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Silicious exposures in the refractory brick industry.

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SILICIOUS EXPOSURES IN THE REFRACTORY BRICK INDUSTRY

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SILICIOUS EXPOSURES IN THE REFRACTORY BRICK INDUSTRY

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INTRODUCTION

Silicosis has long been recognized as an occupational disease caused by the inhalation of small free silica dust particles. Two facts seem to establish the public health need for its control and elimination. First, thousands of workers are engaged in trades which involve potential exposures to damaging amounts of silica dust. Secondly, silicosis is a disabling disease and is, especially in its advanced stages, predisposing to tuberculosis.

The best method of dealing with the problem of silicosis is admittedly that of recognizing all free silica exposures and then proceeding to devise control methods for reducing or eliminating the exposures. It is with these objectives in mind that the following study is undertaken. Should silicious dust exposures be definitely established by this study, an industry-wide silicosis survey will then be conducted. The results of this survey will appear later in a published report.

PART I - THE FIRE BRICK INDUSTRY

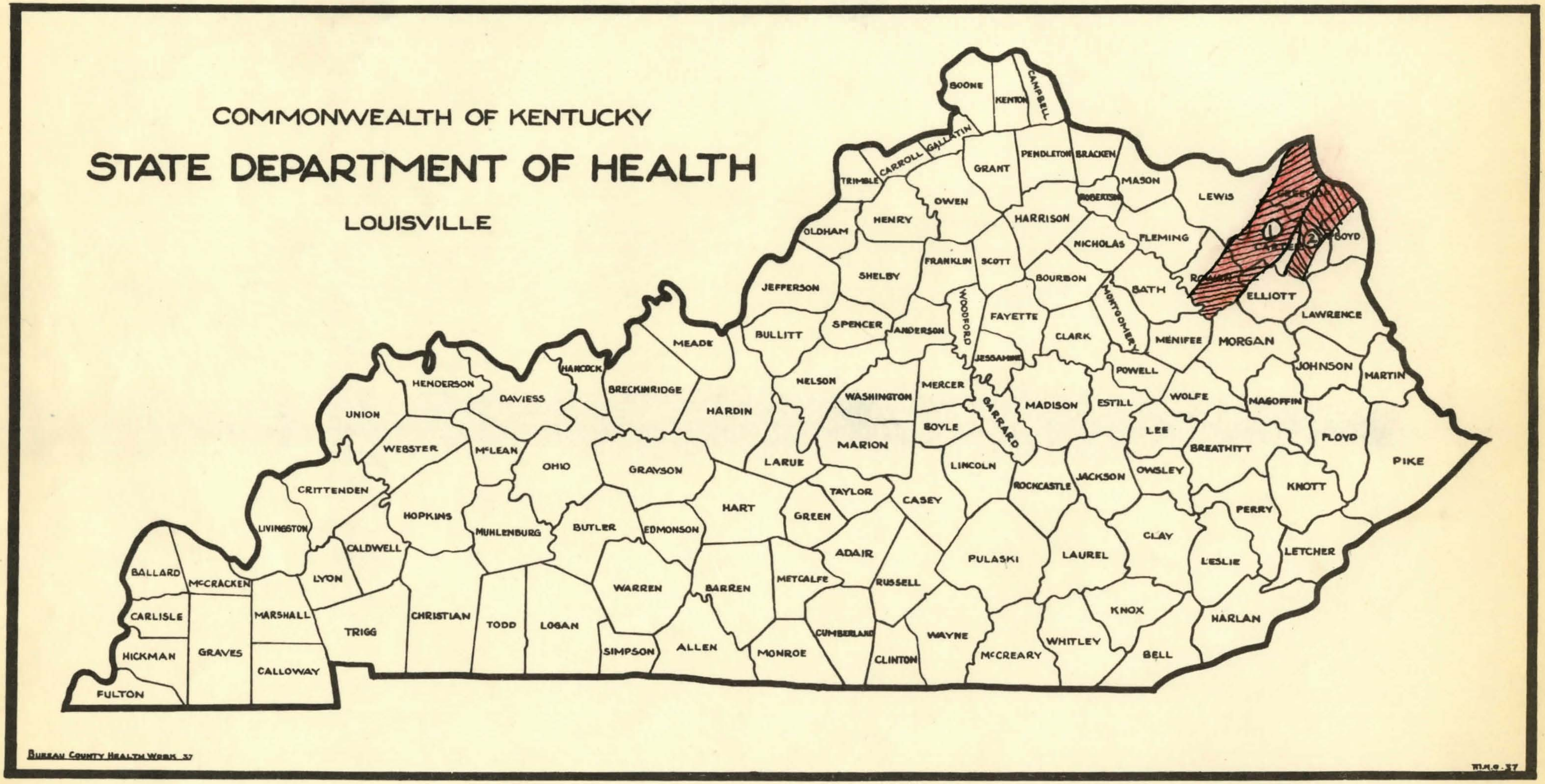

FIG. I Fire-Clay Deposits in N. E. Kentucky

1. Olive Hill District
2. Ashland District

GENERAL DESCRIPTION OF THE INDUSTRY

The refractory brick industry in Kentucky consists of some ten major plants, with a total working population fluctuating from 1400 to 2500, and a variable number of smaller part-time establishments. This is entirely exclusive of clay mining and other steps preparatory to the actual manufacture of marketable refractory products.

The total capacity of the major plants in the State will approach 550,000 bricks daily if measured in terms of standard 9" bricks. According to the 1939 U. S. Census of Manufacturers, Kentucky ranks fourth among the states, both as to clay refractories production and as to number of people employed.

The manufacturing processes employed in these plants are of the conventional type and are basically similar to those described by Fulton, et al. in the Pennsylvania Silica Brick study (1). However, the raw materials and maturing temperatures are quite different from silica brick. The flow sheet in figure 2, will serve as an over-all guide to understanding the sequence of operations in all plants.

Geology and Nature of the Raw Materials. Two raw materials -- plastic and hard (flint and semi-flint) clays are used in the manufacture of fire brick. Both types are obtained almost entirely from deposits found in the two fire clay districts of northeastern Kentucky known as the Olive Hill and Ashland districts. These deposits are found at the contact of the Mississippian limestone and the Pennsylvanian systems and are thought to be sedimentary in nature (2).

The Olive Hill district contains deeper deposits of hard flint and semi-flint clay, which are underlaid by the Mississippian limestone (2); the Ashland deposits appear somewhat later with the Pennsylvanian ferriferous limestone and seem to contain more plastic clay. There can be no distinct division made, however, between the hard and plastic clay deposits in the two districts as pointed out by Ries (3), since there is much overlapping, and both clays are found in pockets or outcroppings in both areas. Typical analyses of clays mined from each district are shown in Table I and a yearly average analysis of clays used by one of the fire brick companies in Table II. It should be understood that these Tables show ultimate analyses, and the percents given represent total amounts of the respective constituents whether combined or uncombined. For example, the 60.54 percent silica found in the Ashland raw clay does not refer to free silica but to total combined and uncombined silica.

The flint clay is fine grained, has a conchoidal fracture, and has been shown by Galpin (4) to contain kaolinite and hydromica and small amounts of pyrite, quartz, rutile, zircon and tourmaline. The quartz grains are present where the flint clay grades into sandstone. A semi-flint or semi-hard clay is found rather sharply separated from the flint clay. It is different from the flint clay in that it has noticeable plasticity and shows the presence of numerous slickensided surfaces (3).

The plastic clay (#2 plastic) differs from the other two clays in that it has decided plasticity, is softer, and is the least refractory of the three.

Analyses made chemically, petrographically, and by means of x-ray diffraction on screened raw clay samples taken during this study from three of the refractory brick manufacturing plants, showed the following average percents of free silica.

