

Composition and Approximate Softening Points of Pyrometric Cones.

No. of Cone.	Composition.				Fusing-point.	
					°F.	°C.
.022	{ 0.5 Na <sub>2</sub> O } { 0.5 PbO }		{ 2.0 SiO <sub>2</sub> } { 1.0 B <sub>2</sub> O <sub>3</sub> }		1,094	590
.021	{ 0.5 Na <sub>2</sub> O } { 0.5 PbO }	0.1 Al <sub>2</sub> O <sub>3</sub>	{ 2.2 SiO <sub>2</sub> } { 1.0 B <sub>2</sub> O <sub>3</sub> }		1,148	620
.020	{ 0.5 Na <sub>2</sub> O } { 0.5 PbO }	0.2 Al <sub>2</sub> O <sub>3</sub>	{ 2.4 SiO <sub>2</sub> } { 1.0 B <sub>2</sub> O <sub>3</sub> }		1,202	650
.019	{ 0.5 Na <sub>2</sub> O } { 0.5 PbO }	0.3 Al <sub>2</sub> O <sub>3</sub>	{ 2.6 SiO <sub>2</sub> } { 1.0 B <sub>2</sub> O <sub>3</sub> }		1,256	680
.018	{ 0.5 Na <sub>2</sub> O } { 0.5 PbO }	0.4 Al <sub>2</sub> O <sub>3</sub>	{ 2.8 SiO <sub>2</sub> } { 1.0 B <sub>2</sub> O <sub>3</sub> }		1,310	710
.017	{ 0.5 Na <sub>2</sub> O } { 0.5 PbO }	0.5 Al <sub>2</sub> O <sub>3</sub>	{ 3.0 SiO <sub>2</sub> } { 1.0 B <sub>2</sub> O <sub>3</sub> }		1,364	740
.016	{ 0.5 Na <sub>2</sub> O } { 0.5 PbO }	0.55 Al <sub>2</sub> O <sub>3</sub>	{ 3.1 SiO <sub>2</sub> } { 1.0 B <sub>2</sub> O <sub>3</sub> }		1,418	770
.015	{ 0.5 Na <sub>2</sub> O } { 0.5 PbO }	0.6 Al <sub>2</sub> O <sub>3</sub>	{ 3.2 SiO <sub>2</sub> } { 1.0 B <sub>2</sub> O <sub>3</sub> }		1,472	800
.014	{ 0.5 Na <sub>2</sub> O } { 0.5 PbO }	0.65 Al <sub>2</sub> O <sub>3</sub>	{ 3.3 SiO <sub>2</sub> } { 1.0 B <sub>2</sub> O <sub>3</sub> }		1,526	830
.013	{ 0.5 Na <sub>2</sub> O } { 0.5 PbO }	0.7 Al <sub>2</sub> O <sub>3</sub>	{ 3.4 SiO <sub>2</sub> } { 1.0 B <sub>2</sub> O <sub>3</sub> }		1,580	860
.012	{ 0.5 Na <sub>2</sub> O } { 0.5 PbO }	0.75 Al <sub>2</sub> O <sub>3</sub>	{ 3.5 SiO <sub>2</sub> } { 1.0 B <sub>2</sub> O <sub>3</sub> }		1,634	890
.011	{ 0.5 Na <sub>2</sub> O } { 0.5 PbO }	0.8 Al <sub>2</sub> O <sub>3</sub>	{ 3.6 SiO <sub>2</sub> } { 1.0 B <sub>2</sub> O <sub>3</sub> }		1,688	920
.010	{ 0.3 K <sub>2</sub> O } { 0.7 CaO }	0.2 Fe <sub>2</sub> O <sub>3</sub> 0.3 Al <sub>2</sub> O <sub>3</sub>	{ 3.50 SiO <sub>2</sub> } { 0.50 B <sub>2</sub> O <sub>3</sub> }		1,742	950
.09	{ 0.3 K <sub>2</sub> O } { 0.7 CaO }	0.2 Fe <sub>2</sub> O <sub>3</sub> 0.3 Al <sub>2</sub> O <sub>3</sub>	{ 3.55 SiO <sub>2</sub> } { 0.45 B <sub>2</sub> O <sub>3</sub> }		1,778	970
.08	{ 0.3 K <sub>2</sub> O } { 0.7 CaO }	0.2 Fe <sub>2</sub> O <sub>3</sub> 0.3 Al <sub>2</sub> O <sub>3</sub>	{ 3.60 SiO <sub>2</sub> } { 0.40 B <sub>2</sub> O <sub>3</sub> }		1,814	990
.07	{ 0.3 K <sub>2</sub> O } { 0.7 CaO }	0.2 Fe <sub>2</sub> O <sub>3</sub> 0.3 Al <sub>2</sub> O <sub>3</sub>	{ 3.65 SiO <sub>2</sub> } { 0.35 B <sub>2</sub> O <sub>3</sub> }		1,850	1,010
.06	{ 0.3 K <sub>2</sub> O } { 0.7 CaO }	0.2 Fe <sub>2</sub> O <sub>3</sub> 0.3 Al <sub>2</sub> O <sub>3</sub>	{ 3.70 SiO <sub>2</sub> } { 0.30 B <sub>2</sub> O <sub>3</sub> }		1,886	1,030
.05	{ 0.3 K <sub>2</sub> O } { 0.7 CaO }	0.2 Fe <sub>2</sub> O <sub>3</sub> 0.3 Al <sub>2</sub> O <sub>3</sub>	{ 3.75 SiO <sub>2</sub> } { 0.25 B <sub>2</sub> O <sub>3</sub> }		1,922	1,050
.04	{ 0.3 K <sub>2</sub> O } { 0.7 CaO }	0.2 Fe <sub>2</sub> O <sub>3</sub> 0.3 Al <sub>2</sub> O <sub>3</sub>	{ 3.80 SiO <sub>2</sub> } { 0.20 B <sub>2</sub> O <sub>3</sub> }		1,958	1,070
.03	{ 0.3 K <sub>2</sub> O } { 0.7 CaO }	0.2 Fe <sub>2</sub> O <sub>3</sub> 0.3 Al <sub>2</sub> O <sub>3</sub>	{ 3.85 SiO <sub>2</sub> } { 0.15 B <sub>2</sub> O <sub>3</sub> }		1,994	1,090
.02	{ 0.3 K <sub>2</sub> O } { 0.7 CaO }	0.2 Fe <sub>2</sub> O <sub>3</sub> 0.3 Al <sub>2</sub> O <sub>3</sub>	{ 3.90 SiO <sub>2</sub> } { 0.10 B <sub>2</sub> O <sub>3</sub> }		2,030	1,110
.01	{ 0.3 K <sub>2</sub> O } { 0.7 CaO }	0.2 Fe <sub>2</sub> O <sub>3</sub> 0.3 Al <sub>2</sub> O <sub>3</sub>	{ 3.95 SiO <sub>2</sub> } { 0.05 B <sub>2</sub> O <sub>3</sub> }		2,066	1,130
1	{ 0.3 K <sub>2</sub> O } { 0.7 CaO }	0.2 Fe <sub>2</sub> O <sub>3</sub> 0.3 Al <sub>2</sub> O <sub>3</sub>	4 SiO <sub>2</sub>		2,102	1,150
2	{ 0.3 K <sub>2</sub> O } { 0.7 CaO }	0.1 Fe <sub>2</sub> O <sub>3</sub> 0.4 Al <sub>2</sub> O <sub>3</sub>	4 SiO <sub>2</sub>		2,138	1,170
3	{ 0.3 K <sub>2</sub> O } { 0.7 CaO }	0.05 Fe <sub>2</sub> O <sub>3</sub> 0.45 Al <sub>2</sub> O <sub>3</sub>	4 SiO <sub>2</sub>		2,174	1,190
4	{ 0.3 K <sub>2</sub> O } { 0.7 CaO }	0.5 Al <sub>2</sub> O <sub>3</sub>	4 SiO <sub>2</sub>		2,210	1,210

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5	{ 0.3 K <sub>2</sub> O } { 0.7 CaO }	0.5 Al <sub>2</sub> O <sub>3</sub> 5 SiO <sub>2</sub>	2,246	1,230
6	{ 0.3 K <sub>2</sub> O } { 0.7 CaO }	0.6 Al <sub>2</sub> O <sub>3</sub> 6 SiO <sub>2</sub>	2,282	1,250
7	{ 0.3 K <sub>2</sub> O } { 0.7 CaO }	0.7 Al <sub>2</sub> O <sub>3</sub> 7 SiO <sub>2</sub>	2,318	1,270
8	{ 0.3 K <sub>2</sub> O } { 0.7 CaO }	0.8 Al <sub>2</sub> O <sub>3</sub> 8 SiO <sub>2</sub>	2,354	1,290
9	{ 0.3 K <sub>2</sub> O } { 0.7 CaO }	0.9 Al <sub>2</sub> O <sub>3</sub> 9 SiO <sub>2</sub>	2,390	1,310
10	{ 0.3 K <sub>2</sub> O } { 0.7 CaO }	1.0 Al <sub>2</sub> O <sub>3</sub> 10 SiO <sub>2</sub>	2,426	1,330
11	{ 0.3 K <sub>2</sub> O } { 0.7 CaO }	1.2 Al <sub>2</sub> O <sub>3</sub> 12 SiO <sub>2</sub>	2,462	1,350
12	{ 0.3 K <sub>2</sub> O } { 0.7 CaO }	1.4 Al <sub>2</sub> O <sub>3</sub> 14 SiO <sub>2</sub>	2,498	1,370
13	{ 0.3 K <sub>2</sub> O } { 0.7 CaO }	1.6 Al <sub>2</sub> O <sub>3</sub> 16 SiO <sub>2</sub>	2,534	1,390
14	{ 0.3 K <sub>2</sub> O } { 0.7 CaO }	1.8 Al <sub>2</sub> O <sub>3</sub> 18 SiO <sub>2</sub>	2,570	1,410
15	{ 0.3 K <sub>2</sub> O } { 0.7 CaO }	2.1 Al <sub>2</sub> O <sub>3</sub> 21 SiO <sub>2</sub>	2,606	1,430
16	{ 0.3 K <sub>2</sub> O } { 0.7 CaO }	2.4 Al <sub>2</sub> O <sub>3</sub> 24 SiO <sub>2</sub>	2,642	1,450
17	{ 0.3 K <sub>2</sub> O } { 0.7 CaO }	2.7 Al <sub>2</sub> O <sub>3</sub> 27 SiO <sub>2</sub>	2,678	1,470
18	{ 0.3 K <sub>2</sub> O } { 0.7 CaO }	3.1 Al <sub>2</sub> O <sub>3</sub> 31 SiO <sub>2</sub>	2,714	1,490
19	{ 0.3 K <sub>2</sub> O } { 0.7 CaO }	3.5 Al <sub>2</sub> O <sub>3</sub> 35 SiO <sub>2</sub>	2,750	1,510
20	{ 0.3 K <sub>2</sub> O } { 0.7 CaO }	3.9 Al <sub>2</sub> O <sub>3</sub> 39 SiO <sub>2</sub>	2,786	1,530
21	{ 0.3 K <sub>2</sub> O } { 0.7 CaO }	4.4 Al <sub>2</sub> O <sub>3</sub> 44 SiO <sub>2</sub>	2,822	1,550
22	{ 0.3 K <sub>2</sub> O } { 0.7 CaO }	4.9 Al <sub>2</sub> O <sub>3</sub> 49 SiO <sub>2</sub>	2,858	1,570
23	{ 0.3 K <sub>2</sub> O } { 0.7 CaO }	5.4 Al <sub>2</sub> O <sub>3</sub> 54 SiO <sub>2</sub>	2,894	1,590
24	{ 0.3 K <sub>2</sub> O } { 0.7 CaO }	6.0 Al <sub>2</sub> O <sub>3</sub> 60 SiO <sub>2</sub>	2,930	1,610
25	{ 0.3 K <sub>2</sub> O } { 0.7 CaO }	6.6 Al <sub>2</sub> O <sub>3</sub> 66 SiO <sub>2</sub>	2,966	1,630
26	{ 0.3 K <sub>2</sub> O } { 0.7 CaO }	7.2 Al <sub>2</sub> O <sub>3</sub> 72 SiO <sub>2</sub>	3,002	1,650
27	{ 0.3 K <sub>2</sub> O } { 0.7 CaO }	20.0 Al <sub>2</sub> O <sub>3</sub> 200 SiO <sub>2</sub>	3,038	1,670
28	Al <sub>2</sub> O <sub>3</sub>	10 SiO <sub>2</sub>	3,074	1,690
29	Al <sub>2</sub> O <sub>3</sub>	8 SiO <sub>2</sub>	3,110	1,710
30	Al <sub>2</sub> O <sub>3</sub>	6 SiO <sub>2</sub>	3,146	1,730
31	Al <sub>2</sub> O <sub>3</sub>	5 SiO <sub>2</sub>	3,182	1,750

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32	Al <sub>2</sub> O <sub>3</sub> 4 SiO <sub>2</sub> .....	3,218	1,770
33	Al <sub>2</sub> O <sub>3</sub> 3 SiO <sub>2</sub> .....	3,254	1,790
34	Al <sub>2</sub> O <sub>3</sub> 2.5 SiO <sub>2</sub> .....	3,290	1,810
35	Al <sub>2</sub> O <sub>3</sub> 2 SiO <sub>2</sub> .....	3,326	1,830
36	Al <sub>2</sub> O <sub>3</sub> 1.5 SiO <sub>2</sub> .....	3,362	1,850
37	.....	3,398	1,880
38	.....	3,434	1,910
39	.....	3,470	1,940

Although the approximate temperature of fusion of each cone is given in the preceding table, it must be understood that these cones are not intended for measuring temperature, but rather for measuring pyrochemical effects. While the different members of any one make of cones are usually consistent with each other, the same numbers of different makes seldom agree.\* In small test kilns as used in laboratories, when the temperature is not raised too rapidly the softening points of the cones usually approach the indicated temperature within about 20°C., but when used in large commercial kilns where the temperature is raised more slowly, and the cones are subjected to a soaking heat, they usually soften at temperatures considerably below that indicated in the table.

In actual use a number of cones are mounted in fire clay and placed in the kiln at a point where they can be observed through a peep hole, but at the same time will not receive the direct touch of the flame from the fuel, or cold air through the observation hole.

Because of their peculiar properties and ease of use, pyrometric cones will probably be employed for a long time. But as cones are useless during drying, water smoking or cooling, and entirely inadequate for gaging the efficiency of firing, the use of indicating and recording pyrometers in the ceramic industries is rapidly increasing. Such pyrometers indicate accurately, temperature, and the variation of temperature with time, and are therefore of great value in the ceramic industries. An accurate independent measure of these two most important variables in firing is necessary in order to correlate temperature with other variables, some of which are difficult to control, or unknown.

\*H. E. Ashley, Trans. Am. Cer. Soc. VIII, p. 159 (1906).

