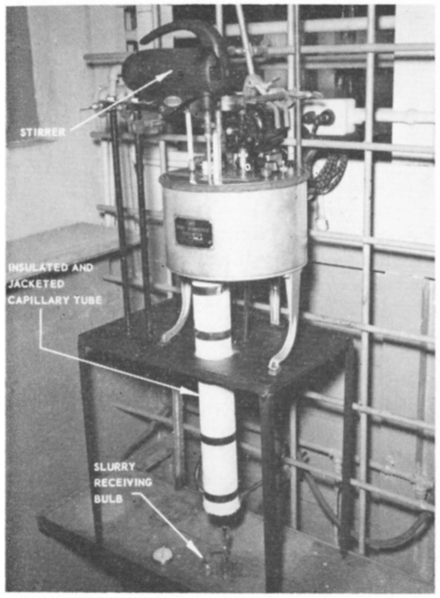

Figure 2. A commercial Saybolt viscosimeter was altered in several ways for use in measuring the apparent viscosity of slurries.

slurry receiving bulb was specially designed to provide a nearly constant pressure against which flow occurred during each viscosity determination. As shown in Figure 2, the receiving bulb was really two bulbs, the capillary extending into one. In making a run, timing of the flow through the capillary was not begun until this bulb had filled almost to the point of overflowing. Through very nearly all of the run, therefore, the liquid level remained just at the point which was necessary to cause the liquid to run into the second bulb.

Viscosity determinations were made for all slurries employed in the heat-transfer study proper after the apparatus was calibrated using liquids of known viscosities. For reasons which will become evident later, the volume fraction occupied by the solid particles in the bed which resulted from prolonged settling (as much as one month) was also determined for each slurry.

Typical results are shown by Figure 3 with fluidity instead of viscosity plotted as a function of the concentration of solid material. While it must be admitted that the fluidity-concentration curves such as given in Figure 3 permit considerable leeway in locating the point of zero fluidity, smooth curves were obtained in every case when this point was taken as that representing conditions in a bed produced by gravity settling. This is the point plotted as a fluidity of zero on the figure.

The fluidity results showed that, while wide variation in the effect of the concentration of solid material was evident, all the curves were of the same general shape. In order to exploit this characteristic, a reduced plot of the fluidity data was made. The ordinate, instead of being fluidity alone, was now the fluidity of the slurry divided by the fluidity of pure liquid at the same temperature, while the abscissa, instead of being simply the volume per cent of solid material, was plotted as the volume fraction of solid material composing the slurry divided by the volume fraction of solid material which was found in a sedimentation bed. The empirical relationship

$$\mu_s = \frac{\mu_L}{\left(1 - \frac{x_v}{x_{vb}}\right)^{1.8}}, \quad (7)$$

where x_{vb} is the volume of particles in the

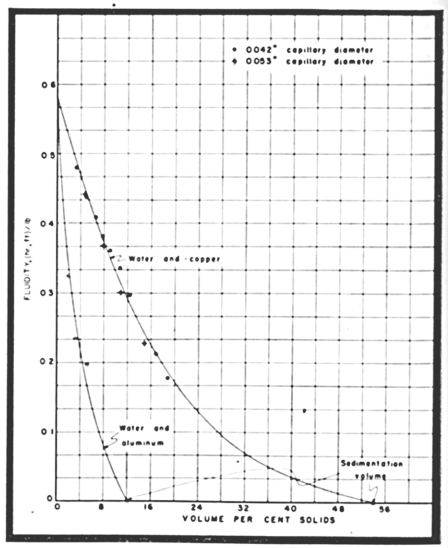

Figure 3. Fluidity versus volume per cent solids for water-copper and water-aluminum slurries.

sedimented bed, was then found to represent these data within acceptable limits.

Although the data will not be presented in this article, other viscosity determinations were made so that shear diagrams could be constructed. These diagrams indicated that, of the slurries employed, only those of highest concentrations deviated greatly from Newtonian characteristics. Were this not the case, the correlation represented by Equation 7 would be of little value.

As it is, Equation 7 represents the viscosities of the suspensions investigated with sufficient accuracy to be employed in correlating heat-transfer data.