1 - Raw Plastic Clay - 17.7 percent SiO_2

2 - Raw Flint Clay - 7.1 percent SiO_2

The fire clays are basically hydrated aluminum silicates as described by J. C. Warner (5) for which Al_2O_3 2 SiO_2 $2H_2O$ may be considered the type formula corresponding to 39.5 percent alumina, 46.5 percent silica and 14 percent water. Although the final composition of fire clays are rather variable, their formation

TABLE I - RAW CLAY ANALYSES *

TYPICAL ANALYSES - ASHLAND DISTRICT

	Per Cent
Silica	60.54
Alumina	25.89
Ferric Oxide	1.75
$Mn\ O_2$	.26
Lime	.53
Magnesia	.12
Potash	1.85
Soda	.65
H_2O	2.05
Loss on Ign.	7.43
Sulfuric Anhydride	.12
Titanic Acid	1.28 - 2.21
Fusion Point	3092 - 3290° F

TYPICAL ANALYSES - OLIVE HILL DISTRICT

	Per Cent
Silica	44.0
Alumina	42.5
Iron Oxide	1.0
Lime	0.5
Fusion Point - Cones	32.5 - 33

* Compiled from Kentucky Geological Survey. Ser. IV, Vol. I - Part II, p. 633, 663 and 668, July 1913.

TABLE II - YEARLY AVERAGE CLAY ANALYSES *

	#1 Hard Clay Raw	#1 Hard Clay C.B.B. **	#2 Plastic Clay Raw	#2 Plastic Clay C.B.B. **
Loss on Ignition --	12.15%	- -	10.14%	- -
Silica (Total) ----	48.00	54.64	52.72	58.67
Alumina -----------	35.41	40.31	30.74	34.21
Titania -----------	2.00	2.28	1.90	2.11
Ferric Oxide ------	1.59	1.81	1.46	1.62

BURNT BRICK

Silica ----------------	54.56%
Alumina ---------------	39.12
Ferric Oxide ----------	1.92
Titania ---------------	2.08
Lime ------------------	0.26
Magnesia --------------	0.46
Alkalies --------------	1.89

** C.B.B. = Calculated to Burned Basis

* A Report Submitted by one of the Refractory Brick Manufacturing Plants and now in the Official Files of the Division of Industrial Hygiene, Kentucky State Health Department.

is largely due to the reaction of water and carbon dioxide on the feldspars (i.e., orthoclase, $K_2O\ Al_2O_3\ 6\ SiO_2$ and albite, $Na_2O\ Al_2O_3\ 6\ SiO_2$, etc.) which are present in most rocks. This reaction produces kaolin $Al_2O\ 2\ SiO_2\ 2H_2O$ and, according to Alexander (6), may be represented by the equation:

$$K_2O\ Al_2O_3\ 6\ SiO_2 + CO_2 + nH_2O = K_2CO_3 + Al_2O_3\ 2\ SiO_2\ 2H_2O + mH_2O.$$

The letters n and m denote indeterminate numbers of water molecules.

The so called flint, which makes up about 35 percent of the constituent batch in the pottery industry, is apparently quite different from the flint or hard clay used in the refractory brick industry. In the West Virginia pottery study (7), the ground pottery flint was shown to contain more than 99 percent quartz, while the ground refractory flint clay seems to contain quartz or free silica only in variable amounts (averaging 7.1 percent) somewhat as an incidental associate.

While free silica in the raw clays is found usually as the crystalline form of quartz, the crystallographic picture seems to undergo considerable change during the brick burning or firing process. Consequently, much of the free silica is found as cristobalite in the finished burnt brick.

ENGINEERING STUDY

METHODS USED

Preliminary studies were made in ten major refractory brick plants, during which time over-all industrial surveys were made, and information was collected concerning the manufacturing processes and materials used. Based upon the preliminary investigations and some follow-up work, four of these plants proved representative and were selected for detailed engineering studies.

It should be mentioned rather parenthetically here that a fifth plant selected for study is an Electrocast Refractories plant making super-refractory brick for glass furnaces and is inherently different than the conventional fire brick industry, both in the nature of raw materials employed and the methods of manufacturing. This particular plant will, therefore, be set up as an individual study (Page 26).

The following procedure has been employed in studying the five plants:

1 - Representative settling dust samples were taken from rafters, etc., in the vicinity of each different operation, and, where practicable, vacuum cleaner samples were drawn directly from the atmosphere. Samples were also taken of the raw clays and the finished brick. These samples were all analyzed for free silica by a combination of chemical and petrographic methods, as suggested by Knopf (8) and Bloomfield and Dalla Valle (9), or by the x-ray diffraction method.

2 - Atmospheric dust samples were collected by means of the Bureau of Mines Type Midget Impinger (10) (11) (12) using a collecting media of 10% alcohol and 90% distilled water. The samples were counted by the standard light field technique recommended by the Public Health Service (9) and the Bureau of Mines (13).

Samples were collected for particle size determination by means of the Owens-jet type dust counter (14), by a vacuum cleaner, an electrostatic precipitator, as suggested by Drinker and Hatch (15), and also by means of the midget impinger as outlined by the Public Health Service (9). Dust particles in the impinger samples were prepared for measurement by the usual method of rapidly evaporating several drops of the sample to dryness on a slide glass. Two hundred particles for each impinger sample were then measured at 1000 magnifications by means of the filar screw micrometer and oil immersion objective.

3 - Finally, all existing control measures were evaluated and recommendations submitted for alterations when necessary. In a few cases, where effective control measures have been installed since the beginning of this study, comparative dust counts made before and after the installations are included.

THE MANUFACTURE OF FIRE BRICK

I. Receiving and Storing Raw Materials. The fire clay is shipped principally by rail from the mine to the factory. Upon reaching the factory site, the clay is handled in one of two ways, depending upon the common practice of the plant and the comparative purity of the clay:

1. Unloaded directly into a Crusher (or Breaker) Pan where the clay is subjected to a preliminary crushing.
2. Unloaded onto open clay piles where it is exposed to the weather for a variable period — often one year.

II. Grinding and Screening to Size. From either the Crusher Pan or open storage piles the clay is brought into a Dry Pan Mill by conveyor belts or wheelbarrows. The various grades of clays, including rejected burnt brick, are ground separately in the dry pan. From this mill the ground clay or brick is conveyed up to the screens, which are usually located at the top of the dry pan mill house. The screening is adjusted to the requirements of the particular product and generally ranges from 6 to 30 mesh. Finer material then passes through the screen and by way of chutes to storage bins, while coarser material is returned to the dry pan for further size reduction.

III. Mixing and Molding Clay. At this point a division may be noted in the flow of production (see fig. 2). Thus, the clays are generally mixed by one of two methods depending upon which of the following products is desired.

A. Hand Molded Forms (Soft Mud Process). For the larger and special shaped forms weighed amounts of ground clays and burnt brick are either hauled from the storage bins by "dirt buggies",