*Pyrometers.* The types of pyrometers\* suitable for use in the ceramic industries are:

1. The Thermocouple (preferably platinum, platinum-rhodium),
2. The radiation pyrometer,
3. The optical pyrometer.

*Thermocouples.* If two different metals are placed in contact an electro-motive force (e.m.f.) is set up, the magnitude of which depends upon the temperature of the metallic junction and upon the metals used. This e.m.f. due to a junction of two dissimilar metals is called the Peltier e.m.f.

If a wire of homogenous material is heated at one end an e.m.f. is developed between the hot and cold ends of the wire, the magnitude of which depends upon the metal and upon the difference in temperature of the hot and cold ends. This is called the Thomson e.m.f.

The total e.m.f. acting in a circuit composed of two dissimilar wires is the sum of the Peltier e.m.f. at each junction and the Thomson e.m.f.

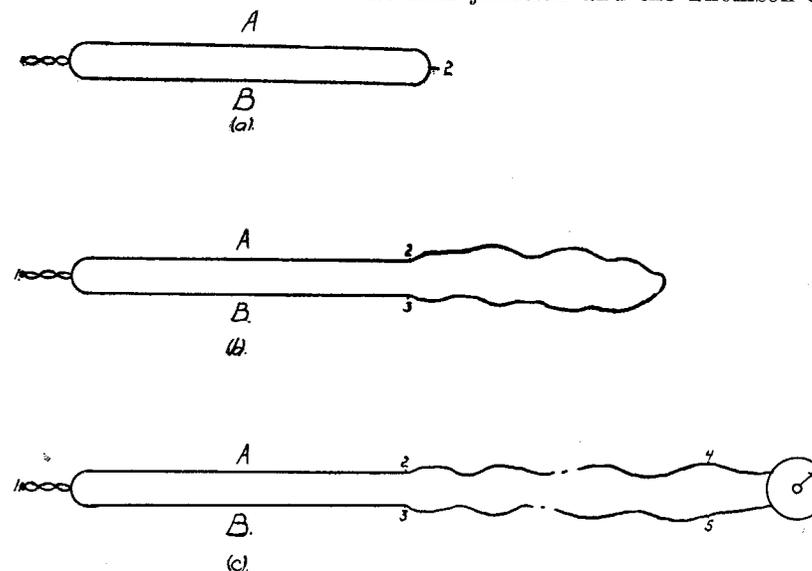


Figure 16.—Drawing illustrating principle of thermocouple.

over each wire, with due consideration given to the algebraic signs. The total e.m.f. in such a circuit depends upon the properties of the metals used in the couple and the temperature of the two junctions. If the temperature of one junction is fixed the temperature of the other junction can be determined by measuring the e.m.f. developed by the circuit.

Figure 16a shows two dissimilar metals, A and B, in a closed circuit. If junction 1 is at the same temperature as junction 2 there will be an

\*For a discussion of pyrometers and an explanation of their uses see—  
Symposium on Pyrometry, Am. Inst. Min. & Met. Eng. (1920),  
Pyrometric Practice, Tech. Paper 170 U. S. Bur. of Standards (1921).

equal and opposite Peltier e.m.f. at each junction. The Thomson e.m.f. in each wire will be zero, and the total effect will be zero. If junction 1 is at a higher temperature than 2 the Peltier e.m.f.'s will be unequal and each wire will develop a Thomson e.m.f. The total e.m.f. of the circuit is then equal to the sum of the different effects noted, and depends upon the temperature of the two junctions.

If the circuit is closed by means of a third wire C, as is necessary in order to read the e.m.f. by some form of meter, the circuit may be represented by figure 16b. Provided junction 2 is at the same temperature as junction 3, the introduction of the third wire has no influence upon the e.m.f. of the circuit.

In practice the circuit shown in figure 16c is used. In this case so long as the leads C.C. are of the same material, the junctions 2 and 3 at the same temperature, and junctions 4 and 5 at the same temperature not necessarily the same as that of 2 and 3, the e.m.f. depends solely upon the couple AB and the temperatures of the junction 1 and 2-3. Frequently it is desirable to have the fixed junction at the meter rather than at the point where the leads join the couple, because the latter junction (2-3 in figure 16c) is much nearer the kiln its temperature varies more than the former (4-5 in figure 16c). In this case the leads C are made one of A and one of B, thus extending the fixed junction (frequently called cold junction) to the meter at 4-5. Such leads are called compensating leads.

Although any two dissimilar metals might be employed for a thermocouple, certain combinations are very unsatisfactory because of very small e.m.f., or the e.m.f. may increase, then decrease, become zero and change sign as the temperature increases. The desirable properties are:

- Resistance to corrosion and oxidation,
- Relatively large e.m.f.,
- Steady increase of e.m.f. with increasing temperature.

Several different types are employed for general work. Copper-constantan (an alloy of copper and nickel) may be used for precise work up to 360°C., and up to 500°C. with 5° or 10°C. error. The useful range of this couple limits its application to drying operations in the ceramic industry. For this purpose it is very satisfactory as this couple give a higher e.m.f. at low temperatures than any other.

Special alloys of chromium and nickel, and of aluminum and nickel, such as "chromel-alumel" or "nichrome-alumel" make satisfactory couples, even for continuous use, between 350° and 1100°C. Below 350°C. the e.m.f. does not change uniformly with the temperature of the hot or varying junction. Above 1100°C. the wires become oxidized and change their properties. For kilns fired at temperatures not exceeding 1100°C. or cone 1, this type of base metal couple may be used.

The LeChatelier (noble metal) couple (platinum, with an alloy of 90% platinum and 10% rhodium) is the most satisfactory couple. This couple calibrated at the melting points of copper, antimony, and zinc, is used to define the standard temperature scale between 450°C. and 1100°C. It is the best means available for measuring temperatures between 300° and 1500°C., up to cone 18 or 20, and can be used in kilns burning any clay product. Even the highest temperatures attained in burning fire-brick and porcelain seldom exceed that corresponding to cone 15 or about 1400°C.

The couple is made by twisting together the two wires for mechanical strength and welding the ends by means of an oxygen blowpipe. Noble metal couples are made usually of wire about 0.5 m.m. (.02 in.) in diameter, and the base metal couples of No. 20 wire for low temperatures and of No. 8, 6, or larger wire for higher temperatures and when there is danger of contamination. One or both of the wires are insulated by threading through small porcelain or quartz tubes, asbestos sleeves, or winding with asbestos. If subject to severe furnace conditions all base metals must be protected by a closed tube of iron, steel, nichrome, quartz, porcelain, etc.

Noble metal couples are insulated by porcelain or quartz tubes and protected by a tube of porcelain glazed on the outside only, or of fused silica, hemispherically closed at the hot end, and an outer tube of fire clay. The open end is mounted with the head of the couple. Noble metal couples must always be protected carefully by the above tubes as the platinum is very readily contaminated by furnace gases. In use it is best to have the couple mounted permanently in the kiln to avoid cracking the porcelain protection tube, as frequently happens when the cold tube is inserted into a hot kiln.

Two different types of indicators and recorders are used for measuring the e.m.f., and indirectly the temperature of a thermocouple. The simplest indicator is a galvanometer, having a moving coil mounted between the poles of a permanent magnet. The deflection of the pointer or boom attached to the coil connected to the thermocouple is proportional to the current passing through the coil, and the current varies directly as the e. m. f. of the couple and inversely as the resistance of the circuit. If the resistance of the circuit is constant the deflection of the galvanometer is directly dependent on the e.m.f. of the couple. While it is impractical to keep the total resistance of the thermocouple circuit constant, the resistance seldom varies more than 4 or 5 ohms; so that if the total resistance of the circuit is high (500 to 1200 ohms), the errors in the indicated temperature will not exceed 1%. The high resistance is most conveniently mounted in the galvanometer box, and is considered part of the galvanometer as this resistance greatly affects the reading of the galvanometer. Robust galvanometer

indicators having a resistance of 500 ohms or more are readily available. The importance of having a high resistance galvanometer can not be over-emphasized, as a simple galvanometer indicator or recorder of low resistance is always subject to large errors from small changes in the resistance of the circuit.

The most accurate method for measuring the e.m.f. of a thermocouple is by means of a potentiometer, which completely eliminates any error due to changing circuit resistance as it measures the e.m.f. of the couple directly with no current flowing. The potentiometer is available both as an indicator or as a recorder of the single or multiple point type.

As has been pointed out, the e.m.f. of a thermocouple depends as much upon the temperature of the cold junction as upon the temperature of the hot junction. For the chromel-alumel base metal couple the e.m.f. is approximately proportional to the difference in temperature between the two junctions. With such couples a change in 50 degrees in temperature of the cold junction causes an error of 50 degrees in the indicated temperature of the hot junction, which can be corrected by adding to the observed temperature the difference between the cold junction temperature and the temperature of cold junction for which the couple was calibrated. For other couples this relation does not hold and this difference must be multiplied by various factors depending upon the temperature of the hot junction. These corrections may be applied directly, without computation, by setting the pointer of the galvanometer to read the cold junction temperature on open circuit. The setting is made by turning the zero adjustment screw of the indicator when the couple is disconnected. Special adjustments are available on potentiometers for compensating for cold junction temperatures in a way simpler than that suggested for galvanometers.

For use in ceramic kilns, the couple, properly protected, is best extended into the kiln at least 6" beyond the inner face of the wall for temperatures below 1300°C. From 1300°C. to 1450°C. 3 to 4 inch immersion is generally found best. Above 1450°C. adequate protection of the couple is very difficult and the general practice is to withdraw the couple and tubes until the tip is just flush with the inner face of the wall, or even within the wall. In such a position the lag is very great and the indicated temperature will be considerably below the correct value. Generally the couple is inserted through the roof in intermittent kilns and in continuous kilns of the tunnel and chamber types. In large kilns, proportionately more couples are required. The best points for installing couples can be determined only by experience. Portable outfits for this experimental work are furnished by all pyrometer manufacturers.

The recording instrument is almost indispensable. Among its important advantages over indicators, are its accurate record of "set-backs", or of steady temperature rise in intermittent kilns, and its absolute independence from failure of the human element. The record of "set-backs", and rate of temperature rise are the two most important advantages possessed by thermocouples over the pyrometric cones. Multiple point recorders are best for tunnel kilns and such intermittent kilns as require more than one couple. The recorder may be installed in the superintendent's office with an indicator mounted near the kiln or other arrangement may be made to suit conditions.

*Radiation Pyrometers.* Radiation pyrometers are peculiarly useful in cases where it is impractical or inadvisable to use any form of pyrometer which must be brought into contact with the substance whose temperature is to be measured; whether for reasons of inaccessibility or motion of the object, or because such contact might be detrimental to the object or to the pyrometer, or where a rapid examination for uniformity of temperature over a considerable area is required, some form of pyrometer entirely separated from the object or furnace, and acting at a distance is required. Such pyrometers are divided into two classes, the total radiation pyrometer, and the optical pyrometer.

The total radiation pyrometer, usually called the radiation pyrometer, measures the total radiant energy of all wave lengths emitted by the object by focusing the radiation on the hot junction of a small thermocouple. The temperature to which this hot junction rises is approximately proportional to the rate at which energy falls upon it. The rise in temperature of the hot junction generates an e.m.f. which can be measured and recorded by any of the methods used for thermocouples. The temperature of the cold junction need not be controlled in radiation pyrometers as the hot and cold junctions are equally affected by changes in room temperature. The cold junction is always shaded from the heat energy radiated by the object.

The temperature indicated by a radiation pyrometer is limited to an accuracy of about 2 per cent. Dust and dirt allowed to accumulate upon the mirror may cause the reading to be 100° to 200°C. too low. Black body conditions are necessary for the accurate measurement of temperature by radiation pyrometers, and the entire field of the instrument must be completely covered by the object. If reflected radiation or burning gases are present, as is frequently the case in ceramic kilns, black body conditions necessary for accurate readings may be obtained by sighting the radiation pyrometer into the bottom of a fire clay or graphite tube of sufficient size to cover the field of the pyrometer with a uniformly heated area. Radiation pyrometers are useful in ceramic industries for measuring the higher temperatures when a temperature

time record is desired and for exploring a kiln for temperature distribution, but are generally less satisfactory than the optical pyrometer for the latter purpose.

*Optical Pyrometers.* Optical pyrometers measure the intensity of one definite wave length of the radiant energy from a hot object, and determine the temperature of the object by this means. The wave length measured is usually that of 0.65  $\mu$ . (0.00065 m.m.) corresponding to red light, all other radiation being filtered out by a special red glass in the ocular, or eye piece, of the telescope. A number of different styles of optical pyrometers are on the market. The most satisfactory type is that known as the disappearing filament type as shown in figure 17. In the focus of an ordinary telescope is placed a small electric

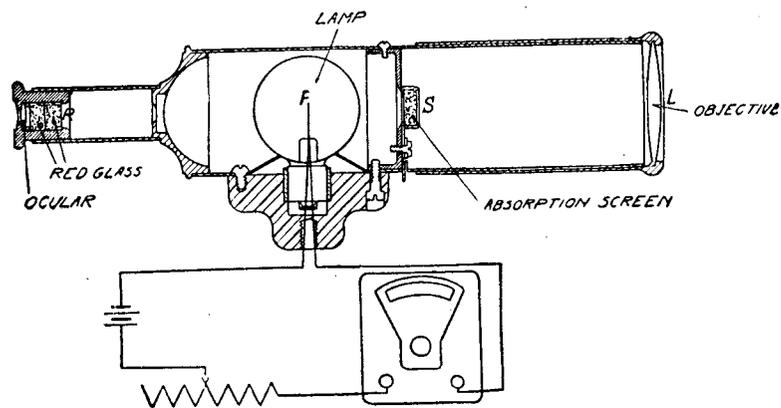


Figure 17.—Disappearing filament optical pyrometer.

lamp whose filament is heated by a current from a battery controlled by a rheostat and measured by an ammeter. The current through the lamp is adjusted until the tip of the filament is of the same brightness as the object sighted upon. The outline of this section of the filament is then indistinguishable from the surrounding field. The temperature is then obtained from a table showing the relation of filament current to temperature. This type of radiation pyrometer is the basis for the temperature scale above 1400°C. and therefore gives the most accurate temperature readings above the range of the platinum thermocouple. In the commercial form this pyrometer, when properly calibrated, can be relied upon to within 5°C. at 1500°C. Like the total radiation pyrometer the optical pyrometer must be used under black body conditions or the necessary corrections applied.

The only serious objection to the industrial use of the optical pyrometer is the fact that it has not yet been made automatically recording. The introduction of the human element into the readings affords an opportunity for dishonest or prejudiced readings. In the portable form

this optical pyrometer is useful in experimental work, and may be employed to great advantage for routine adjustment of kilns to a uniform temperature in much less time and more accurately than can be done with cones.

*Burning Processes.* Burning a clay produces marked changes in its chemical and physical properties. While the changes are much the same for all clays, they vary greatly in degree. They may be roughly divided into three stages, dehydration, oxidation, and vitrification, each indicated by certain reactions but with no sharp division, as the changes of one stage begin before those of the preceding stage are completed. The effect of heat or burning on the individual chemical compounds present in clay has been considered with the chemical compounds in clay. The present discussion is confined to a consideration of the effect of heat, or burning, upon the clay as a whole.