Heat Transfer

Figure 4 shows the heat-transfer apparatus which was designed so that vertical, upward flow of the slurry was required. The heat-transfer section itself consisted of three elements—a 3/8-inch copper pipe, a surrounding steam jacket of 4-inch iron pipe and a 2-inch iron pipe separating the copper pipe and the outside jacket except for a small passage at the upper end of the section. The purpose of this inner wall was to separate the steam condensed on the copper pipe from that condensed on the outside wall. Thermocouples were buried at intervals in the copper pipe wall, and their leads were brought out through ports in both the separating and outer walls of the exchange section. The entire exchange section was insulated with standard thickness, 85 per cent magnesia pipe insulation.

The copper pipe through which heat was transferred in the exchange section extended beyond each end of the exchange section. At the lower end, the extension was about 70 pipe diameters long and served as a straightening section in which erratic flow characteristics were eliminated. The temperature of the slurry entering the heat-transfer section was measured with a thermocouple installed in the lower part of the straightening section. The vertical copper pipe extended a short distance beyond the upper end of the heat-exchange section. It terminated inside a chamber designed so that the bulk temperature of the leaving slurry might be obtained.

The slurry next passed through a cooler where its temperature was reduced to its initial level.

Upon leaving the cooler, the fluid flowed back into the mixing and storage tank from which its initial passage through the system was begun. A three-way cock was located in the line between the slurry cooler and mixing tank in order that the flow could be diverted from time to time into a smaller tank for purposes of determining the flow rate.

Heat was supplied to the heat-transfer section by condensing steam. The necessary pressure-regulating and control valves as well as other equipment with which to determine steam quality, etc., were provided.

Experimental data were obtained on the heat-transfer properties of slurries having various compositions, undergoing various rates of flow and receiving heat at various rates. Slurries of water with copper, graphite and aluminum powders, glass beads and clay and of ethylene glycol with graphite and aluminum powders were studied. Data obtained by investigators at Columbia University for slurries of water and chalk are also included in the final correlation.

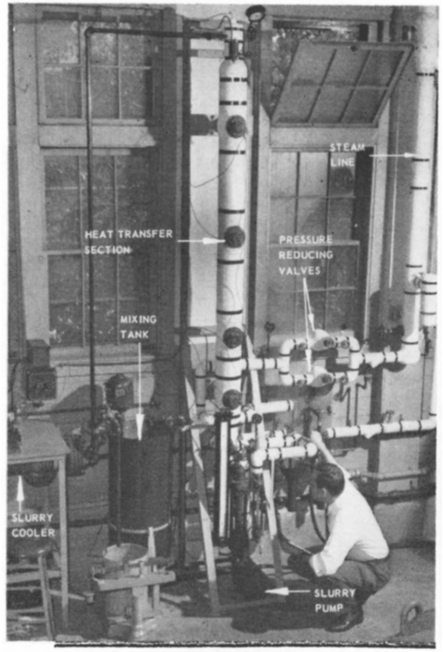

Figure 4. The author's heat-transfer apparatus.

Before going into the correlation, it may be well to consider the range of variables covered by this work. The physical properties of the solid materials ranged from a density of 513.8 lb./ft.^{3} for copper powder to a density of 124.2 lb./ft.^{3} for graphite, a conductivity from about 220 B.t.u./(hr., ft.^{2}, °F. per ft.) for copper to 1.3 B.t.u./(hr., ft.^{2}, °F. per ft.) for chalk, a heat capacity from about 0.22 B.t.u./(lb., °F.) for graphite to about 0.093 B.t.u./(lb., °F.) for copper and a particle size from a medium diameter of 260 microns for the largest glass beads to an average diameter of about 1.8 microns for chalk. The liquids, water and ethylene glycol, differed in viscosity by a factor of about 10, in conductivity by a factor of about 3, and in heat capacity by a factor of almost 2. Reynolds numbers from the lower limit of turbulent flow to 300,000 were employed. Concentrations up to 45.7 per cent solid material by weight were used.

Figure 5 presents the results available on the heat-transfer properties of slurries at the time this report was written. It may be seen that the figure presents a plot based on Equation 2—written for slurries instead of for liquids; that the solid line through the experimental points corresponds to the equation as it appears when it is solved to separate Reynolds number from the other factors. In using the equation, the heat conductivity of the slurry was evaluated with Equation 3; the viscosity of the slurry was taken as that indicated by Equation 7; while the specific heat and density of the slurry, being additive properties, were taken as the weighted average of the properties of the individual components. While considerable scatter of the data is evident, the scatter is quite random and is about that which has become accepted as inevitable in heat-transfer work.