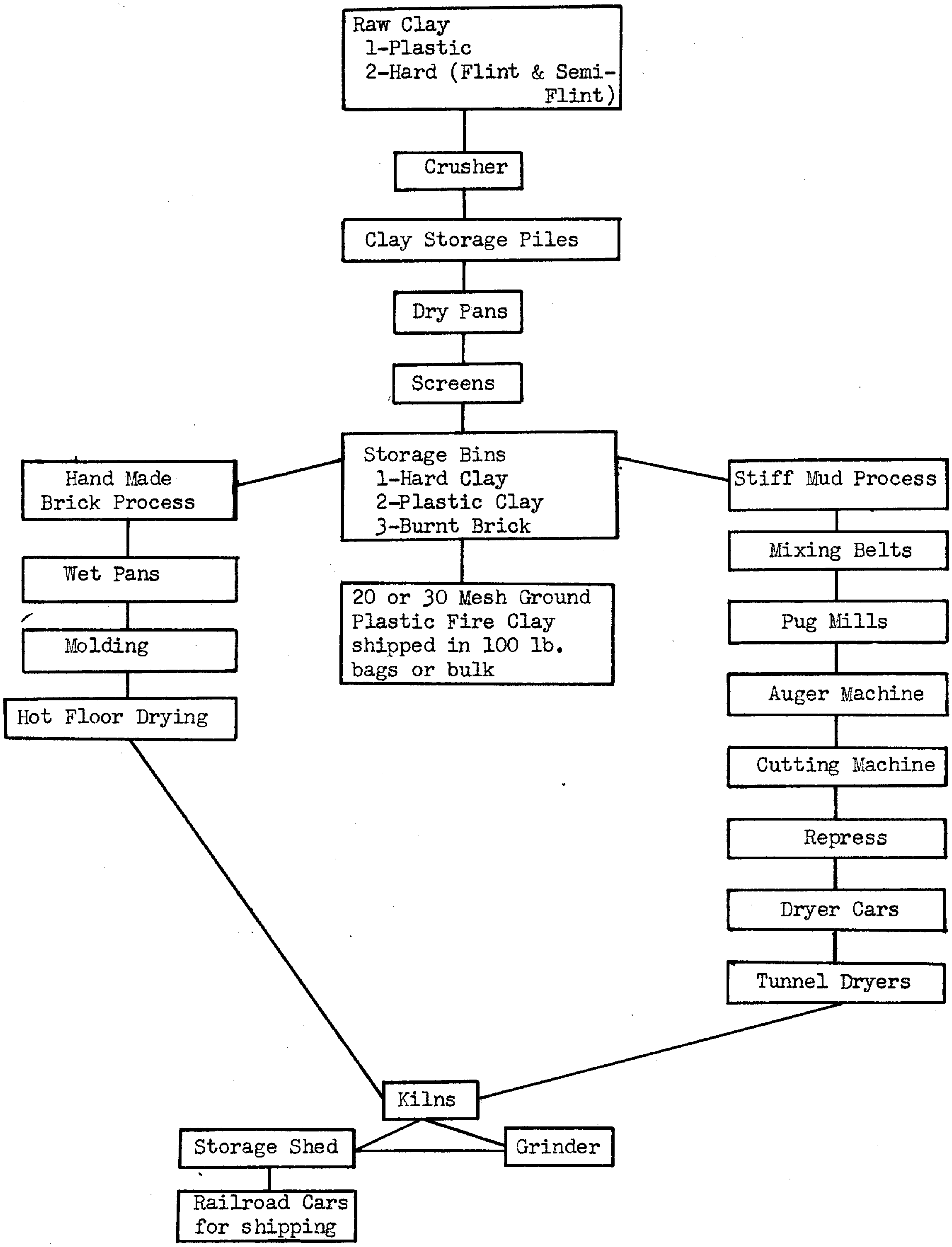

FIGURE 2 - TYPICAL FLOW SHEET of Fire-Brick Manufacture

wheelbarrows, etc., or fed by gravity to a Wet Pan, where they are mixed with water to the consistency of mud. This soft mud mass is then pressed into molds either by hand or by a power-driven soft-mud brick machine. Both methods are usually employed in each plant -- the older hand method being reserved for large and special shaped forms. The machine has a capacity of 1000 to 5000 bricks per hour and is used in making the standard size bricks.

B. Machine Molded Forms (Stiff Mud Process). Specified amounts of ground clay and burnt brick are emptied from the bins onto Mixing Belts, which convey the mixture to a Pug Mill. In this mill the dry clay is mixed with water and tempered. The mud is now soft enough to be squeezed through a die under pressure but is much stiffer and contains less water than the soft mud previously mentioned. The pugged clay is now fed into an auger machine wherein it is usually de-aired and then forced through a die. Coming out of the die in the form of a bar whose cross sectional dimensions are equal to a standard brick face, the stiff mud moves along a belt conveyor onto a cutting table where the bar is automatically cut into bricks. From here the stiff mud bricks go through a repressing machine where they receive true shape and dimensions.

Some of the plants employ still another method, known as the Dry-Press process for making machine molded bricks. Here the dry clay, usually containing less than 15 percent moisture, is fed from overhead bins or belts into the press hopper through several canvas tubes. As the machine operates, the charger moves over the mold to fill it and then withdraw. Top and bottom plungers then move toward each other in the mold, thus subjecting the clay to a great pressure and finally forming a very compact brick.

IV. Drying Bricks

A. Hand Molded Forms. The larger and special shaped forms, after being molded, are set on a concrete floor, called a "Hot or Dry Floor", where they are allowed to dry out very slowly. This floor is often laid on top of a series of drying ovens which furnish an economical source of heat. In other cases, heat is supplied by steam pipes which run underneath the floor.

B. Machine Molded Forms. As the stiff mud and dry press bricks come off the machines, they are placed directly onto "dryer cars" and moved into long tunnel dryers. In these tunnels the moist bricks are exposed to a carefully controlled atmosphere (temperature, humidity, and air movement). The loaded cars are pushed into the tunnels on a predetermined schedule, so that for each car of moist bricks going into the tunnel a car of dry bricks will leave it.

V. Setting and Firing Bricks. The dried bricks removed from the hot-floor and tunnel driers are then taken to the Kiln-yard where they are properly set in the kilns. This job is handled by a group of four to six men known as the "Kiln Setter Gang." Coarse sand is usually spread on top of the rows of brick to prevent them from fusing with one another during burning.

The kilns, which were either coal or gas fired, were of the circular down-draft and periodic types in all of the plants studied. However, one of the plants was converting to the more modern continuous-tunnel-type kiln and had discontinued the use of many of its periodic kilns before the study was completed.

After the bricks are set in the kilns, firing begins. The firing process, which requires from 7 to 9 days, is a very important step in the manufacture of refractories, since this step gives the brick much of its final strength, durability and quality. Pyrometric cones (see glossary) are placed in the kilns with the bricks to serve as a guide in advancing the firing temperatures. While the temperature is actually increased more or less gradually up to the 7th to 9th day of firing, the process might be divided into the following three general stages to illustrate the objectives accomplished.

1 - Water Smoking (Dehydration) for 3 or 4 days - to 600° F - during which time mechanical moisture and some of the chemically combined water of hydration is driven off.

2 - Oxidation - 5th and 6th days - up to 1800° F all organic matter ignited, oxidizable minerals as iron, carbon, and sulphur are oxidized and some shrinkage takes place.

3 - Bonding - 7th, 8th and sometime 9th days - 2300° F to 2705° F (Cones 10 to 18, but seldom above 14) - shrinkage is brought to completion, the material is bonded and partially vitrified.

Finally, all fires are withdrawn from the kiln and the bricks are allowed to cool for several days. The better grade, high refractory bricks are, thus, capable of withstanding much higher temperatures than those encountered in the kiln burning process and have average pyrometric cone equivalents of 32 to 33 (see glossary).

VI. Tearing Down and Cleaning Kilns. After a sufficient cooling period, bricks are removed from the kiln by the "Burnt Gang" or "Drawer Gang", which consists of four to six men, namely, one Tosser, two Wheelers and one Hacker. The "Tosser" removes the bricks from the top of the stack and tosses them to the "Wheelers", who then haul the bricks in wheelbarrows to the storage room. Here the job of setting bricks in rows for storage is left to the "Hacker."

VII. Grinding, Storing and Shipping. Final trueing of brick surfaces is accomplished by grinding the bricks (mostly special sizes and blast furnace brick) to specified dimensions. Most plants employ double-disc Bridgeport grinders fitted with specially designed exhaust hoods for this purpose. The completed bricks are now placed either directly into freight cars for shipping or in storage sheds.

VIII. Bag Loading - A Periodic Operation. Fine ground plastic clay is loaded into 100 lb. sacks directly from the storage bin chutes by two sackers who immediately prepare it for shipment. This operation is periodic (one or two weeks) and of short duration in most plants.

Results of Study

All dust counts, free silica analyses, and particle size measurements are shown in Tables III, IV, and V and figure 3.