*Dehydration.* Before burning the clay, a large part of the water added to make the clay plastic is removed in the drier. This air drying is done carefully to avoid cracking the ware while shrinking due to the loss of absorbed water. The air dried clay is then further dehydrated during the early part of the burning period in the kiln. These last traces of moisture (pore water) as well as the combined water are driven off during the "water-smoking" period which is accompanied by less shrinkage than air drying. The driving out of the moisture should be done by raising the temperature slowly and by allowing a large amount of air to pass through the kiln to remove the water vapor. If the temperature is raised too fast steam forms within the clay faster than it can escape and popping of the ware results. If a good circulation through the kiln is not maintained, the kiln atmosphere becomes saturated with moisture which is deposited on the surface of the ware producing the effect known as "scumming" or "whitewashing." This is caused by the sulphur dioxide in the fire gases being absorbed by the condensed water, forming sulphurous acid ( $H_2SO_3$ ) which attacks certain compounds (especially lime) in the clay forming soluble sulphates that are left as a white scum on the surface of the ware when the moisture evaporates. In a dry atmosphere sulphur dioxide would pass through causing no scum. Low sulphur fuel forming little water on combustion is very desirable. After the pore water is driven off the combined water follows as the temperature is raised to about 400°C. and is usually completely driven off at 700°C.; the loss of combined water starts at a very low, just visible, red heat, and is generally completed at a bright red heat.\* Before dehydration is complete other gases begin to pass off, including some carbon dioxide ( $CO_2$ ) from the lime and iron carbonatés, and some sulphur dioxide from the pyrite.

\*See combined water on previous pages.

*Oxidation.* Oxidation begins below 500°C and should be completed before 900°C. Ferrous oxide is most easily oxidized at about 490°C<sup>1</sup>. At this temperature carbon dioxide will oxidize ferrous oxide to ferric acid if no free oxygen is available. As this reaction is too slow and does not oxidize the carbon or sulphur in the clay, free oxygen in the kiln gases is necessary for oxidation of the clay. The need for free oxygen can be met only by passing through the kiln a large amount of excess air over that needed for complete combustion of the fuel. The more porous the clay the more rapid is the oxidation, as a close textured, fine grained clay retards the entrance of the oxygen and the escape of the carbon dioxide. Generally, oxidation takes place most rapidly at about 750°C. At lower temperatures the rate of reaction is proportionately reduced, and at higher temperatures there may be some vitrification or eutectic formation that closes up the pores and prevents the free entrance of the oxygen. Any condition that checks the free entrance of oxygen and escape of carbon dioxide, sulphur dioxide, or other gases, will prevent complete oxidation and cause early failure of the clay.

Oxidation takes place slowly without the aid of heat, as during weathering of the clay pyrite ( $\text{FeS}_2$ ) and siderite ( $\text{FeCO}_3$ ) may be changed to the oxide, and even organic matter is slowly eliminated.

*Vitrification.* Vitrification may begin about 900°C but usually not below 1000°C and in some cases it may not begin even at 1200°C. The vitrification is due to the formation of a melt as has been described, and is accompanied by marked physical and chemical changes. Some new compounds, complex silicates, are formed even before the melt. These chemical changes and the filling up of the pores with the melt cause the clay to shrink and to become less porous as the product becomes hard burned and vitrified.

Purdy and Moore<sup>2</sup> have found that the rate of decrease in apparent specific gravity, due to closing of the pores, seems to be proportional to the rate of vitrification. If this is true, measurements of the apparent specific gravity afford a simple and accurate method of following the burning of a clay, and a safe means of judging the value of the clay.

If the carbon and sulphur have not been completely oxidized out of the clay and all the iron oxidized to the ferric condition before vitrification begins, the clay becomes black and swells as vitrification proceeds. Ferrous iron forms black complex silicates which give the clay its black coloration. The sulphur is liberated as sulphur dioxide or trioxide by the substitution of silicic acid for the sulphur or sulphates, and is the major cause for swelling. Carbon prevents the oxidation of sulphur

<sup>1</sup>Bauer and Glaessmer, *Zeit. physical Chem.* 43, p. 354 (1903).

<sup>2</sup>*Trans. Am. Cer. Society IX*, p. 204 (1907).

and may also cause swelling in forming gases (carbon monoxide and carbon dioxide) during vitrification.

Even in well oxidized ware there may be some swelling or bloating as the clay is fired beyond its vitrification temperature, due to some entrained gases or possibly to the oxygen liberated by reduction of iron to the ferrous condition as occurs at higher temperatures, particularly when forming complex silicates.

*Color.* The color of the burned clay is of the greatest importance for many uses. It is considered to be of such importance that clays are frequently classed as white burning, buff burning, or red burning clays. Iron is the important coloring agent, which is counteracted by lime and sometimes alumina. The greater the amount of iron in the clay the more pronounced is the red color of the burned product.<sup>1</sup> The red color becomes more intense as oxidation proceeds and becomes deeper and darker during vitrification due to the formation of the darker silicates as fusion proceeds.

The normal iron coloration may be destroyed by the effects of the kiln gases. If these gases reduce the ferric oxide, which action becomes more easy as the temperature is raised above 500°C, the red color may be converted to gray, or even blue black. In burning white ware the pure white is obtained without any undesired buff discoloration by cooling the kiln so far as possible in the absence of air to prevent oxidation of the iron in the clay. In the same way some kilns, on account of lack of air in the kilns and carbonaceous matter in the clay, do not develop the full red color possible if the clay were completely oxidized.

Brick made of Michigan clay, which generally contain a large amount of lime, frequently develop a light red color on the surface, which is absent in the interior, or on that part of the surface protected from the direct contact of gases from the fire. This red color on an otherwise buff brick is commonly recognized as being due to fire gases, and is probably caused by the sulphur dioxide and trioxide in the kiln gases uniting with the lime forming calcium sulphate, thereby preventing the combination of the lime with the iron. Occasionally foreign substances, such as particles of coal ash, are carried by the fire gases and deposited on the brick causing spots of colored glaze. This is particularly noticeable on the ends of arch brick in scove kilns, and brick in the bag walls of down draft kilns.<sup>2</sup>

Many brick or tile used for exteriors and interiors of buildings are often darkened on the edges by special treatment during firing, known as fire flashing or simply flashing. The principle of this operation depends on the formation of ferrous silicate and ferrous oxide during burn-

<sup>1</sup>See minerals in clay, iron.

<sup>2</sup>Carl Giessen, *Trans. Am. Cer. Soc. I*, p. 69 (1899).  
Iowa Geol. Surv. Vol. XIV, p. 59 (1904).  
Seeger's Collected Writings, Vol. I, p. 109.

ing of the brick and then subsequent partial oxidation after incipient vitrification has taken place to the red or ferric form. This oxidation takes place during cooling, for if the kiln is closed so as to shut off the supply of air at the end of the burn, the bricks have the light gray tint characteristic of reduced iron.

The degree of flashing is affected by a number of factors.<sup>1</sup> The clay should contain enough iron to make a normally light burning brick but not enough to give a red burning brick (about 2 to 4 per cent). Clays high in silica and with the iron soluble in acid give the better results. As the iron must be brought into combination with the silica an easily vitrified clay is desired. The longer the cooling period, or the slower the brick is cooled, down to 700°C the deeper or darker is the flash color.

Crystalline silicates are sometimes developed on cooling of clay heated to thorough vitrification or higher. In the study of these, more attention has been given to porcelain than other types of ware.<sup>2</sup>

<sup>1</sup>See "Notes on Flashing" by A. V. Bleininger, *Trans. Am. Cer. Soc.* II, p. 74 (1900).

<sup>2</sup>W. Vernsdsky, *Bull. Soc. Min. France* XIII, p. 256 (1890).

Anon, *Sprechsaal* XXXIX, p. 1387 (1906).

J. W. Mellor, *Journal Soc. Chem. Ind.* XXVI, p. 375 (1907).

C. H. Wegermann, *Trans. Am. Cer. Soc.* IX, p. 231 (1907).

E. Plenske, *Sprechsaal* XLI, Nos. 19, 20, 21, 22, 23 (1908).

## Chapter V

### KINDS OF CLAY

A number of different classifications of clays based on as many different principles have been proposed by various investigators.<sup>1</sup> It is recognized that no single classification can satisfy all demands. As clays have been described according to their origin in an earlier section of this report, this chapter considers clays from the standpoint of their economic uses.

**Kaolins or China Clays.** Kaolins have been discussed under residual clays. Made up largely of hydrated aluminum silicates and silica, they are white burning residual clays usually highly refractory. Sometimes white burning sedimentary clays of similar properties are also included within this class. H. Ries suggests the name of plastic kaolins for these to distinguish them from the residual kaolins. Another suggestion is "primary kaolins" for residual kaolins and "secondary kaolins" for sedimentary deposits of the same material. Kaolins are only slightly plastic, with a low air-shrinkage, white or nearly so in color, and contain only small amounts of iron or lime.<sup>2</sup> After washing, kaolins are used in the manufacture of white ware, china, porcelain, floor and wall tiles, paper filling, and in preparing slips and glazes. Silica is added to decrease the shrinkage, and ball clay to give the mass plasticity. Feldspar is also used as a bond for some purposes.

There are no known deposits of kaolin in Michigan and apparently little chance of any being found in this State.

**Ball Clays.** Ball or bond clays are plastic, white burning, sedimentary clays used with kaolin in the preparation of mixtures for white ware, porcelain, and tile, to give the body sufficient plasticity and strength that it may be formed into the desired shape. They are white or nearly so, must contain little or no iron, be highly plastic, and preferably refractory.<sup>3</sup> There is no known deposit of true ball-clay in Michigan and very little chance of any being found.

<sup>1</sup>Edward Orton, *Ohio Geol. Survey* VII, Part I, p. 52.

Beyer, *Iowa Geol. Survey* XIV, p. 40.

G. P. Grimsley, *W. Va. Geol. Survey* III, p. 70.

H. A. Wheeler, *Missouri Geol. Survey* XI, p. 25.

Geo. F. Ladd, *Georgia Geol. Survey Bull.* 6a, p. 10.

E. R. Buckley, *Wisconsin Geol. and Nat. History Survey Bull.* VII, Pt. I, p. 14.

<sup>2</sup>N. C. Geol. Surv. Bull. 13, pp. 59, 62 (1897).

U. S. Geol. Surv. 19th Ann. Report, Pt. VI continued, pp. 402, 416.

Pa. State College Ann. Rept., p. 36 (1898-99), p. 11 (1899-1900).

Mo. Geol. Surv. XI, pp. 562, 578 (1896).

U. S. Geol. Surv. Prof. Paper 11, p. 39 (1903).

<sup>3</sup>Bleininger & Loomis, *Trans. Am. Cer. Soc.* XIX, p. 601 (1917).

N. J. Geol. Survey VI, p. 443.

Mo. Geol. Survey XI, p. 556 (1896).

U. S. Geol. Survey, Professional Paper 11.

Jerome Alexander, *J. Am. Cer. Soc.* III, p. 612 (1920).

Fire Clays. Refractory clays should not soften at temperatures below cone 27 or about 1600°C. No definite standard exists in this country and many clays that do not withstand this temperature are called fire clays. In many parts of the country fire clays and bricks are graded as number 1 and 2, but in the trade these terms are almost meaningless except for the individual manufacturers, as they have no standardized definition.

A common misuse of the term "fire clay" is to apply the term to all clays or shales underlying coal seams. In several of the eastern states valuable fire-clays frequently underlie the coal, but this is not true in Michigan, and the clays so found should not be called fire-clay in this State. The most refractory clays found in Michigan are the Coal Measures clays but even the best fail at cone 18.

As has been pointed out under Burning Properties the chemical composition of fire clays must be such that no easily fusible eutectics can form. The amounts of iron, lime, magnesia, and the alkalies present must be small. If there is considerable excess silica<sup>1</sup> or quartz present the refractory qualities will be reduced by the formation of an eutectic.

Texture of the burned clay is important, as, other things being equal, the coarser grained clay of open texture is usually the more refractory, probably because the particles are in less intimate contact and the eutectics cannot form so readily. On the other hand the denser more plastic clay as used for glass pots, and blocks for glass tank furnaces, will withstand the action of molten materials better because the pores are closed and the corrosive molten mass cannot penetrate into the clay so easily. The greater the plasticity of the clay the denser the burned ware. Frequently plastic clay is added for the above reason and to make working easier, although the refractoriness may be decreased by so doing.

Fire clays may be either residual or sedimentary, the latter being far more important economically. The sedimentary clays are also divided in plastic fireclays and flint-clays. The former, as their name indicates, are plastic when wet, and the latter hard, like flint, with a smooth shell-like fracture and dense texture. They have little plasticity even when finely ground, but are usually very refractory. Some flint-clays<sup>2</sup> have more alumina than is required for kaolinite, and may contain pholerite and some bauxite ( $Al_2O_3 \cdot 3H_2O$ ).

Fire clays have not been found and there is little possibility of such clays being found in Michigan. Some Michigan clays and shales<sup>3</sup> are semi-refractory or can be made so by treatment,<sup>4</sup> but there is no indication of any Michigan clay or shale being sufficiently refractory to be

<sup>1</sup>Free silica over the amount combined with the alumina.

<sup>2</sup>Sidney L. Galpin, Trans. Am. Cer. Soc. XIV, pp. 301-346 (1912), "Flint Clays".

<sup>3</sup>Some coal measure clays will stand up to cone 17, see samples Nos. 74 and 157.

<sup>4</sup>Sample No. 95 from red burning Antrim shale fails at cone 8, but an acid treatment of this sample yielded a clay of slight plasticity that stood up to cone 23 and burned buff.

classed as a fire clay. The surface clays always contain too much lime or iron to expect that any of them in Michigan should have refractory properties.

Fire clays are used not only for the manufacture of fire-brick, furnace linings, and crucibles but also floor tiles, conduits, terra cotta, pressed and paving brick.<sup>1</sup>

The physical properties of fire clays differ widely, with the exception of the refractory and burning properties which are the most important means for determining the value and use of fire clays.

Good fire clay must maintain an open structure throughout the entire temperature range used in the ceramic industries. On the other hand, a refractory material that has an early vitrification followed by a long fusion range before failure or viscosity is required in the stoneware industry in order to give an extremely dense, vitrified body to the ware. Because of this striking difference in burning properties Purdy and Moore<sup>2</sup> class refractory clays into three groups.