Using the correlation obtained, calculations may be made regarding the relative

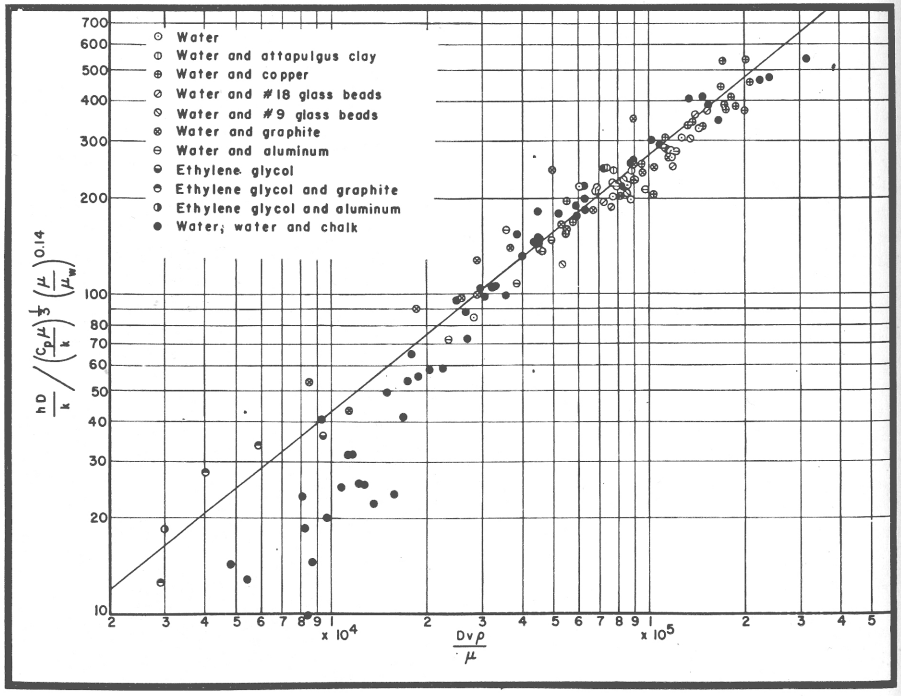

Figure 5. Comparison of experimental data with theoretical relations calculated from Equation 2.

merits of liquids and slurries as heat-transfer agents. The question immediately arises as to what conditions may be made the basis for comparison—volume rate of flow, Reynolds number, pressure drop, pumping cost, etc. Since economic considerations would lead afield, comparison will be limited to (1) identical volume rates of flow, (2) identical Reynolds numbers, $\frac{Dv_s\rho_s}{\mu_s}$, and (3) identical pressure drop due to friction. Quite arbitrarily, water will be considered for the pure liquid and will be compared with a slurry composed of water and 10 volume per cent copper powder. It will be assumed that the same apparatus is used in the comparison and that the same bulk fluid temperature, 150° F., exists in each case. Using the correlations developed above, the slurry would be found to be a better heat-transfer medium than water alone by about 22 per cent if identical volume rates of flow were employed, water alone would be somewhat better medium if comparison were made at identical Reynolds numbers, while the slurry would be a slightly better agent on the basis of constant pressure drops. The latter calculation assumes the friction factor for a slurry to be described by the usual Fanning friction factor versus Reynolds number plot if the Reynolds number is evaluated using the bulk mean velocity of the slurry, the density of the slurry and the viscosity of the pure liquids. While the subject of pressure drop is not covered in this report, other phases of this investigation indicated that the above assumption is generally acceptable.

* * * * *

From this work, three principle conclusions may be drawn:

1. The average individual coefficient of heat transfer between a pipe wall and a slurry flowing turbulently inside the pipe can be arrived at as if the slurry were a homogeneous liquid under all conditions studied if a mean thermal conductivity and viscosity are evaluated, if density and heat capacity are calculated as the weighted average of the values for the individual components and if other terms are evaluated in the usual fashion.

2. The thermal conductivity of a slurry is given in Equation 3.

3. The viscosities of the slurries investigated are best described by Equation 7. This equation, being simple and easy to evaluate, should be useful in work other than that pertaining to heat transfer.

RECENT STATION PUBLICATIONS

These abstracts cover publications subsequent to those listed in the July, 1953, issue. Others will be published as space permits. A complete list of the Engineering Experiment Station's publications may be obtained without charge from the Publications Office.