TABLE III - DUST CONCENTRATIONS BY PROCESS & PLANT
in million particles per cubic foot

PLANT	NUMBER OF SAMPLES	MINIMUM				MAXIMUM				AVERAGE				TOTAL COMBINED AVERAGE
		A	B	C	D	A	B	C	D	A	B	C	D	
Breaker Pan	6			42	8.4			500	12			227	10.2	118.6
Dry Pan	13	87	1086	27	141.6	129	2742.2	542.2	387	108.1	1735.2	281	199.7	581
Dry Pan Controlled	3	4.8				17.2				10				10
Screen Mill	20	63.6	597	37.5	130.4	78	791.1	1176	597	70.5	673.4	396	350.5	372.6
Screen Mill Controlled	5	8.8				12.4				10.3				10.3
Wet Pan	5	4.8				18				11.9				11.9
Loading Dirt Buggy	5	24.4				402.4				153.5				153.5
Pug Mill	3				18				36				25	25
Mixing Room	7				444				514.8				481.9	481.9
Hand Molding	4			40				55.8				47		47 *
Machine Molder	10	7.5	16.8		7.8	12	20.4		13	9.8	18.8		10.3	38.9
Hot Floor	20	4.2	8.1	3.8	7.8	17.2	187.5	23	26.4	10.6	64.7	13	16	26
Sweeping Hot Floor	12		41	14.8	13.2		52	226.5	45		44.1	119	29.1	64
Brick Grinding	15	18.3	29.2	23	11.2	59.4	84.5	57	28	54.9	54.4	38	11.2	39.6
Ball Mill	3			83				150				104		104
Bag Loading	6		162	306			195	1932			174	914		544
Total Counts	142													

* Hand Molding in other plants corresponds to Hot Floor Counts

TABLE IV - FREE SILICA ANALYSES

Kind of Sample (S.D. = Settling Dust)	Number of Samples	Per Cent Free Silica Minimum	Maximum	Average
Breaker Pan (S.D.)	1	8	8	8
Dry Pan (S.D.) [1]	4	6	23	10
Screen Mill (S.D.)	1	11	11	11
Dirt Buggy (S.D.)	1	7	7	7
Hot Floor (S.D.)	5	7	19	11.3
Hot Floor Sweeping	1	17.7	17.7	17.7
Mold & Separating Sand	3	77	96	89
Burnt Brick (S.D. and Stock)	5	1	30 [2]	10.3
Plastic Clay (Ground Stock)	3	12.3	25	17.7
Hard Clay (Ground Stock)	3	6	7.4	7.1
Semi-Flint Clay (Ground Stock)	1	14	14	14
TOTAL	28			

1 = Two of four samples collected from atmosphere by vacuum cleaner

2 = One special insulating brick showed 40% SiO_2

TABLE V - REFRACTORY BRICK DUST - SIZE FREQUENCY DISTRIBUTION

200 Particle Size Determinations Per Sample

Kind & Location of Sample	Size Groups in Microns										
	0-0.49	0.5-0.99	1-1.49	1.5-1.99	2-2.49	2.5-2.99	3-3.49	3.5-3.99	4-5	5-over	Median
Midget Impinger Samples	Percent in Size Groups										
Breaker Pan	5	25	27	20	4	4	4	4	1	6	1.74
Hot Floor Gen. Atmosphere	4	10.5	15.5	24.5	15.0	11.0	6	5.5	5	3	1.79
Dry Pan Mill	3	9	14	22	19	14	5	5	4	5	2.24
Dry Pan Mill		2	10	30	25	20	5	3	4	1	2.33
Screening	5	12.0	16	16	16	9	7	6	5	8	2.32
Screening	1	11	25	20	15	14	2	2	6	4	2.11
Clay Mixing Room		6	28	34	15	9	5	1		2	1.88
Elect. Ppt. Sample											
Hot Floor	5	22	25	21	10	8	2	2	2	3	1.69
Vacuum Cleaner Sample											
Dry Pan Mill	0	0	0	6	18	22	14	16	14	10	3.35

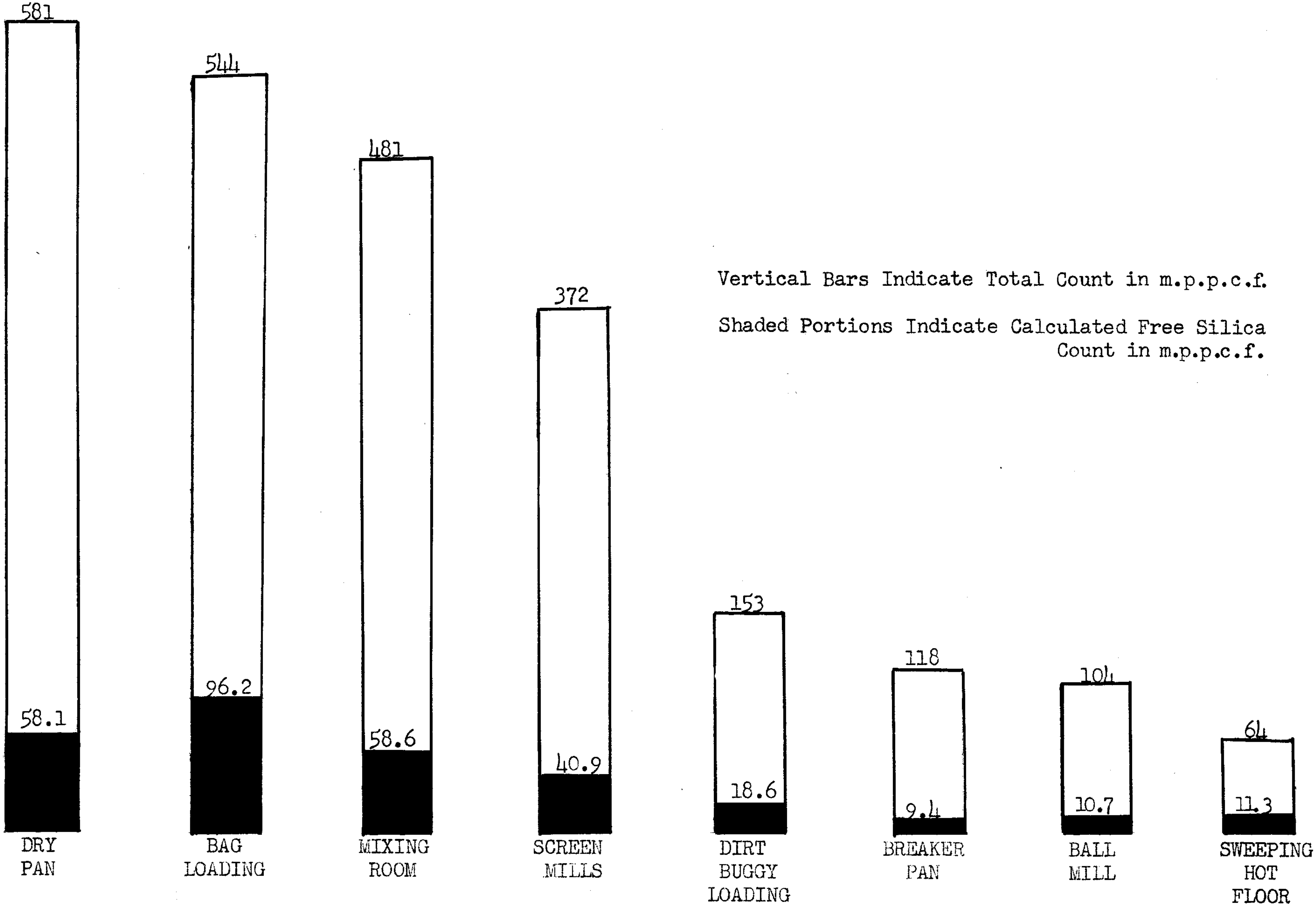

FIGURE 3 - ILLUSTRATION OF COMPARATIVE DUST EXPOSURES

DISCUSSION

DUST EXPOSURES AND THEIR CONTROL

The processes in the refractory brick industry which produce the most hazardous, sustained concentrations of atmospheric dust, both total and free silica, are the (1) dry pan milling, (2) screening, and (3) clay mixing operrations. Although other operations, such as (4) bag loading, (5) dirt buggy loading, (6) breaker pan, (7) ball milling, and (8) hot-floor sweeping produce temporary unsafe levels of dustiness, these operations are either periodic or so located near or on the outside of main working areas that they present exposures of only secondary importance.

Tables III, IV and V and figure 3 are self-explanatory and serve to illustrate, without further comment, amounts and nature of dust exposures and their control. Thus it is deemed necessary to discuss these exposures only to the extent required to establish a need for their control.