*First Class Fire Clay.* Refractory clay of the first class does not vitrify until very high temperatures are reached and fails or softens at

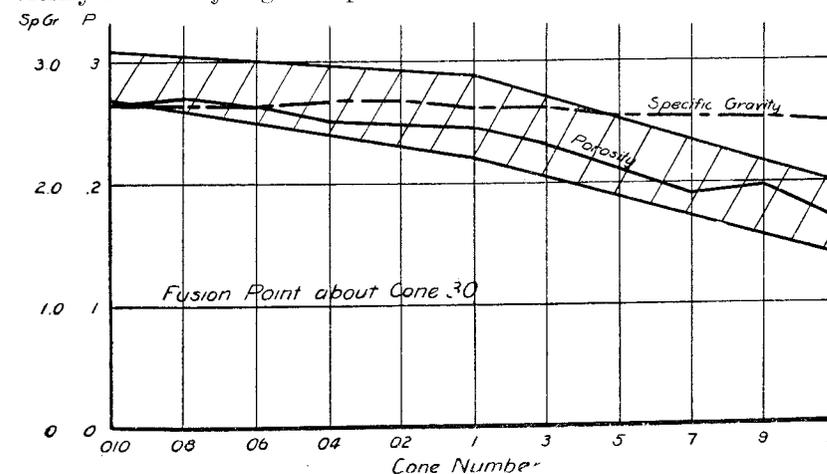


Figure 18.—Burning properties of typical refractory clay No. 1 showing range of porosities.

about cone 30 or 1700°C. Its burning properties are as represented by the typical No. 1-fire clay, and the change in porosity is within the range indicated in figure 18.

<sup>1</sup>Ala. Geol. Survey Bull. 6 (1900).  
Ind. Geol. Nat. Res. 29 Ann. Rept. (1905).  
Mo. Geol. Survey XI (1896).  
Ohio Geol. Survey VII (1893).  
Pa. Second Geol. Survey MM.  
N. J. Geol. Survey VI.  
W. Va. Geol. Survey III.  
U. S. Geol. Survey Bull. 315 (1907).  
Ill. Geol. Survey Bull. 4.  
Ky. Geol. Survey Bull. 6.  
N. D. Geol. Survey 4th Biennial Report.  
Trans. Am. Cer. Soc. LX, p. 461 (1907).

<sup>2</sup>Trans. Am. Cer. Soc. IX, p. 242 (1907).

R. C. Purdy, *Ibid.*, 10 p. 365 (1908), gives the burning properties of flint fire clays.

*Second Class Fire Clay.* Refractory clay of the second class shows a more rapid decrease in porosity and also in apparent specific gravity, because of more rapid vitrification, than No. 1 Clay. The complete fusion or softening of the clay is at about cone 30 or about the same as the first class, but the early vitrification and long fusion or burning range permits its use in making the more dense refractory products, and for vitrified ware such as paving brick, sewer pipe, stoneware, and the better grades of terra cotta. For the latter products this clay may be mixed with other clays that make for still earlier vitrification in the final mixture. Figure 19 shows the burning properties and ranges of class two fire clay.

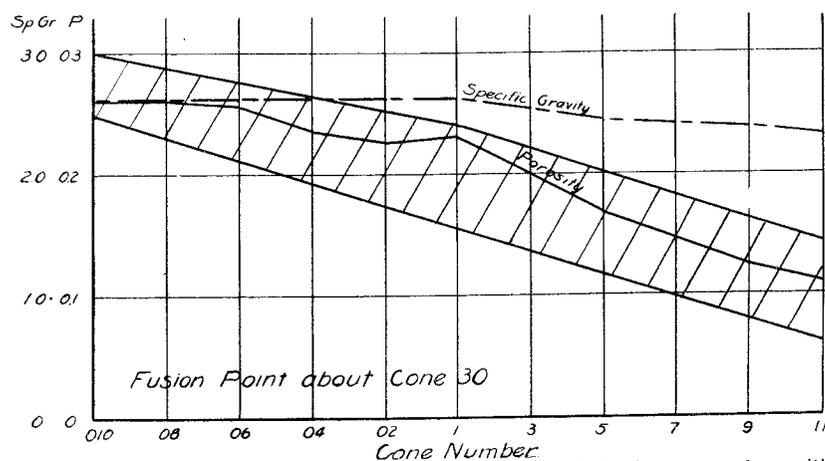


Figure 19.—Burning properties of typical refractory clay No. 2 showing range of porosities.

*Semi-Refractory Clay.* Refractory clay of the third class softens at about cone 17 or 1450°C and should be regarded as semi-refractory. The porosity and specific gravity fall off faster than in the preceding class, as indicated in figure 20. These clays cannot properly be called fire clays as they do not stand up above cone 17, but are the most suitable clays for vitrified products such as sewer pipe, stoneware, and paving brick. The so-called "fire clay" found in the coal measures of Michigan is frequently of this class.\*

The limits indicated for the three classes of refractory clays may overlap, but the point to be brought out is that each successive class vitrifies at a lower temperature, making a firmer denser structure that is better for stoneware or paving brick but less refractory.

Refractory clays of the first class are non vitrifying; that is, they do not develop a vitrified structure during burning.

Refractory clays of the second class can be used for vitrified products as these clays will vitrify if heated to high temperatures at about cone

\*See samples 74, 157.

17 to 18. The vitrification takes place very slowly over a wide range of temperature which makes it easy to obtain a vitrified product without overburning; but because high temperatures are required to develop a thoroughly vitrified body the cost of burning is high and these clays are used only in manufacturing high grade products that must have great strength and resistance to shock in a thoroughly vitrified body, such as stoneware and paving blocks, or must possess high refractory qualities and a dense body, such as glass pots.

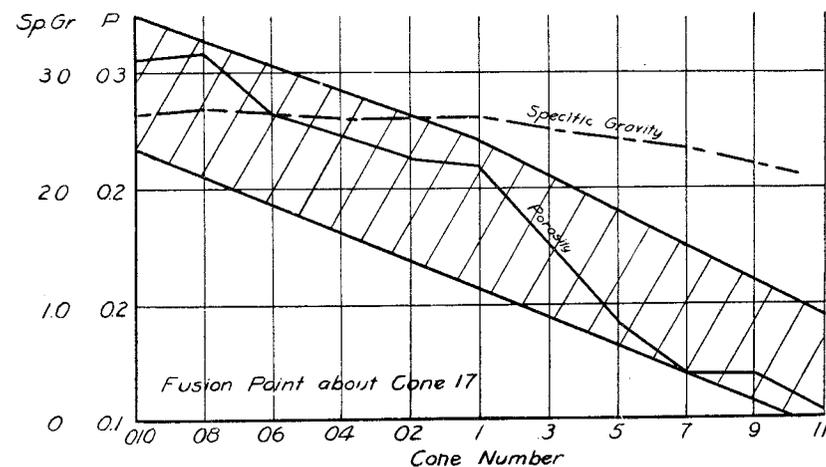


Figure 20.—Burning properties of typical semi-refractory clay, showing range of porosity

The third class, or semi-refractory clays, cannot be used where high refractory qualities are demanded; but because they vitrify at a lower temperature (about cone 5 to 12) over a wide temperature range, such clays offer the advantage of much lower burning costs in the manufacture of vitrified ware. Purdy and Moore<sup>1</sup> found the more slowly vitrification develops the greater the resistance of the product to abrasion and shock, so that for some particular uses the second class refractory clays may offer advantages over the third class for vitrified ware; but the difference in this respect is not great and may generally be ignored, except for very exacting demands or when refractory properties are required.

The maximum strength<sup>2</sup> of fire clay and stoneware bodies is generally developed by burning to cone 8, even when the porosity and shrinkage data seemed to indicate that the clay is under- or over-fired. When the body shows maximum shrinkage and minimum porosity at cone 8 the ware has maximum strength.

For developing a vitrified product the clay must have a burning range of at least 6 or 8 cones, i. e., the temperature interval between incipient

<sup>1</sup>Trans. Am. Cer. Soc. IX, p. 242 (1907).

<sup>2</sup>H. G. Schurecht, J. Am. Cer. Soc. IV, p. 366 (1921).

vitrification and failure or viscosity must be equivalent to at least 6 or 8 cones, or 120°-150°C (200°-250°F). If the burning range is less than this it is practically impossible to vitrify all the ware in a kiln without an excessive proportion of failures or over-burns.

It is also very desirable that the shrinkage of the clay is constant or nearly so for a considerable interval within the range of vitrification so that all of the product will shrink a like amount and be of uniform size. This property of uniform or constant shrinkage is a practical necessity in clays used for paving blocks, face brick, and all similar products, and is required of all clays classed as good vitrifying clays.

**Vitrifying Clays.** *Stoneware clays* are usually second class refractory or semi-refractory (third class refractory) clays, although occasionally non refractory vitrifying clays are used. They must have sufficient plasticity and toughness to be turned on a potters wheel or formed into intricate shapes, a rather low uniform fire-shrinkage with relatively early vitrification and yet be refractory enough to hold their shape in burning. Most stoneware is now made from a mixture of clays including kaolin, ball clay, fire clays, and feldspar, to obtain the proper qualities before and after burning. The mixture is frequently aged for six months or a number of years before use to develop the great plasticity demanded of clays used to form the intricate shapes used in chemical stoneware.<sup>1</sup>

It has been stated that stoneware clays<sup>2</sup> must be plastic and have maximum shrinkage at cone 07 to cone 4. But in this country stoneware clays usually mature to a hard vitrified body at about cone 8. Such clays are used for the manufacture of all grades of stoneware, art, earthenware, and for terra cotta.<sup>3</sup>

*Terra Cotta* is generally made from a semi-refractory clay, or mixture of refractory and non refractory clays or shale, which matures to a hard dense body at cone 6 or 8. The clays should be free from soluble salts, of low shrinkage, and wide burning range to give a dense body without warping.<sup>4</sup>

*Sewer Pipe Clays* must be vitrified in burning and still be refractory enough to hold their shapes. For this reason some fire-clay is occasionally mixed with the vitrifying clay, but it is usually cheaper and there-

<sup>1</sup>For "properties of some Stoneware Clays" see U. S. Bur. of Mines Tech. Paper 233 by H. G. Schurecht.

H. G. Schurecht, J. Am. Cer. Soc. 1, p. 267 (1918).

Iowa Geol. Survey XIV, p. 233 (1904).

Ala. Geol. Survey Bull. 6, p. 176 (1900).

Mo. Geol. Survey XI, p. 564 (1896).

N. J. Clay Rept., p. 99 (1878).

N. C. Geol. Survey Bull. 13, p. 78 (1897).

Ohio Geol. Survey VII, p. 94 (1893).

W. Va. Geol. Survey III, p. 162 (1906).

Ind. Dept. Geol. and Nat. Res. 29, Ann. Rept., p. 508 (1904).

<sup>2</sup>Rev. Mat. Contr. Trav. Pub. 140, 67-69B (1921), J. A. Cer. Soc. IV, p. 692 (1921).

<sup>3</sup>Mo. Geol. Survey XI, p. 575 (1896).

N. Y. State Museum Bull. 35, p. 821 (1900).

N. Y. Geol. Survey Fin. Rept. VI, p. 459 (1904).

<sup>4</sup>N. J. Geol. Survey Final Rept. VI, p. 270 (1904).

fore better practice to use, if possible, one clay and vary the size of particles from very fine to very coarse in order to get the wide burning range required. This can be done in grinding of the shale, which is usually used instead of clay for this purpose.

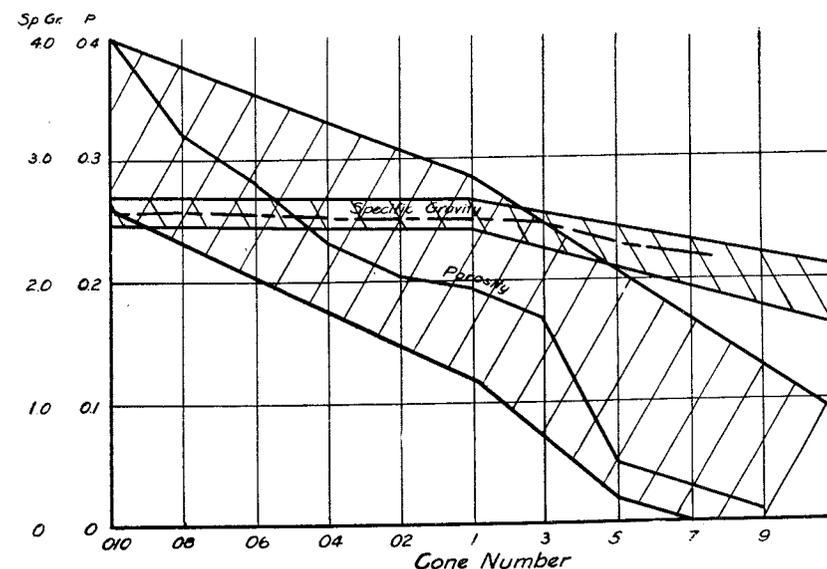


Figure 21.—Burning properties of clay or shale suitable for paving brick or sewer pipe, showing range of porosities.

*Paving Brick Clays* are very similar to those used for sewer pipe manufacture, frequently the same clay or shale is used at the same plant for both products. Paving Bricks are rectangular blocks of burned clay which possess to a marked degree the properties of hardness and toughness.<sup>1</sup> Vitrification tends to produce hardness and proper regulation of the rate of cooling makes for toughness in the product. As both these products are vitrified the clays must have a wide burning range, 6 to 8 cones between incipient vitrification and viscosity. It is generally true that clays developing a vitrified structure at temperatures below cone 5 or with an absorption of more than 5%<sup>2</sup> are too friable to resist the abrasion that good paving blocks must withstand. Figure 21 shows the burning properties and ranges of clays suitable for paving bricks.<sup>3</sup> The carboniferous or coal measure shales are the best sewer pipe and paving brick clays in Michigan. In some places the older Devonian shales show possibilities, particularly for sewer pipe, as do some deposits of Pleistocene clay. But to the author's knowledge Pleistocene clay has never been used for sewer pipe in Michigan.

<sup>1</sup>C. W. Rolfe, Ill. Geol. Survey, Bull. 9.

<sup>2</sup>G. H. Brown, Trans. Am. Cer. Soc. XII, p. 265 (1910).

<sup>3</sup>Purdy and Moore Trans. Am. Cer. Soc. IX, p. 204 (1907).

Non-vitrifying Clays. *Brick and Tile Clays* are used for extruding hollow tile, drain tile, and wire cut brick. They should have moderate yet sufficient plasticity to flow smoothly through the die (about 18 per cent water of plasticity), fair tensile strength for easy handling, and burn to a good hard body not completely vitrified, at a low temperature (cone 06 to 1). Similar clays of greater plasticity when possessing a good burning range and very smooth plastic qualities may be used for some forms of pottery, as flower pots, jugs and some art products.

*Face Brick*, a hard fine colored brick as used for building fronts, houses, etc., may be made from sewer pipe, paving brick shales, and brick or tile clays that have a wide burning range and develop a good color and a steel hard product at a moderate or low temperature. *Pressed Brick* are face brick made by pressing the clay into molds. These bricks are made in the eastern part of the country largely from buff-burning semi-refractory clays. In Michigan, face brick are extruded and red burning clays are used. The red burning clays usually develop a hard brick of good color between cones 06 and 3 or 5, while the buff burning clays used through the eastern part of the United States require a temperature of cone 6 or 8 unless the clay contains considerable lime.

It is almost useless to set any definite limits on the burning properties of face brick because of the great variety of materials from which they can be made. Any good vitrifying clay, as well as some non-vitrifying clays, with a steady uniform shrinkage throughout a good part of the burning range and developing a good color, may be used.