BULLETIN

T. A. Wastler, P. M. Daugherty and H. H. Sineath, **Industrial Raw Materials of Plant Origin. II. Recent Developments in Vegetable Waxes, Gums, and Resins,** Bulletin No. 15, 1953, 31 pages. Gratis.

This bulletin, the second in a series on industrial raw materials of plant origin, discusses the economic and technological developments in the field of vegetable waxes, gums and resins between January 1 and December 31, 1952. Following a general summary on the more important developments in the field during the period surveyed, the bulletin presents specific information on the demand for and supply and uses of waxes, gums and resins. Waxes included in this survey are carnauba, candelilla, cauassu, Douglas fir bark, jojoba, ouricuri, sorghum grain and sugar cane. Agar, gum arabic, gum tragacanth and sandarac gum are discussed under gums and resins. The bulletin concludes with a section on naval stores. Some topics under this section are: dichlorethane extraction of rosin from wood stumps, maleopimaric acid from pine gum, method of improved pine gum distillation, terpene hydroperoxides from turpentine, testing methods for rosin oils, turpentine-based lubricants and new uses for tall oil.

REPRINTS

G. W. Reid, **Microkjeldahl Procedure in Water and Sewage Analysis,** Reprint No. 57, 1952, 3 pages. Twenty-five cents.

This paper reports the results of an investigation on the use of the Hengar microkjeldahl procedure and slightly modified equipment for the analysis of nitrogen and phosphorous in slime, and of nitrogen in sewage, water, sludge, slime and algae. The results of this study indicate that the microkjeldahl technique gives slightly lower results than does the standard Kjeldahl method but that the two methods are in reasonable agreement. The microkjeldahl technique, therefore, should prove particularly useful to sanitary engineering laboratories where space is at a premium providing a representative sample can be obtained in spite of the reduced volume used.

Herbert P. Peters, **Power-System Arithmetic,** Reprint No. 58, 1952, 4 pages. Twenty-five cents.

With the tools avaialable today for the engineer's use, such as the A-C network calculator, few companies can afford the luxury of providing their engineers with the time to solve complicated electrical network problems mathematically. However, the engineer is required to solve the simpler problems daily. This article discusses some of the "tricks of the trade" which enable the engineer to obtain mental solutions to these problems.

C. Orr, Jr., H. G. Blocker and S. L. Craig, **Surface Areas of Metals and Metal Compounds: A Rapid Method of Determination,** Reprint No. 59, 1952, 4 pages. Twenty-five cents.

Within recent years gas adsorption methods have been developed for measuring the surface area of finely divided materials and have become extremely valuable in research on the corrosion and the catalytic activity of metals. Unfortunately, these methods are unsuited for most routine control work such as that encountered in powder metallurgical operations and in processes employing metal catalysts because they require rather elaborate apparatus and a single determination is so time-consuming. This paper discusses a rapid method for determining the surface areas of metals, metal catalysts and metal oxides. The method consists of the liquid-phase adsorption of a unimolecular layer of stearic acid on the surface of a sample of material. The quantity of stearic acid adsorbed and the weight of the sample are used to calculate the specific surface area.

Ziegler, W. T., **Properties of Metals below —300° F,** Reprint No. 60, 1952, 5 pages. Twenty-five cents.

During the last 15 years a number of developments have greatly increased the need for an understanding of the behavior of metals and alloys at temperatures within a few degrees of absolute zero. This article reviews briefly the effect of temperature on some of the properties of metals and alloys at these low temperatures and points out some relations existing between these properties. Among the properties discussed are the mechanical properties, specific heat, thermal expansion, and electrical and thermal conductivities.

LIBRARY RESEARCH

Continued from Page 2

tremendously. Our librarians tell us that technological libraries must plan to double their storage capacity about every 20 years. The increasing amounts of technical publications stem from several factors including increases in population and advances in education, but by far the most important factor is today's phenomenal increases in organized research efforts.

As our technology develops, progressive industry is compelled to refer constantly to the libraries' vast store of information. In planning every advancement, it is necessary to study what others have thought about the subject. If other men's thoughts are not sought, much time and money will be wasted through duplication of their efforts.

Georgia Tech is proud of its new library building and the collection which it houses. We are optimistic about the position which this library will play in the development of the South. The library is a fundamental part of the education system for young engineers and scientists; furthermore, it is a major factor in conducting the many research programs carried out on the campus. It is hoped, too, that industry will utilize the Georgia Tech library and the Experiment Station's literature search staff to find needed data or to study earlier solutions to perplexing problems.