1. Dry Pan Mill: - The highest concentration of atmospheric dust encountered in the fire brick industry was 2742.2 million particles per cubic foot where men are employed in a dry pan mill room. The average concentration was 581 million particles in this operation, and the free silica count alone, calculated on the basis of its lowest analysis (6% in hard clay), would be 34.8 million particles per cubic foot of air. An average free silica concentration would be 102 million particles when grinding plastic clay and 59.8 million when grinding burnt brick. The accepted standard safe limit of 5 million free silica particles per cubic foot is, therefore, exceeded six to twenty times in this operation.

   The dust produced by this mill presents a potential hazard not only to the two to twelve men immediately exposed in each plant, but also to an indefinite and variable number of workers throughout the entire working area. This is especially true where the dry pan mill opens into or stands adjacent to the main working floor, which is nearly always the case. Thus, dust concentrations in such operations as hand molding, machine molding, and hot floor activities tend to vary inversely as their distance from the dry pan mill (e.g., Plant B and D).

In the plant (Plant A, Table III), where control was effected by enclosing the mill, the average dust count was reduced from 108 million to 10 million particles per cubic foot, or more than ten times.

2. Screen Mill: - Because of the close relationship of the screen mill with the dry pan mill, it is difficult to separate the two operations even for the purpose of dust studies.

The screen mill, like the dry pan mill, when not controlled by enclosure is a constant source of dust emanation which ultimately contaminates much of the plant. In most of the plants studied visual observation confirmed the fact that leaking screen chutes and storage bins played a major part in contaminating the general atmosphere.

In the same plant (Plant A, Table III), where the dry pan was enclosed, good control was effected in the screen mill by completely enclosing all screens, chutes, and conveyors and maintaining the enclosure under negative pressure. Average dust counts before and after this control was completed showed 70.5 million particles per cubic foot and 10.3 million particles per cubic foot, respectively, or a reduction of approximately seven times.

3. Clay Mixing: - The only open-belt clay mixing process encountered during this study was in one plant (Plant D, Table III), where the dry pan mill room adjoined the mixing room. Consequently, some cross contamination was unavoidable between the two rooms. Visible dust production in the mixing room, however, furnished at least partial evidence of the dusty nature of

the mixing operation itself.

Reference to Table III, page 14, will show the average dust count to be 481.9 million for this operation, and in no case while mixing was in progress did the count fall lower than 444 million. The average concentration of dust even ten minutes after the mixing belt had stopped was 141 million particles per cubic foot. Thus, a low mean exposure all during the working shift would be 311 million particles as total dust and 37.9 million particles calculated as free silica dust.

No actual control installation for this operation was made during the study, but operation analysis indicated a control was needed, such as that suggested in Table VI, page 23. Since, however, a direct mill-feed system would dispense with the necessity for any open mixing method, a slight alteration of process layout incorporating the direct feed appears to be the most satisfactory plan for eliminating this exposure.

4. Bag Loading: - Although this operation is periodic and of short duration, it produces total concentrations of dust far above the recommended limit for even non-toxic nuisance dust. Reference to figure 3, page 17, reveals the average total dust concentration to be 544 million, while the average calculated free silica (17.7 percent in plastic clay) count is 96.2 million particles per cubic foot.

In two plants where the bag loading operation was studied dust arising from this operation unquestionably contaminated part or much of the main working areas of the plants. This fact was borne out by visual observation as well as by general atmospheric dust samples.

The control suggested in Table VI is effective for two reasons. First, isolation will limit floor and settling dust to a small room and prevent its distribution by wind throughout other plant areas. Secondly, fine atmospheric particles will be removed near the source of generation by the exhausting hood, thus protecting the operators.

An alternative control measure has been proposed as an economical substitute for the exhaust hood. This consists of attaching a dust tight sack clamp to the loading chute, just above the discharge spout, and placing the unfilled bags within metal cans or containers. Then if the can is placed on a platform of the proper height and the edge of the open sack is fastened tightly by the circular clamp, each sack could be loaded with a minimum of dusting. This method of control is offered only as a temporary dust reducer until the exhaust hood can be installed and not as a complete permanent control within itself.

5. Dirt Buggy Loading; 6. Breaker Pan; 7. Ball Mill; and 8. Sweeping Hot Floor - have been adequately treated under effective control in Table VI.

9. Brick Grinding: - While brick grinding has often been considered an obnoxious dust producing operation in the refractories industry, it has been found in this study to be fairly well controlled and to produce no consequential silica exposure. The average dust concentration in the vicinity of grinding wheel operators was 39.6 million particles. Based upon 10.3 percent free silica found in the burnt brick dust, the free silica count would be 4.0 million particles per cubic foot. It has been found, however, that free silica in burnt brick dust is more often 3 percent or less. No explanation can be given as to why some burnt brick batches contain 30 or even 40 percent free silica. Because of this unpredictable silica content, it is, of course, important to maintain grinding wheel hoods and suction at maximum efficiency.

10. Kiln Setting and Cleaning: - These operations were essentially identical with the setting and cleaning operations described in the earlier Silica Brick study (1). Kiln setting showed an average dust concentration of 16.3 and tunnel cleaning 29.2 million particles per cubic foot in that study.

Since both operations were periodic and showed much variability from plant to plant, additional dust sampling did not appear justifiable and, based upon the above concentrations, the exposure would be relatively inconsequential in the case of fire brick.

TABLE VI - EFFECTIVE CONTROL OF DUSTY OPERATIONS

OPERATION	EFFECTIVE CONTROL *
DRY PAN	- Complete enclosure of mill, allowing only small necessary openings for passage of belts, pulleys, etc. The enclosure is exhausted to a dust collector to the extent necessary to maintain a minimal air velocity of 300 F.P.M. at all openings. Mill made easily accessible by equipping enclosure with access door.
SCREEN MILL	- Complete enclosure of screening system (screens, elevator conveyors, belt conveyors and chutes). Exhaust to central dust collector. Avoidance of leaks in duct work very important. Storage bins receiving screened materials covered with dust proof flooring or metal tops which are provided with man-holes or trap doors. Respirators worn where periodic work inside of bins is absolutely necessary. Proper vertical layout of bins would obviate workers entering bins at all.
MIXING ROOM	- Control depends upon mixing method. Complete or partial enclosure of clay conveyor belts exhausting at least 300 F.P.M. through open face of hood and away from operator. (It is suggested that the manufacturing process be so designed that the mixing operation can be avoided, and a method of direct feed to the respective mills be employed instead).

* Only Dry Pan and Screen Mill control measures have been established as definitely effective by actual dust counts. Controls for all other operations are based upon careful process analyses.

BAG LOADING - Isolation of operation and partial enclosure of bag loading chute outlet with a three-side enclosed canopy-type hood. At least, 300 F.P.M. to be exhausted through open side of hood and away from operator by connecting exhaust duct to rear side of hood.

DIRT BUGGY LOADING - Load Dirt Buggy under a stationary, exhaust hood similar to the bag loading hood. (Such control would necessitate either an extension of chutes from storage bins to the loading hood or an extensive and costly exhaust hood to enclose all bin outlets. It is, therefore, suggested that this operation be avoided whenever possible, employing direct mill feed instead).

BREAKER PAN - Isolation of pan from rest of plant or complete enclosure and exhaust similar to Dry Pan Mill.

BALL MILL - A matter of good maintenance when mill is enclosed and under negative pressure. Any necessary openings on the positive pressure side to be covered with fine mesh filters.

SWEEPING HOT FLOOR - Replace the broom with an industrial vacuum cleaner. Otherwise, postpone all sweeping possible until end of shift. Good housekeeping extremely important for general dust control. All floors, stairways, landings, platforms, machinery, duct work, rafters and overhead structures should be periodically cleaned of settling dust.

SUMMARY

1. Fire clays used in the manufacture of fire brick are basically hydrated aluminum silicates. Although they vary in chemical composition, certain average amounts of free silica have been found in the clays -- plastic clay 17.7 percent, flint clay 7.1 percent, semi-flint clay 14 percent and burnt brick 10.3 percent.