Frequently face brick or front brick is colored by fire flashing or by addition of a glaze. The latter is called *enameled brick*.

*Roofing Tile Clays* are a special type of face brick clays that answer the more exacting requirements for roofing tile. Such clays must be plastic to properly form the thin shapes, extruded or molded, yet have a drying shrinkage of not over 5% to prevent cracking and warping. The fire shrinkage should not exceed 15 per cent, to prevent warping and cracking of the burned tile. The clay must burn to a hard but not vitrified structure having a porosity of 10-25 per cent and a light good red color at a low temperature (about cone 05 to 1).

When shales are used for roofing tile they are generally burned to vitrification to develop the full strength, but clays are not vitrified as they become brittle. Sometimes the porous non-vitrified tile is preferred for industrial construction, as in cold weather water vapor condenses on the under side of the tile roof, and is absorbed by the unvitified ware but drips down to the annoyance of workmen when vitrified non-porous tile is used.\*

\*An excellent report on Roofing Tiles is that by Orton and Worcester, Geological Survey of Ohio Series IV, Bull. 11 (1910).

Figure 22 shows the burning properties of a typical first class roofing tile clay, and the range of drying and burning shrinkage and of porosity of clays known to make a high grade roofing tile.\*

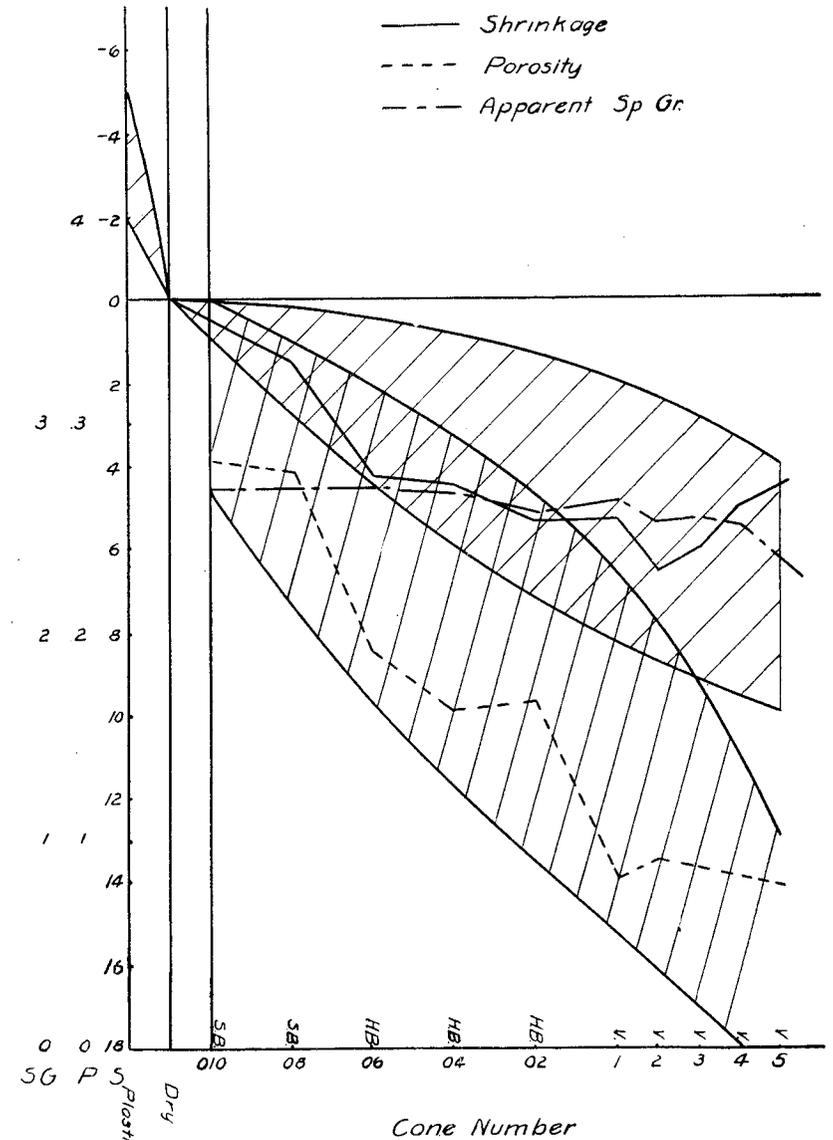


Figure 22.—Burning properties of roofing tile clay.

*Common or Soft Mud Brick Clays* are usually low grade red-burning sandy clays that cannot be extruded. They should mold easily and burn

\*Prepared by H. W. Jackman from data of Orton and Worcester loc. cit.

hard at a low temperature with a minimum loss from cracking and warping. Many Michigan boulder clays deposited as glacial drift contain lime pebbles that cause excessive loss from "lime pops," or stones that render an otherwise useful clay worthless. Common brick will not always bear the cost of transportation and it is sometimes advisable to use the best material that can be obtained locally even though it is not thoroughly satisfactory.

**Special Clays.** *Slip Clays* are fine grained clays with a low air-shrinkage and low plasticity, which melt to a greenish or brown glass forming a natural glaze at the temperature of cone 5 or less. Natural slip clays generally give much better results as to gloss and color than any artificial mixture. The clay is mixed with water to a mixture of creamy consistency, called a slip, and applied to the ware by dipping or spraying.<sup>1</sup>

*Fuller's Earth* is a peculiar type of clay formed by decomposition of basic rocks (hornblendes and augites rather than feldspars) and having high absorbing powers for many substances. Because of this property it is used for decolorizing many liquids, such as oils. A practical test is the only satisfactory means for evaluating the earth.<sup>2</sup>

Petroleum or mineral oils are bleached by allowing the oil to flow down through columns of the dried earth. The first oil passing through is colorless but it gradually becomes darker as the absorbing powers of the earth are reduced. The earth can be revived by burning off the adhering oil in rotary kilns. When a product of uniform color is desired the earth is mixed with the oil, allowed to settle, and filtered off.

Vegetable oils are treated at about 100°C and the earth cannot be renewed as with petroleum. The bleaching efficiency of an earth is due principally to its physical properties among which a high degree of porosity is most important.<sup>3</sup>

*Paper Clays* are mixed in with the pulp fiber during the beating process. Such clays must be white and free from grit, such as washed kaolin. The pulp will generally retain more of a plastic clay than of a clay with low plasticity.<sup>4</sup>

*Polishing and Abrasive* properties are possessed by many clays containing very finely divided sand grains. The "Bath Brick" used for scouring is simply a brick made from a fine-grained siliceous clay found

<sup>1</sup>Ohio Geol. Survey VII, p. 105 (1893).

Ries, Clays, p. 230.

R. W. Jones, Trans. Am. Cer. Soc. 18, p. 242 (1916), Albany Slip Clay.

<sup>2</sup>See H. Ries, Clays Occurrence, Properties, Uses; p. 516, John Wiley & Sons (1908).

D. T. Day, J. Frank, Inst. C. L. (1900).

C. L. Parsons, Fuller's Earth and Application to Bleaching Oils, J. Am. Chem. Soc. XXIX, April, 1907.

J. T. Porter, Properties and Tests of Fuller's Earth, U. S. Geol. Survey Bull. 315, p. 268, 1907.

David Wesson, Min. and Eng. World 37, p. 667 (1912).

H. D. Miser, U. S. Geol. Survey Bull. 30 (1911).

<sup>3</sup>Shearer, Geol. Survey of Georgia Bull. 31, 1917.

<sup>4</sup>Ries, Clays, p. 232.

C. S. Gwinn, Trans. Am. Cer. Soc. XIV, p. 571 (1912).

along the banks of the Parrot River in England. Some clay is also used as a binding agent in making grinding wheels. The clay is burned before use and bonds the abrasive material when vitrified.

*Ocher* is often simply a fine grained ferruginous clay colored by limonite. Certain clays and shales when ground and mixed with oil make good mineral paint for wood surfaces.

*Gumbo* is a term applied to fine grained, highly plastic, tenacious surface clays of general uselessness because of their high shrinkage and dense character. In Missouri they are burned and used locally as railroad ballast.<sup>1</sup>

*Bentonite* is a peculiar variety of clay, yellowish-green when fresh, but rapidly becoming light cream on exposure. It is very fine grained, soft, and absorbs three times its weight of water, accompanied by swelling. It has a specific gravity of about 2.18. Bentonite has been used in many ways including the manufacture of soap, for diluting powerful drugs in the powdered form, as an adulterant of candy, for de-inking paper, in the manufacture of antiphlogistine, and as a retarder for cement plasters; but its chief use so far is for weighting and filling paper.<sup>2</sup>

Bentonites are supposed to be transported stratified clay formed by the alteration of volcanic ash shortly after deposition.<sup>3</sup> The silica, alumina, water ratio is about 61:18:10, and the other 10 or 11 per cent being made of oxides of iron, magnesium, lime, titanium, alkalies, and small amounts of sulphur, phosphorus, and carbon.<sup>4</sup>

In composition bentonites are mixtures of two or more materials rather than one.<sup>5</sup> The exact composition of these is not known but they are probably mixtures of colloidal silicates and fine-grained kaolinite in varying proportions. These materials are characterized by the following properties: Conchoidal fracture; an index of refraction between 1.48 and 1.54; high water of plasticity and volume drying shrinkage varying from that of highly plastic clays to 114.61% and 195.9%, respectively; and a high alkali plus alkali earth content, usually above 5%. When added in small amounts to certain clays, some bentonites increase the dry strength to a remarkable extent. In firing they vitrify at about

<sup>1</sup>Wheeler, Missouri Geol. Survey XI, p. 542 (1896).  
Iowa Geol. Survey XIV, p. 534 (1904).

<sup>2</sup>W. C. Knight, Eng. & Min. Jour. LXIII, p. 600 (1898).

W. C. Knight, Eng. & Min. Jour. LXIV, p. 491.

Wyoming Experiment Sta. Bull. 14 (1893).

U. S. Geol. Survey Bull. 285, p. 446.

N. H. Darton, Geologic Atlas Folio No. 107 (1904).

U. S. Geol. Survey Bull. 260, p. 559 (1905).

T. T. Rhead, Eng. & Min. Jour. LXXVI, p. 48 (1903).

Ladoo, U. S. Bur. Mines Report 2289 (1921).

Jerome Alexander, Ind. Eng. Chem. 16, p. 1140 (1924).

H. Ries, Clays, Occurrence, Properties and Uses, J. Wiley.

The Chemical Age, 7, p. 668 (1922).

M. E. Manson, J. Am. Cer. Soc. 6, p. 790 (1923).

<sup>3</sup>Hewitt, J. Wash. Acad. Sci. 7, 196 (1917).

Wherry, Ibid. 7, 576 (1917).

<sup>4</sup>H. S. Spence, "Bentonite" Mines Branch Can. Dept. of Mines, Ottawa, Can. (1924).

<sup>5</sup>H. G. Schurecht and Doncla, J. Am. Cer. Soc. 6, p. 940 (1923).

1000°C, soften at cones 1-14 and burn to a buff to brown color and therefore can only be used in small amounts in white ware.

It is possible by adding finely ground quartz and small amounts of bentonite to certain fire clays to produce mixtures approaching the Arkansas and certain other glass pot clays in physical properties and in index of refraction. Adding too much bentonite to clays causes them to crack in drying.

*Portland Cement Clays.* Portland cement is the finely ground clinker obtained by heating an artificial mixture of lime, silica, alumina, and iron oxide to a clinkering temperature (1400-1500°C). The finely ground clinker composed of calcium aluminates and silicates has the well known property of setting to a hard rock-like substance when mixed with water. Clays used for Portland cement must be free from sand, gravel, or concretions, and contain a ratio of

$$\frac{\text{silica (SiO}_2\text{)}}{\text{iron (Fe}_2\text{O}_3\text{ + alumina (Al}_2\text{O}_3\text{))}}$$

such that the cement clinker will have a value of not less than 2 nor much over 3 for this ratio.<sup>1</sup> Analyses of clays used for cement<sup>2</sup> indicate that these limits are frequently exceeded, running as low as 1.7 and

as high as 4, but Michigan practice seems to limit the ratio of

$$\frac{\text{SiO}_2}{\text{Fe}_2\text{O}_3 + \text{Al}_2\text{O}_3}$$

in the clinker from about 2 to 3. As the limestone used is generally very pure all the silica, alumina, and iron are supplied by the clay or shale which then determines the value of this ratio in the clinker. High alumina tends to make the cement set too rapidly and is counteracted by adding gypsum to the cold clinker. The Magnesia (MgO) should not exceed 3.5 or 4 per cent as a maximum. Phosphates cause trouble in making a cement set very slowly.

Gravel and coarse sand in the clay is removed in the disintegrator used in all wet process plants, and eliminated from the clay before burning. Very fine sand in moderate amount passes through the kiln causing no trouble. But medium fine sand passes through disintegrator with the clay and degrades the product.

<sup>1</sup>A. V. Bleining, Trans. Am. Cer. Soc. 6, p. 155 (1904) gives  $\frac{\text{SiO}_2}{\text{CaO}} = \frac{1}{2.56}$  and  $\frac{\text{SiO}_2}{\text{Al}_2\text{O}_3} = \frac{3}{1}$  as the best proportion. This corresponds to  $(2.8 \text{ CaO} \cdot \text{SiO}_2) + (2 \text{ CaO} \cdot \text{Al}_2\text{O}_3)$ .

<sup>2</sup>Ries "Clays", p. 233.

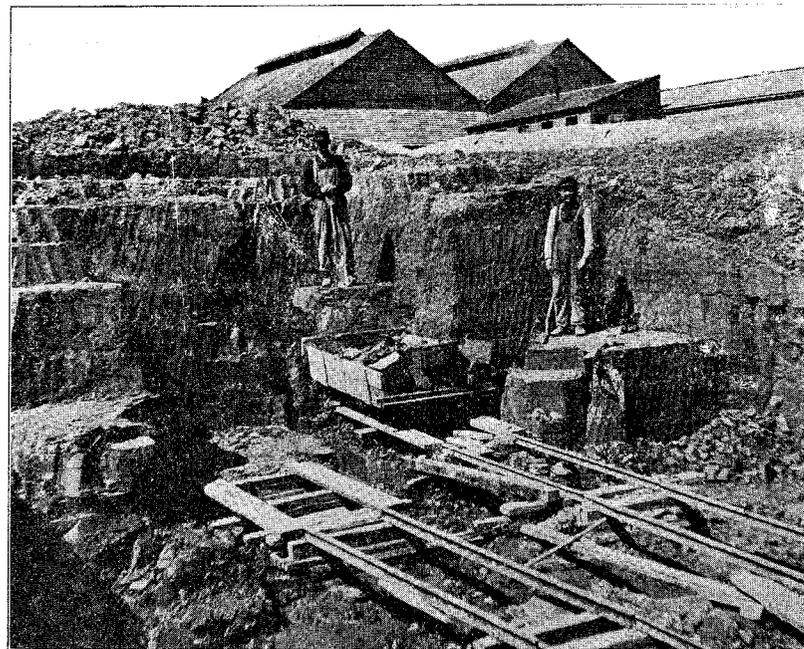


Plate I, Figure 1.—Spading clay in the pit of the old Detroit Roofing Tile Co. (Cut from Ohio Geological Survey.)

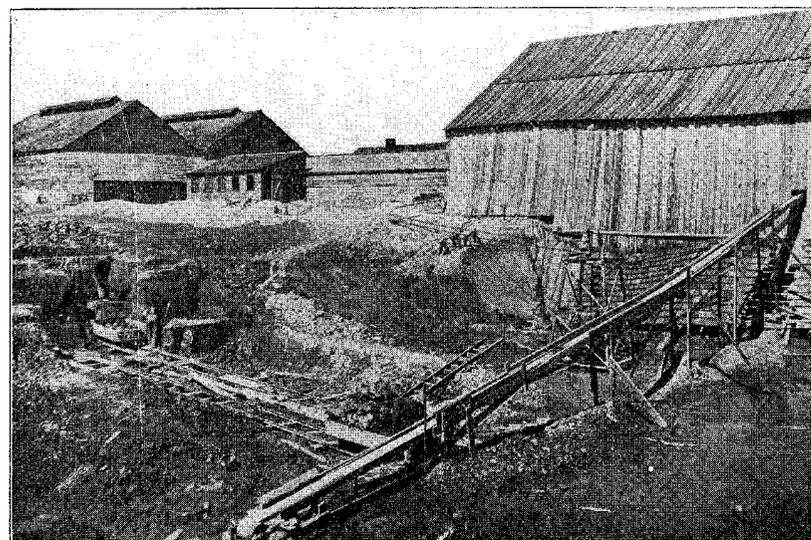


Plate I, Figure 2.—Belt conveyor used to convey clay from pit to plant, Detroit Roofing Tile Co. (Cut from Ohio Geol. Surv.).



Plate II, Figure 1.—Scraper and tractor, Muskegon Brick Co.

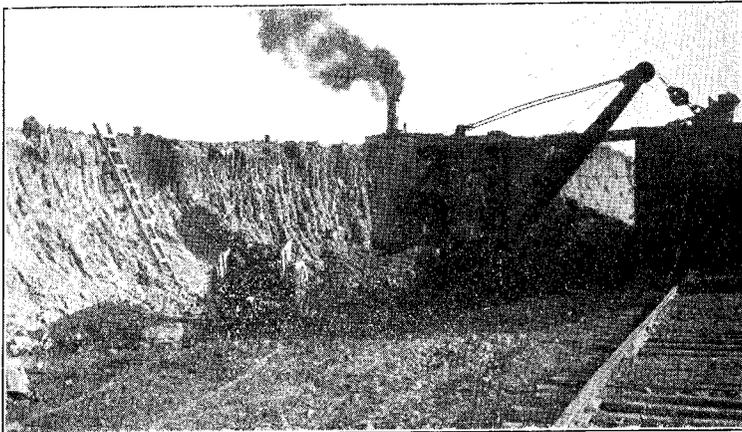


Plate II, Figure 2.—Steam shovel loading railroad cars at Kerby, Shiawassee County.

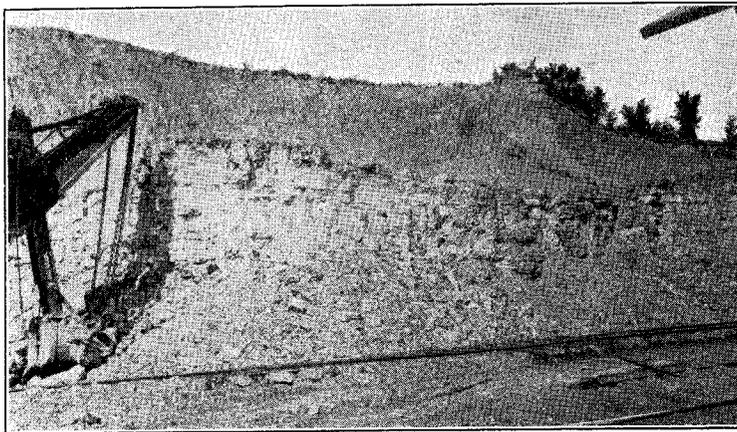


Plate II Figure 3.—Steam shovel at Ellsworth shale quarry, Antrim County.

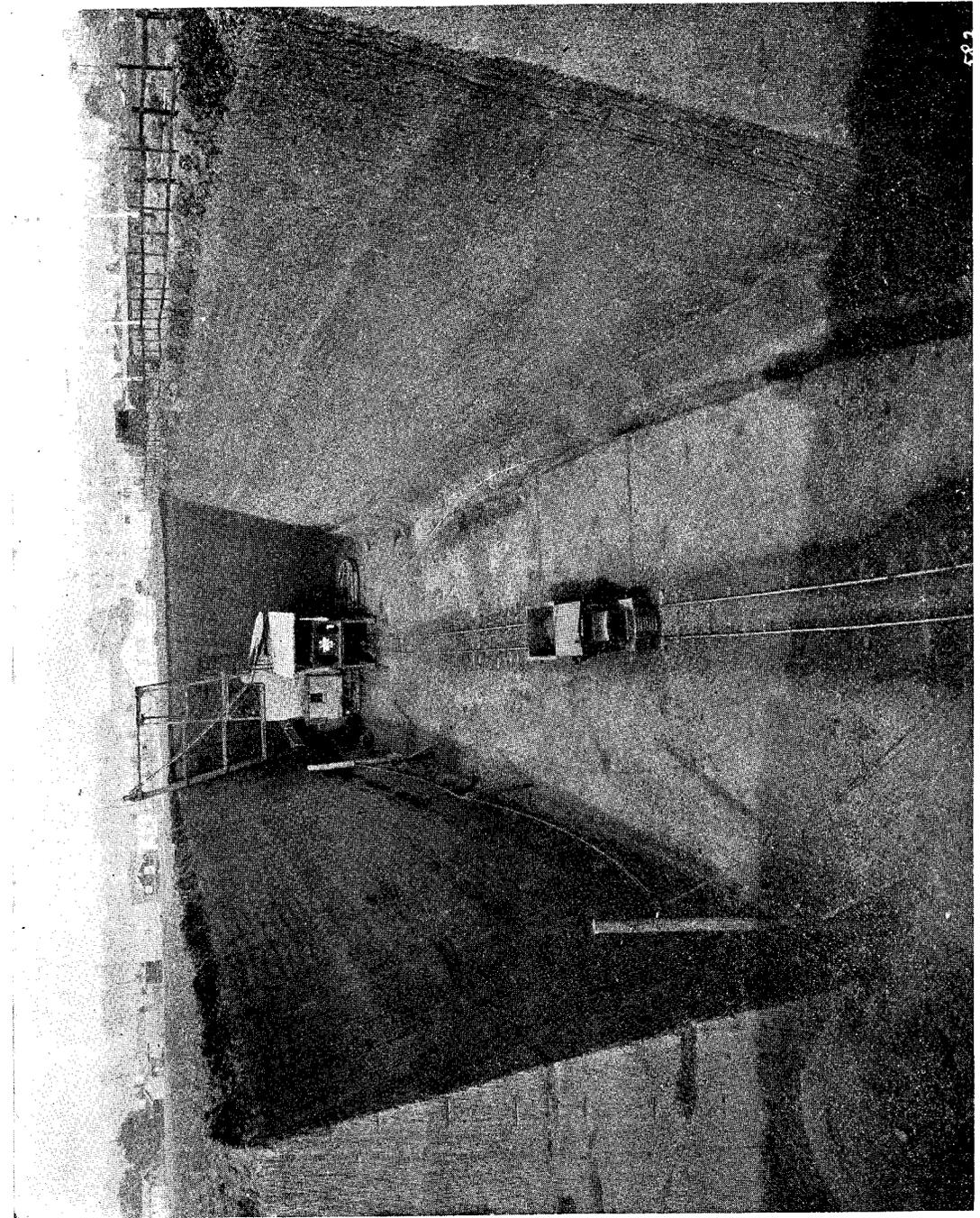


Plate III.—Shale planer in cut (Courtesy of Eagle Iron Works).

## Chapter VI

## METHODS OF MINING AND MANUFACTURE

## PIT AND QUARRY OPERATIONS

Clay and shale deposits are worked either as open pits or quarries, or by underground methods. The open pit, that is any kind of a cut in the surface from which the clay can be won, is the general method when the deposit lies at or near the surface and there is little or no overburden to remove. The method is in many ways the most difficult as the deposit is subjected in all stages of working to the influence of weather. Rains drive the workmen from the pit and may make the clay too wet for working when delivered to the factory. If the clay is soft, of cheese-like consistency, and only a small quantity is to be dug, gouge spades are used (Plate I).

Larger works use steam shovels, or occasionally plows and scrapers (Plate II) if the clay is not too hard. The steam shovels are most economical where the scale of operation warrants their use. They are used in working faces 12 to 20 feet high and can excavate even soft shales.

The shale planer (Plates III, IV) is a recent development that offers advantages over the steam shovel under some conditions. The shale is scraped or "planed" off the working face, dropped into a hopper, and loaded onto the skip cars. Like the steam shovel a shale planer is economical only when it can be operated continuously. The upkeep and operating charges of a planer may be somewhat higher than those of a steam shovel, but the planer delivers a well mixed product, which cannot be obtained from the steam shovel, and is of advantage if uniform ware is to be produced from a non uniform deposit.

If the clay is very tough or the shale hard, blasting is generally necessary to loosen up the material before it can be handled by the shovel. This is frequently done by drilling beyond the face of the bank (Plate V) and blasting the face loose. If the bank is high it should be worked in benches to prevent slides and for ease in working. Where the clay is not uniform from top to bottom it may be necessary to strip off each different layer and store it separately, or resort to special methods such as the use of a planer.

Stripping, or removal of the overburden, is an important operation in most pits, and is usually done by plow and scraper.

Drainage is a very important consideration. Surface-waters often trickle through the soil until they reach a clay-surface and then follow it, giving rise to a number of small springs emerging along the top of

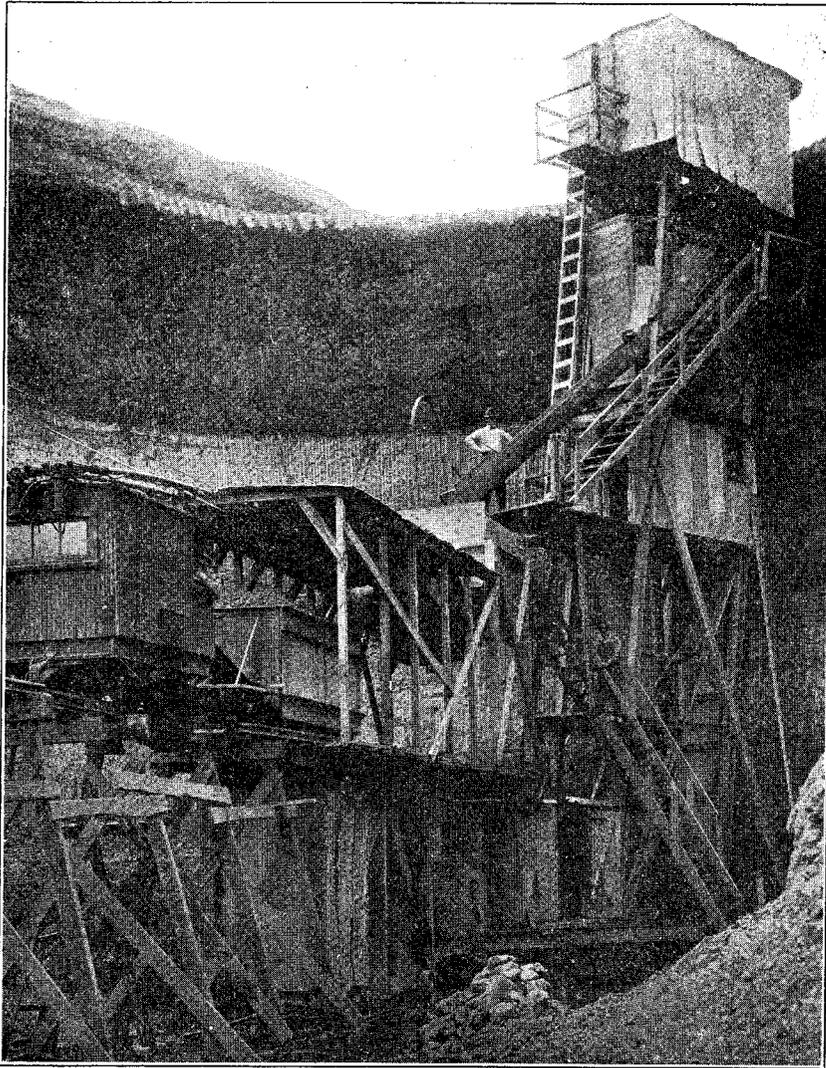


Plate IV.—Shale planer (From Jour. Am. Cer. Soc. 6 p. 267 [1923]).

the clay bank. If an impervious layer underlies the workings in the pit, all drainage will tend to run into the pit and accumulate there. Unless the pit has natural drainage to a lower level, pumping must be employed to keep the workings dry.

After the pit has been opened up, the stripping or overburden from new workings can be used to fill in the pit as the digging proceeds.

In small workings the clay may be conveyed in one-horse carts. If the pit or bank is directly behind the plant, the clay may be shoveled directly into small skip cars which are pulled up into the plant by a cable wound on a power driven drum (Plate VI). The method can be used economically where the diggings are not directly behind the plant, but the layout and operation become more complicated. For larger banks narrow gage tracks should be laid and the cars drawn by horses or power. For hauls of  $\frac{1}{4}$  mile or more gasoline or steam locomotives are more economical provided they are kept steadily employed.

Underground mining is rarely employed for soft clay, and then only in the case of high grade clays when the overburden is relatively thick. Shales, particularly those associated with the coal seams, are mined by shafts, drifts, or slopes. Mining underground\* is more expensive than the methods of open quarrying, but it offers some advantages in giving a material of uniform moisture content the year round.

#### LOCATION OF PLANT AND TRANSPORTATION OF RAW MATERIAL

Usually it is advantageous to build the manufacturing plant as near the clay pit as possible. If the plant can be located adjacent to the deposit and have the facilities for getting the manufactured ware to market and the fuel required for burning, no other location should be considered. The transportation of the raw material is an important item. It is better to extend the railroad to the deposit by means of a switch line than to locate the plant on the railroad and constantly bring the raw material to the plant. If possible the plant should be located below the deposit as the clay may then be brought to the plant largely by gravity, care being taken that the lower land is well drained to prevent moisture accumulating in the kiln bottoms.