2. Analyses of the dust encountered in various operations showed it to contain free silica ranging from 1 percent in some burnt brick dust to 95% in the mold or parting sand. A good over-all average free silica content, however, might be set at 12.2 percent, which represents the average amount of free silica found in an equiponderant mixture of the four raw materials named above.

3. The dry pan and screen mills, with maximum concentrations of 2742.2 and 1176 million particles per cubic foot, respectively, were shown to be the most dangerous sources of sustained dust production in the fire brick industry. An effective and practical control by enclosure of both processes has been demonstrated.

4. The median particle size of all atmospheric dust collected in the industry was found to be under 3 microns and of the same general order as other industrial dusts. In most cases, 74 percent or more of the dust was less than 3 microns and 90 percent or more was less than 5 microns.

5. Effective control measures for the eight operations producing dangerous dust concentrations were discussed and summarized.

PART II - AN ELECTROCAST REFRACTORY BRICK PLANT

INTRODUCTION

The study of this plant has been separated from the refractory clay-brick plants for the following reasons:

(1) The raw materials employed are entirely different, physically and chemically, from the clays used in the manufacture of regular fire-brick.

(2) The manufacturing process differs decidedly from that used in the conventional fire-brick industry, as will be noted by the flow sheets (fig. 2, page 9 and fig. 14, page 33).

(3) The dust exposures encountered in this plant are not similar in nature, nor do the potentially dangerous dusts arise from operations which are similar to those studies in the other refractory plants.

It becomes obvious, upon considering the engineering phase of this study, why neither the engineering nor medical data obtained herein could be used in establishing average exposures for the entire refractories industry. In spite of these basic differences, this plant is, nevertheless, a definite part of the refractories industry in the state. It is, in addition, of special interest because it is the only plant of its kind in the United States. In fact, only two other similar industrial plants are in existence — one being located in Europe and the other in the Orient. Moreover, this plant has responded to recommendations and, in numerous cases, has taken the initiative in installing specially designed control equipment. Thus the study is of particular interest from the industrial hygiene viewpoint, in that the dust picture is shown before and after controls were incorporated.

Fig. 4. General plant view showing part of ventilating system with collectors

Fig. 5. Electro-cast furnaces - one hooded (in foreground) one unhooded (in background)

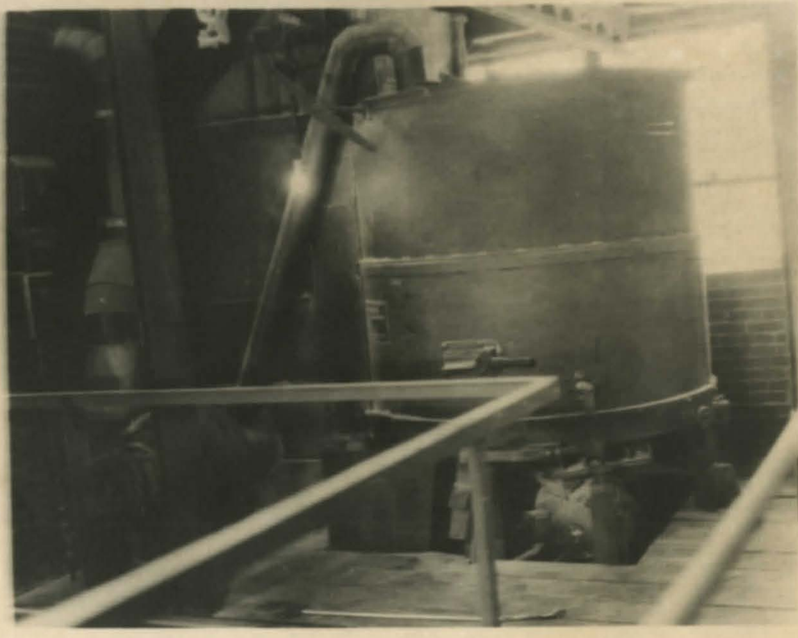

Fig. 6. Enclosed and Exhausted Sand Mixer
for Mold Batch

Fig. 7. Wet Sand Molding

Fig. 8. Pouring molten mass from hooded furnace into molds

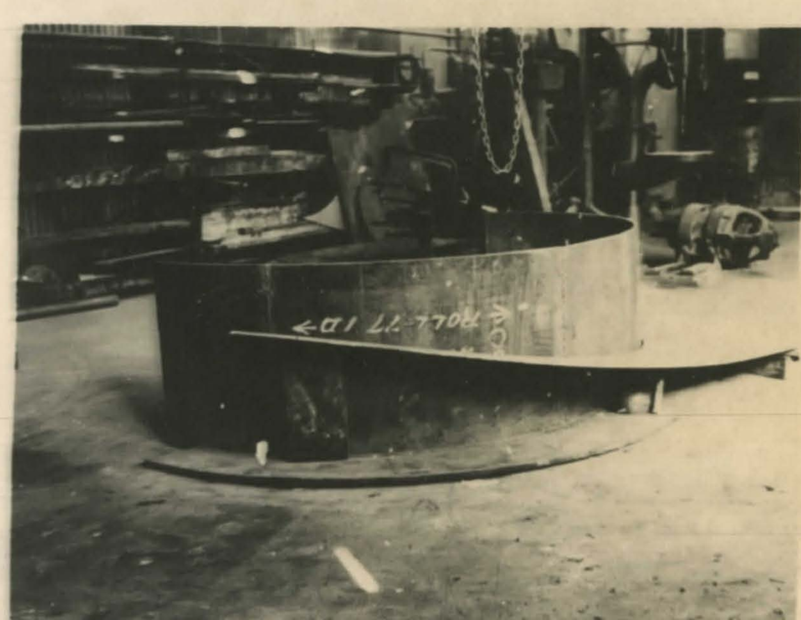

Fig. 9. Unmounted furnace hood

Fig. 10. Removing flask from casting
in font hole

Fig. 11. Can cleaning under canopy hood

Fig. 12. Down draft wire brushing booth

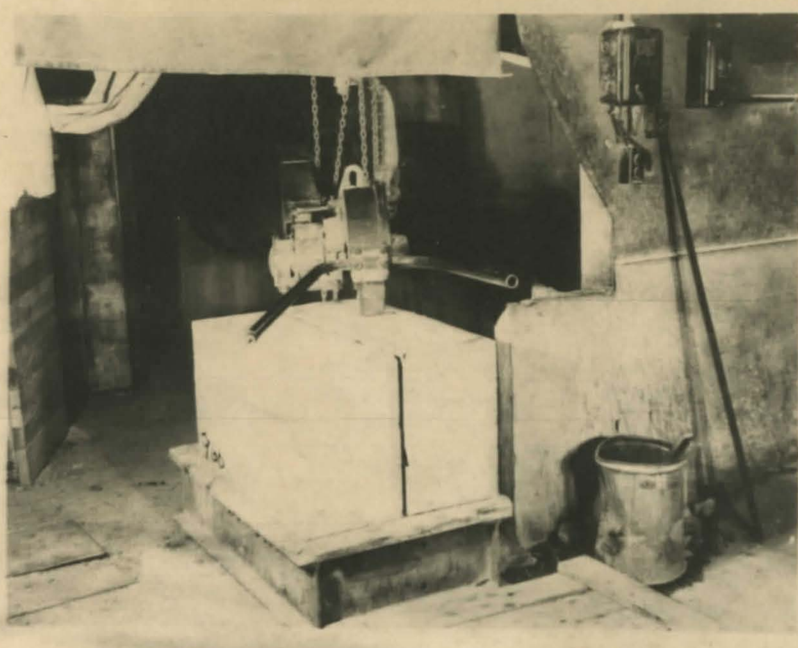

Fig. 13. Swing-frame block grinder
in exhausted booth

MANUFACTURE OF SUPER-REFRACTORY BRICK

Preparatory Milling and Storage of Raw Materials. The aluminous raw materials and zircon bearing ores are unloaded from freight cars, crushed in an outside mill and stored in open piles in the yard. These various materials are separately dried in a rotating cylindrical calciner, run through a uniformizing process, and then stored until needed for furnace charging.