The means used for transportation of clay from the pit to the plant depend largely upon the method of mining and the relative location of the plant to the deposit. In open pits, where the clay is dug by spading, wheelbarrows are occasionally used for distances of even 500 or 600 feet. Although it may be practical when the total clay consumption is less than 50 tons a day to use wheelbarrows at the clay pit for a single short

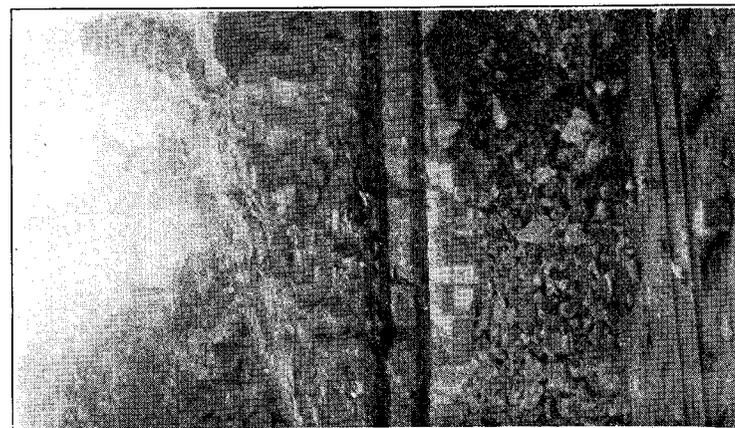


Plate V, Figure 2.—Coal seam in lower part of shale, Grand Ledge, Eaton county.

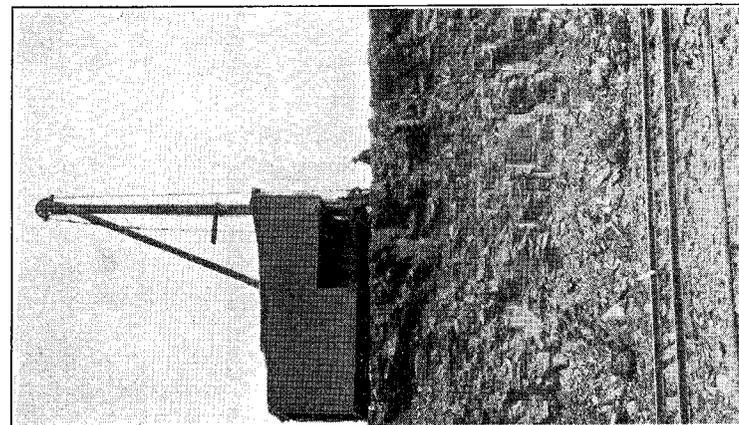


Plate V, Figure 1.—Drilling shale at Paxton, Alpena County, for blasting, Huron Portland Cement Co., Alpena.

\*For methods of mining see—

J. H. Collins, Mineral Industry XIII, p. 472 (1905).  
 A. R. Ledoux, Amer. Inst. Min. Eng. Bi-monthly Bull. No. 9, p. 379 (1906).  
 A. S. Watts, Trans. Am. Cer. Soc. XIII, p. 228 (1911).  
 A. S. Watts, Ibid., XIV, p. 434 (1912).  
 Worcester, Ohio Geol. Survey, Series IV, Bull. 11 (1910).

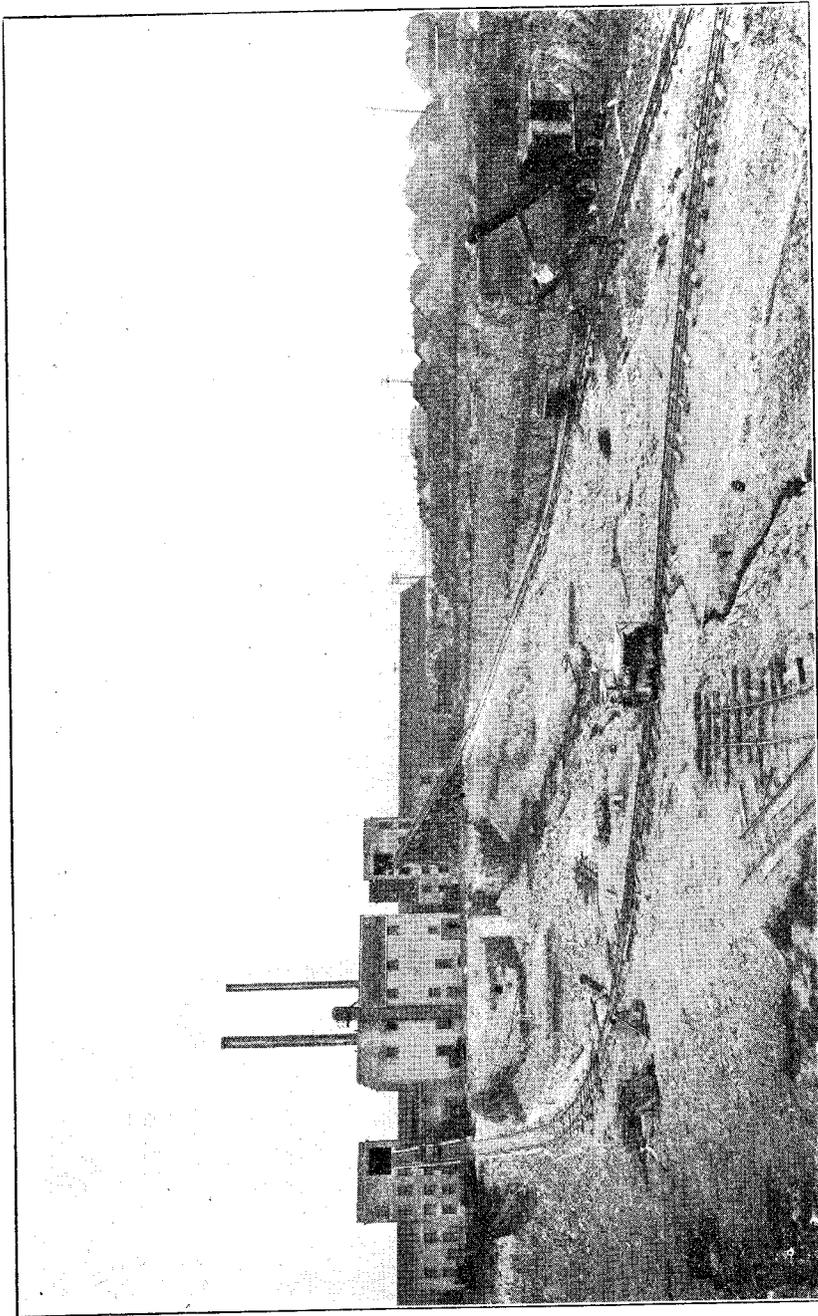


Plate VI.—Pit of J. A. Mercier Brick Co., Detroit. (Photo from J. A. Mercier.)

haul, a wheelbarrow trip of 100 feet indicates bad management. It is also bad engineering when clay once lifted by man-power on a shovel has to be shoveled again before grinding. Small horse carts are more efficient and should be run up an incline to dump the clay into the grinder from which the material is handled by power driven apparatus or by gravity.

Scrapers mounted on large wheels and drawn either by team or tractor may be used to collect and transport the clay over distances up to 1000 feet. When once the clay is in a scraper of any kind it should never be shoveled again. This method is used by the Muskegon Brick Company (Van der Hayden, operator) at Holton, Muskegon County (Plate II). The scraper is loaded by drawing it down the slope of the bank and unloaded directly into a cart from a raised loading tressel.

Tram cars and narrow gage dump cars are generally used and found to be very satisfactory (Plate VI). Where the clay pit is at a lower grade than the plant, as is frequently the case, these cars are drawn up an incline tressel by a cable wound on a power driven drum. The clay is then dumped (Plate VII) into a storage bin or hopper, over the grinders or pug mills. The empty car then coasts down the incline, drawing the cable with it. A brake band is supplied on the end of the drum to control the descent of the car. In some pits it may be possible that the car will run up to the diggers by the momentum it receives in coasting down the incline, but usually it is necessary to draw the empty cars to the diggers and the full cars to the base of the incline by a horse, dinkey steam engine, or gasoline engine.

If the pit is above the plant level, the full car running down to the plant may be used to draw the empty car up to the pit without the expenditure of any power.

If the clay is to be shipped any distance, as is done at Ellsworth (Plate II), and at Quincy, the clay is loaded directly into railroad cars on a siding extending into the pit.

High grade clays such as kaolins, and most clays used in potteries, are frequently washed to remove all gritty material. The washing is generally done by the troughing method. This consists in stirring up the disintegrated clay with water and allowing the thin slip to flow through a series of troughs totaling from 500-1000 feet in length and having a gentle slope of about one inch in 20 feet. The slip drops most of its sandy impurities in the troughs, and the washed clay in the form of a slip passes through a screen of 80 to 100 mesh and finally settles out in the settling tanks. When the clay has settled the clear water is drawn off and the slip is pumped out and filter pressed to remove the greater part of the water.

## THE MANUFACTURE OF CLAY PRODUCTS

The manufacture of clay products may be divided into the following steps:

1. Preparation of clay
2. Tempering
3. Molding
4. Drying
5. Burning

which may be very simple in the case of low priced or low grade products, or extensive and carefully conducted for high grade ware.

**Preliminary Preparation.** Very little clay is in proper condition when it comes from the bank to be formed directly into the product. If hard, as shale, it must be ground, and in all cases it should be thoroughly mixed to give a uniform product, as clay banks are seldom uniform. It is not enough that a certain amount of clay of certain composition be present, the mass must be uniform throughout, in chemical composition, and in physical properties.

**Weathering.** Some clays are allowed to *weather* by distributing the clay over some flat surface where it is slowly but thoroughly disintegrated by the sun, rain, and frost. The clay should be spread in a thin layer about one or two feet in thickness. This weathering is done to increase the plasticity and improve the drying and burning properties, but may tend to develop soluble salts causing "drier" or "kiln" white if not thoroughly carried out. Weathering develops electrolytes which flocculate the clays, making it rapid and easy to filter.<sup>1</sup> Clays that can be slipped or washed up to a creamy state generally give better results if not weathered but slipped and lawned immediately when taken from the pit, and then "aged" or allowed to "rot" after being blended.<sup>2</sup>

E. G. Acheson<sup>3</sup> calls attention to the statement in Exodus, Chapter V, that stubble was substituted for straw fibre by the Hebrews in making brick for the Egyptians. Acheson suggests that the straw was not used as a binder but to increase the plasticity and to make a harder brick. He finds that clays treated with gallo-tannic acid (a compound occurring in straw and stubble) develop a greater strength on drying than the untreated clay on burning, and concludes this to be the real reason for adding straw, as the Egyptians may have made a stronger sun dried brick from straw treated clay, than could be obtained from untreated clay even if burned. Acheson finds the effect of this treatment to be immediate on raw clay, but is of little use on slipped and aged clay, as aging develops about all the advantages of "Egyptianizing."

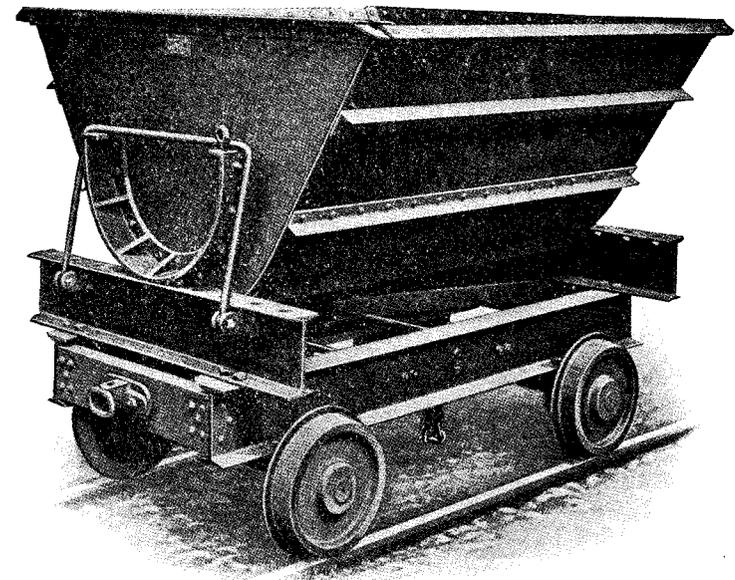


Plate VII, Figure 1.—Skip car. (Cut by Hadfield-Penfield Steel Co.)

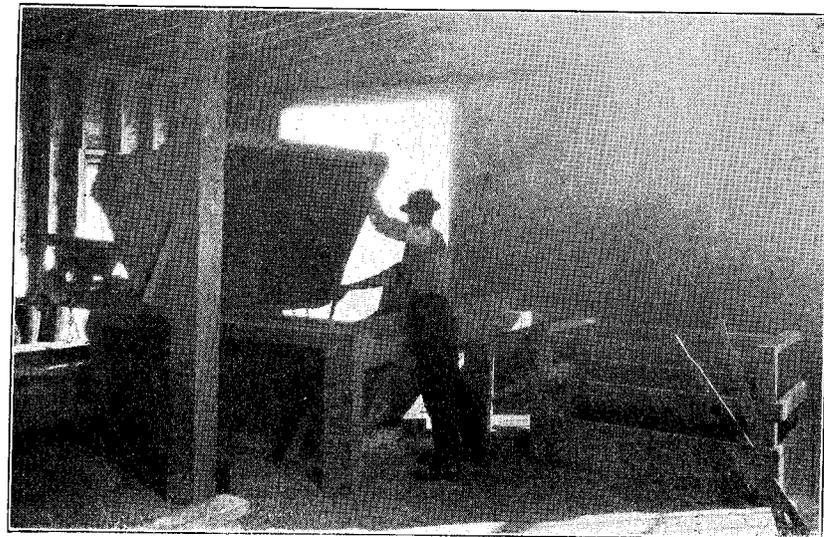


Plate VII, Figure 2.—Dumping Skip car at J. A. Mercier Brick Co., Detroit.

<sup>1</sup>G. E. Thomas, Trans. Am. Cer. Soc. XIV (1912).

<sup>2</sup>E. McK. Ogle, Trans. Am. Cer. Soc. III, p. 171 (1901).

<sup>3</sup>Trans. Am. Cer. Soc. VI, pp. 31, 231 (1904).

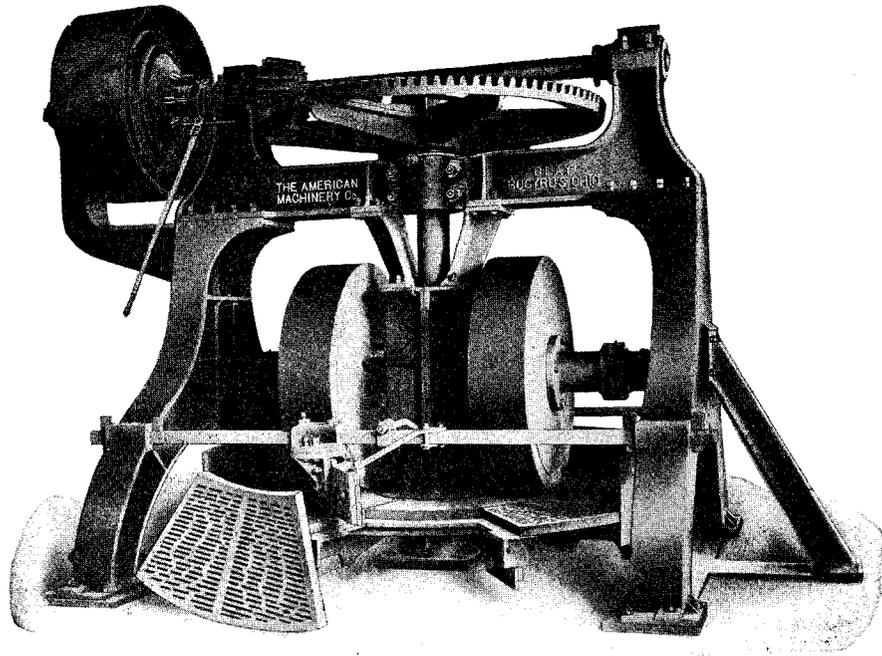


Plate VIII, Figure 1.—Dry pan, perforated bottom plates.