The refractory-like portion of the process might be said to end here. As will be noted on the flow sheet (Fig. 14), the rest of the production process is foundry-like in nature, with the dividing line appearing at the furnace charging operation.

Mold Making. Slightly dampened white sand, mixed with a predetermined portion of bonding material, is discharged from a storage bin directly onto a hand operated slab former.

The single slabs are then placed on racks and baked in gas fired ovens. After cooling, the slabs are moved into the next room where they are sawed to size and assembled into molds of the desired shape.

Mold Packing and Flasking. The finished molds are then taken to the main working area where they are placed into rectangular metal "Cans", reinforced by so called "mold flasks", and packed in the cans with sand. This operation occupies a portion of the main working room area, next to the electric furnaces, known as the "Font Hole."

Melting and Pouring (Electrocasting). Measured amounts of prepared raw materials are taken from storage bins and shoveled (charged) into electric furnaces. Here the charge is heated to a molten mass and then poured directly into the molds, which by this time have been moved up in front of the furnaces on a monorail can-conveyor.

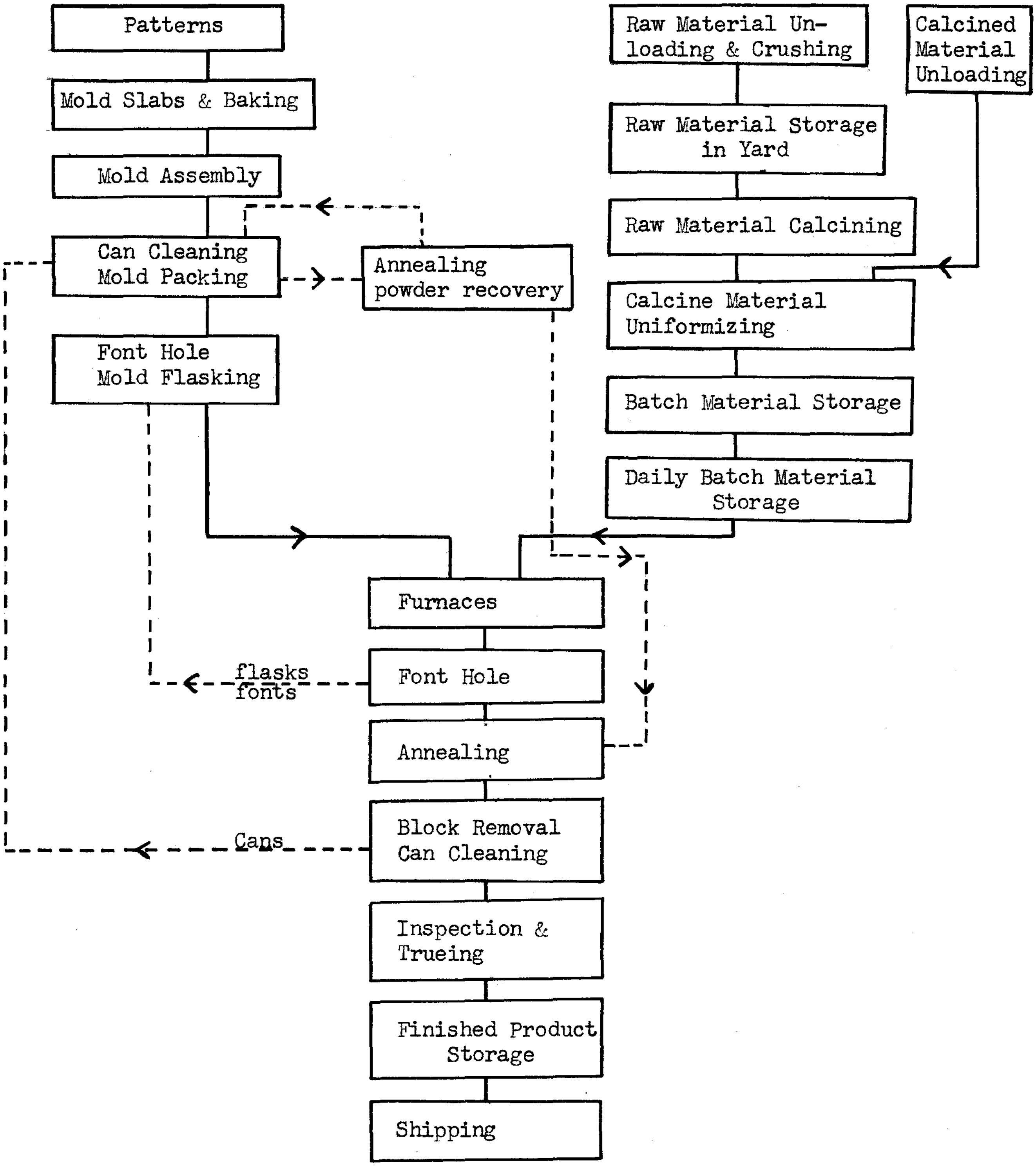

FIGURE 14 - FLOW SHEET OF ELECTROCAST REFRACTORIES PRODUCTION

Annealing. Immediately after pouring, the cans containing molds and castings are conveyed back to the font hole, and before cooling occurs, the flasks and fonts are withdrawn from the castings. The font hole crew then covers the hot refractory casting with a special annealing powder.

The cans are conveyed to a central storage area, where the castings are allowed to remain until annealing is completed.

Can Topping and Cleaning. After annealing is complete, the cans are moved over to one end of the font hole where two to four men shovel the annealing powder out of the top and sides of the can (Can Topping) so the refractory may be then lifted from the can. The powder is placed in a trough-like, canopy-hooded bin which opens to an enclosed conveyor leading to the powder reclaiming mill above.

As soon as the refractory block has been removed from the can, another worker removes the rest of the annealing powder (Can Cleaning). The can is then prepared to receive the next mold and repeat its cycle.

Inspection and Block Trueing. The surfaces of the refractory block are cleaned by means of a hand-operated rotary wire brush which is located inside of an exhausted booth. Each block is then inspected and, if necessary, the block is sent to the swing-frame grinder for smoothing, after which it is stored until shipped.

Nature of the Raw Product. The finished product is a super-refractory block consisting of mullite, corundum and glass. It is used principally for lining glass furnaces.

DISCUSSION

Dust studies have been conducted in this plant periodically for approximately three years. From the industrial hygiene point of view, the industry has afforded an excellent opportunity for study in that numerous control measures have been effected during this period of time.

Dust concentrations in the main work room atmosphere were found to fluctuate and have been influenced throughout the study by the following important but unpredictable factors: -- (1) the number of electric furnaces running, (2) open raw material storage bins and waste piles outside the plant, (3) temporary partial shut-down in the annealing powder reclaiming system and (4) natural wind shifts, temperature and humidity changes, as well as the effects of previous weather conditions on stored materials. Special control methods for these factors were being considered by plant management at the time this particular study was completed.

Free silica analyses on settling dust shown in Table VII, indicates the fact that the free silica content of atmospheric dust tends to increase as the annealing powder area is approached. Accordingly, only 13 percent free silica was found in rafter dust on the far side of the furnace platform, while 25 percent was present in dust collected from the platform near the powder mill.

TABLE VII - FREE SILICA ANALYSES

Operation or Location	Number of Settling Dust Samples	% Free Silica in Material
Sand Mixer Slab Room	1	15
Furnace Platform		
a-side near Powder Mill	1	25
b-far side	2	13
Powder Mill	2	66
Font Hole	2	75

The median particle size of general atmospheric dust collected near the powder mill was 2.56 microns, as shown in Table VIII on size frequency distribution.

TABLE VIII - SIZE FREQUENCY DISTRIBUTION OF GENERAL ATMOSPHERIC DUST NEAR ANNEALING POWDER MILL

(200 particles measured)

Size Groups in Microns										
0-0.49	0.5-0.99	1-1.49	1.5-1.99	2-2.49	2.5-2.99	3-3.49	3.5-3.99	4-5	5-over	Median
Percent in Size Groups										
		9	11	23	28	13	10	4	2	2.56

Based upon free silica content and exposure time, the most hazardous processes in the plant are those in which the annealing powder is handled. The annealing powder was found by petrographic analysis to contain 66% free silica, and since mold and packing sand are added to the powder in the process, the free silica percent tends to increase. Settling dust in the font hole area was found to contain 75% average free silica. Consequently, the operations in the following table, even though under partial control, will still require more adequate control before they can be considered entirely safe.

TABLE IX - OPERATIONS PARTIALLY CONTROLLED WHICH STILL SHOW SOME SILICA EXPOSURE

Operation	Average Total Count (m.p.p.c.f.) after Partial Control	% Free Silica in Material	Calculated Free Silica Count (m.p.p.c.f.)
Sweeping Font Hole	15.2	75	11.4
Can Filling	15.7	66	10.3
Can Cleaning	12.1	66	7.9
Powder Mill	32.7	66	21.5

According to comparative dustiness the operations in Table IX which require additional control are in order of their urgency, Powder Mill, Sweeping Font Hole, Can Filling and Can Cleaning.

As in any industrial plant where dust is produced day after day, considerable settling dust had accumulated on the rafters, machinery, etc. Such dust would have to be removed before an accurate picture of control efficiency could be obtained, since there is no way of knowing the amount of cross-contamination due to this dust. Thus, good housekeeping would be an important control step which should be practiced before a final interpretation could be given to the dust study. In this connection, an industrial vacuum cleaner was being put to use just prior to the completion of this study.

A summary of control methods will not be attempted in this case because of the highly specialized nature of the installations. It is sufficient to say that the control principle employed throughout was that of removing the dust at its point of origin by local exhaust. Isolation of the process was practiced when possible.

TABLE X - DUST CONCENTRATIONS IN M.P.P.C.F.

LOCATIONS OR OPERATIONS	NO. OF SAMPLES	MINIMUM	MAXIMUM	AVERAGES BEFORE CONTROL	AFTER CONTROL OR PARTIAL CONTROL	OVER-ALL
1-Sand Mixing for Slabs	5	16.2	29.2			20.4
2-Slab Saw	2	7.5	8.0			7.5
3-Mold Assembly Room-Gen.Atmos.	2	6.0	9.4			7.7
4-Main Room - Gen. Atmos.						
A-West Aisle	2	17.3	22.6			19.9
B-East Aisle	1	18.	18.			18.
5-Furnace Plat-form	33	1.9	114	41	12	26.5
6-Front of Furnace	10	1.1	40.8	14.3	4.5	9.4
7-Font Hole	44	1.6	51.8	21.2	7.1	14.1
8-Sweeping Font Hole	11	12.3	106.4	46.6	15.2	30.9
9-Can Filling (With Annealing Powder)	11	4.4	23	18.6	15.7	17.1
10-Can Cleaning and Topping	53	2.8	107.2	50.6	12.1	25.8
11-Powder Mill Main Floor	11	8.1	140			32.7
12-Wire Brushing	11	3.5	97			37.1
13-Block Grinding	15	8.0	68.6	23.4	15.1	19.2
Total	-211					

SUMMARY

1. Aluminous raw materials and zircon bearing ores are used in the manufacture of super-refractories.

2. The annealing powder used for covering the hot refractories is largely diatomaceous earth and contains 66 percent free silica. It is in connection with operations employing this powder that the principal silica exposures were found.

3. The median particle size of dust encountered in the general atmosphere near the annealing powder mill was 2.56 microns, 71 percent of the dust is less than 3 microns and 98 percent less than 5 microns in size.

4. Rather extensive and specially designed control ventilation has been provided in the industry since the beginning of this study. However, certain operations in which the annealing powder is handled will require still more adequate control if unsafe silica exposures are to be entirely eliminated.

GLOSSARY

REFRACTORY (FIRE) BRICK - Brick capable of withstanding high temperatures without deforming and having pyrometric cone equivalents (P.C.E.) of not less than 19. It has been recommended (16) that clays with a P.C.E. from 19 to 26, inclusive, be called low heat duty fire clays and that those with a P.C.E. of 27 or higher be designated refractory.

PYROMETRIC CONES - Small trihedral pyramids made of mineral mixtures similar to those of the actual refractory brick or ware and behaving thermochemically so much like the ware that they serve as accurate guides to the proper firing of all ceramic products.

CONE SERIES - A series consisting of 60 different cone bodies ranging from the lowest melting body (cone 022) which is essentially a soda-lead boro silicate glass to the highest melting body (cone 42) which is pure aluminum oxide.

Cone 022 has temp. equivalent of 605° C (1121° F)
Cone 42 has temp. equivalent of 2015° C (3659° F)
Cone 33 has temp. equivalent of 1745° C (3173° F)

VITRIFICATION - The point at which maximum density and lowest porosity of a clay are reached. Beyond this point the clay swells and porosity increases, which indicates the beginning of overfiring.

FIRING RANGE - The temp. interval between vitrification and the beginning of overfiring. Highly calcareous clays have short firing ranges. Clays suitable for vitrified ware have long firing ranges.

TEMPERING - Improving the property of a clay by mixing it to a homogeneous mass which necessitates a uniform reduction in moisture content.

BIBLIOGRAPHY

(1) FULTON, WM. D., BUTTERS, F. E., DOOLEY, A. E., KOPPENHAVER, F. B., MATTHEWS, J. L., and KIRK, R. M.: A Study of Silicosis in the Silica Brick Industry. Bureau of Industrial Hygiene, Pennsylvania State Department of Health, July 29, 1941.

(2) HOEING, J. B., State Geologist: Description of the Fire Clay Districts of Eastern Kentucky. Ky. Geol. Sur., Ser IV Vol. I - Part II, p. 594, July 1913.

(3) RIES, HEINRICH: The Clay Deposits of Kentucky. Ky. Geol. Sur., Frankfort, Kentucky, 1922.

(4) GALPIN, S. L.: Studies of Flint Clays and Their Associates. American Ceramic Society Transactions, 14:301, 1912.

(5) WARNER, J. C.: Chemistry of Engineering Materials, by R. B. Leighou, 4th Edition, Chap. III, p. 109, McGraw-Hill Book Co., 1942.

(6) IBID. Chap. XIV, Alexander, T. R., p. 502.

(7) FLINN, H., DREESSEN, W. C., EDWARDS, R. I., RILEY, E. C., BLOOMFIELD, J. J., SAYERS, R. R., CADDEN, J. F., and ROTHMAN, S. C.: Silicosis and Lead Poisoning Among Pottery Workers. Pub. Health Bulletin No. 244, 1939.

(8) KNOPF, A.: The Quantitative Determination of Quartz (Free Silica) in Dusts. Pub. Health Reports, Vol. 48, No. 8, 1933.

(9) BLOOMFIELD, J. J., DALLA VALLE, J. M.: The Determination and Control of Industrial Dust. Pub. Health Bulletin, No. 217, April 1935.

(10) LITTLEFIELD, J. B., FEICHT, F. L., and SCHRENK, H. H.: Bureau of Mines Midget Impinger for Dust Sampling. Report of Investigation 3360. U. S. Bureau of Mines, December 1937.

(11) LITTLEFIELD, J. B. and SCHRENK, H. H.: Dust Sampling with the Bureau of Mines Midget Impinger, using a New Hand Operated Pump. Report of Investigation 3387. U. S. Bureau of Mines, March 1938.

(12) SCHRENK, H. H. and FEICHT, F.L.: Bureau of Mines Midget Impinger. Information Circular 7076. U. S. Bureau of Mines, June 1939.

(13) BROWN, C. D. and SCHRENK, H. H.: A Technique for Use of the Impinger Method. Information Circular 7026. U. S. Bureau of Mines, June 1938.

(14) OWENS, J. S.: Jet Dust Counting Apparatus. Journal Industrial Hygiene, Vol. 4, No. 12, April 1923.

(15) DRINKER, PHILIP and THEODORE HATCH: Industrial Dust. P. 135 McGraw-Hill, 1936.

(16) The Bulletin of the American Ceramic Society: Vol. 18, No. 6, P. 214, June, 1939.