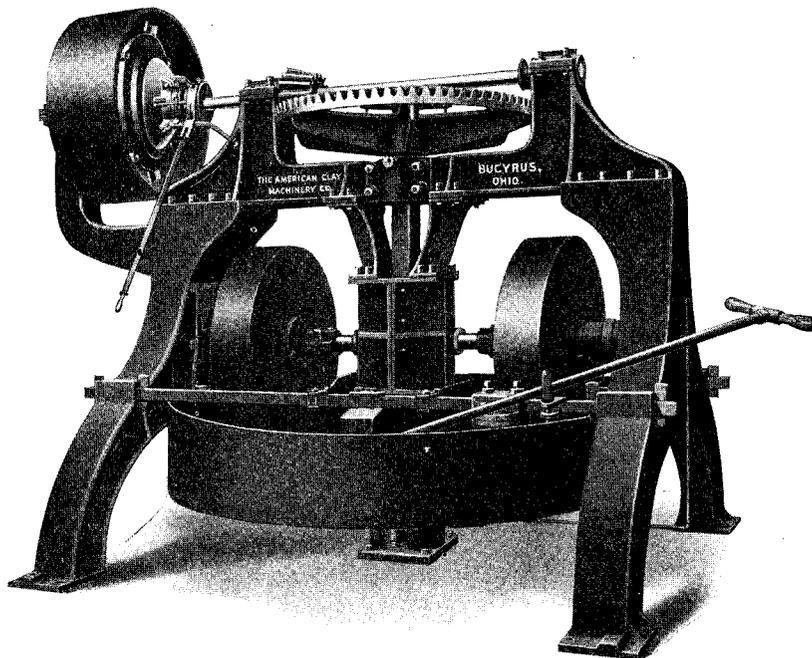


Plate VIII, Figure 2.—Wet pan, solid bottom, unloaded by shovel.  
(Cuts by Hadfield-Penfield Steel Co.)

Few clays used in Michigan are weathered after mining. Most of the surface clays used have already been weathered sufficiently, at least in the upper and more exposed parts of the deposit, to pass directly through the crushers into the mixers. Many of the clays, however, could be improved by a process of weathering.

*Crushing.* The clay as it comes to the plant consists of coarse and fine material and lumps of all sizes. The first step in reducing the clay to the desired condition is to break up the large lumps, particularly in the case of shales and hard clays. Jaw crushers are often used for this purpose when the material is dry and brittle.

*Grinding.* The objects of *grinding* the clay are two-fold; to thoroughly reduce the lumps of clay and mix the different minerals so that the clay will have uniform properties giving a uniform product, and to effectively apply the softening power of water to a large surface area of the clay in order to develop the dormant plasticity of the material.

In general, soft, plastic, surface clays require no grinding to develop their plasticity; in fact frequently sand is added to decrease the plasticity. Grinding of such clays is chiefly for the purpose of obtaining a uniform product by dissemination of the different minerals, and elimination or crushing of the hard lumps and pebbles. The grinding treatment of such clays is often perfunctory or omitted entirely. Shales are fairly homogeneous and the grinding is done for the purpose of developing plasticity.

Grinding may be done on the wet or the dry clay. In general, *wet grinding* is practiced to develop plasticity, as it is a very powerful agent for this purpose, but it is less satisfactory, in sizing and securing a uniform product, than *dry grinding* which is more general where sizing and making a homogenous clay is the more important consideration. The wet grinding is slower and more costly, but may be used to develop plasticity that can be obtained in no other way. Dry grinding is faster, cheaper, and produces a more homogeneous paste without much improvement in plasticity.

*Dry Grinding.* Dry pans (Plate VIII, Fig. 1) are used for grinding the hard dry shale or soft clay delivered either from the crusher or direct from the bank. Dry pans are used very extensively throughout the ceramic industries, because they will pulverize any hard material from broken brick to be used as grog, or flint clays and shales, to the softer raw clays.

A dry pan consists essentially of a revolving circular steel pan, in which two heavy wheels or mullers weighing from one to six tons roll on edge over the bottom. The pans vary from five to twelve feet in diameter. The central part of the floor of the pan which supports the mullers is solid. The outer part of the floor is usually perforated with holes about one-eighth inch in diameter, to form a screen through which

the fine particles fall as the clay is carried out over this part by centrifugal force. The larger particles fail to pass through the screens and are thrown back in front of the mullers by scrapers set in the proper position for this purpose. These machines are not economical of power, but no other machine doing the same work at a lower cost has been found.

If the scrapers used to throw the oversize material under the mullers are omitted and the screening done as a separate operation the dry pan so modified can be operated with less power. The friction of the scrapers absorbs a large part of the power supplied to the pan. In a machine of this type (Plate IX) the material is fed under the mullers and passes over the edge of the pan which is perfectly flat.

Rolls (Plate X) are widely used for breaking up clay and shales, and for crushing pebbles. When the material is perfectly dry, rolls give good results, but when damp the lumps of clay are simply flattened out. In the latter case conical rolls are sometimes used to remove those pebbles and masses of hard material too large to pass between the rolls, and to knead the clay. The surfaces of the rolls are smooth or corrugated and cylindrical or conical. They are revolved in opposite directions at different speeds, crushing the small pebbles and throwing out the larger ones. If the pebble is too hard to be crushed and too small to be thrown out the pebble will pass through the rolls which momentarily spread. This spread is taken up by heavy springs back of the bearings of one roll. If these springs are not supplied, the hard pebbles would either break the rolls or cause them to stop.

In some few cases disintegrators of various forms are used in pulverizing dry clay. All such disintegrators work on the principle of breaking up the lumps by a rapid succession of hammer blows. This is usually done by passing the clay through rapidly rotating wheels bearing spokes or hammers. Disintegrators are satisfactory only when the clay is very dry. They have large capacity and require much power. These are not to be confused with the disintegrators used in the Portland cement industry for washing wet clay.

Ball mills are used for pulverizing and mixing dry clays to be used in the manufacture of the finer grades of ware, and Portland cement, where fine grinding and intimate mixture is important. Ball mills consist of a hollow cylinder rotating on a horizontal axle, into which the clay is admitted through a hole in one end. The mill is about one-third full of water worn flint pebbles which serve as the grinding means during rotation of the mill. In cement plants or for other uses where the introduction of a small amount of iron is not objectionable, the flint balls are usually replaced by balls of special alloy steel. The ball mill when applied to grinding raw material may be intermittent or continu-

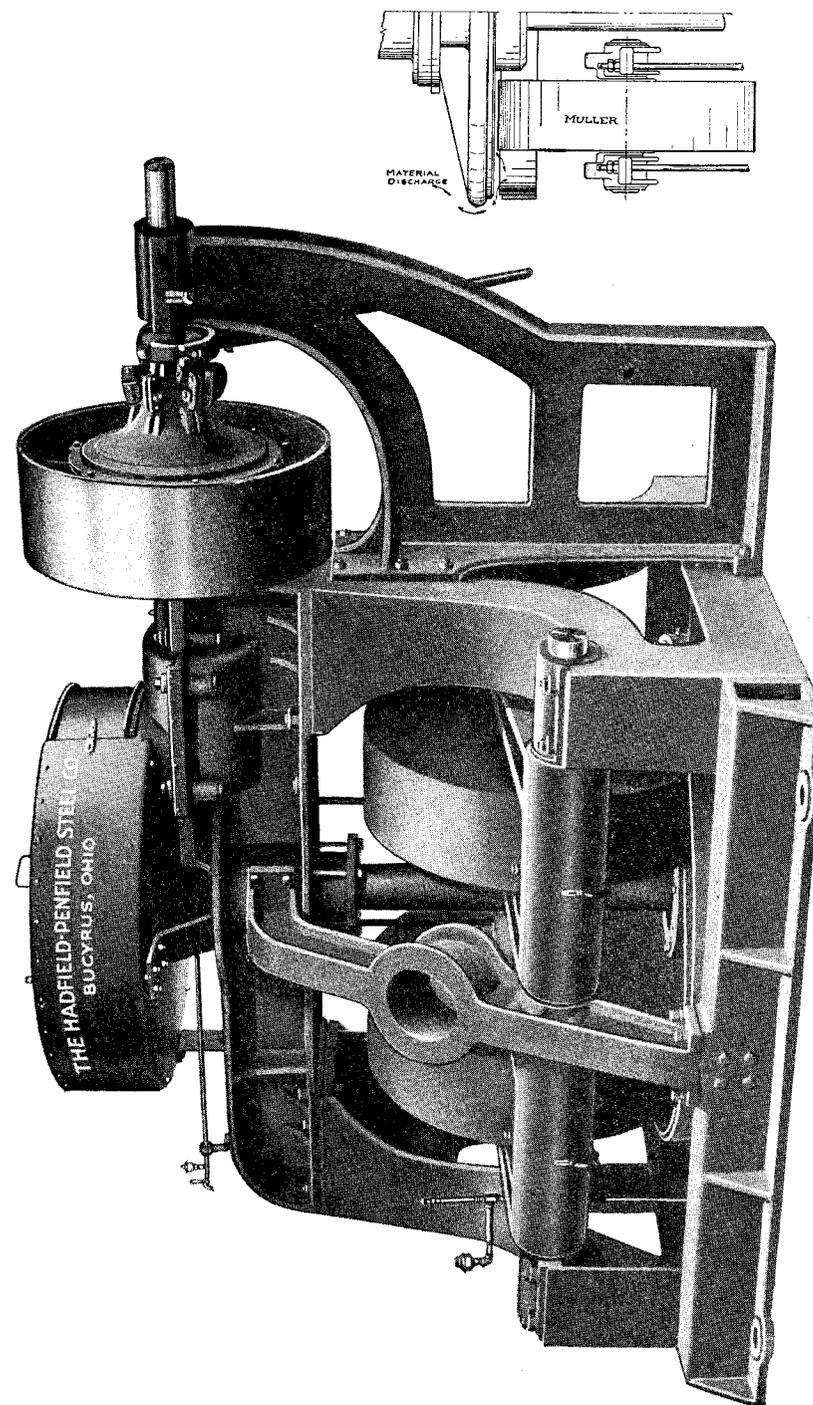


Plate IX. Figure 1.—Clay grinder similar to dry pan but without scrapers and with a solid bottom. Ground clay passes over edge of pan as shown, is screened and over-size returned. Capacity 40 to 70 tons per hour with 50-75 H. P.

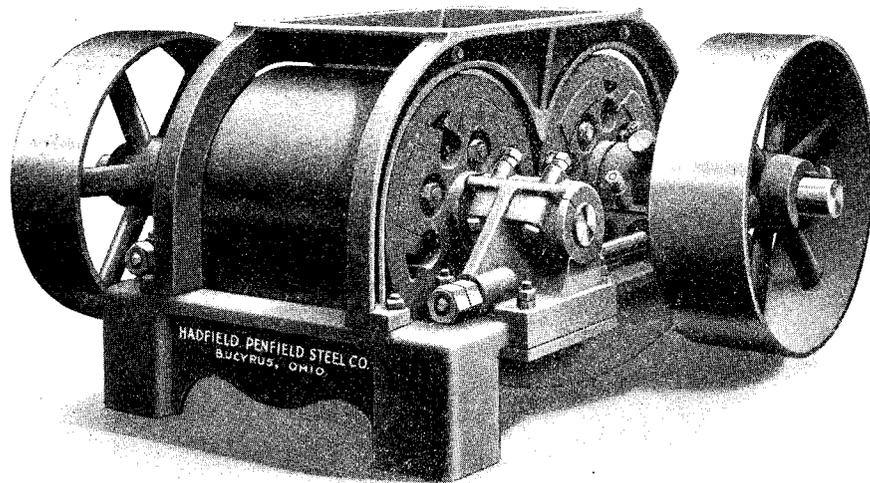


Plate X, Figure 1.—Cylinder rolls for grinding clay.

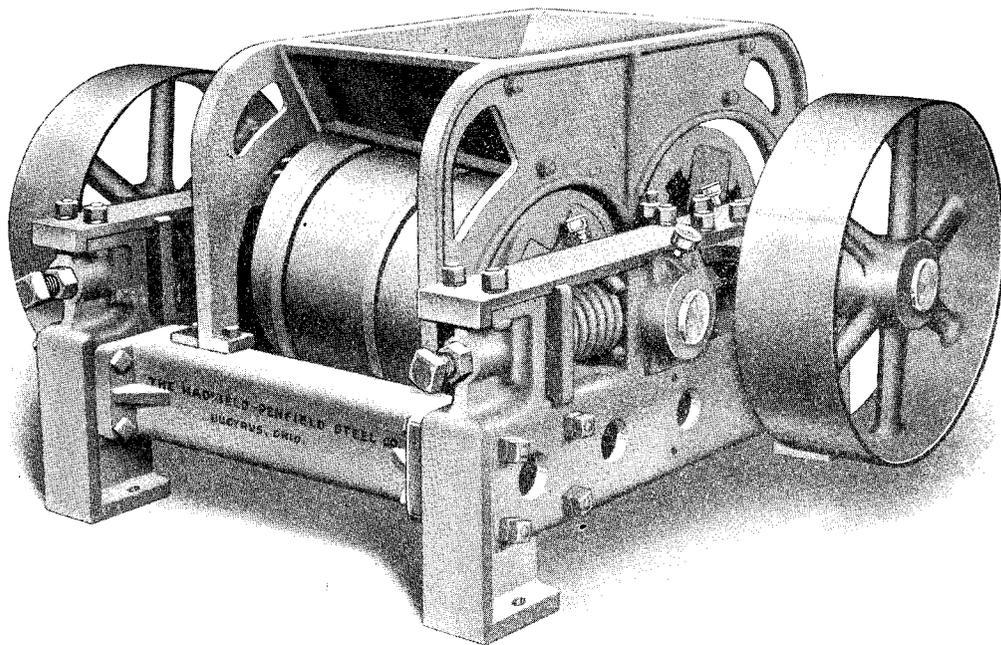


Plate X, Figure 2.—Conical rolls for grinding clay and removing stones. Rolls are set with horizontal shafts. Stones that are not crushed ride the rolls sliding off at the low sides. This sliding of stone may be aided by thread on surface of roll as shown.

ous<sup>1</sup> in operation. When used on wet material the ball mill is always intermittent, as is the wet pan.

*Wet Grinding.* For purposes of *wet grinding* to develop plasticity, the wet pans, rolls, and chaser mill are used. The wet pan (Plate VIII, Fig. 2), of exactly similar construction to that of the dry pan, except for a solid bottom, is used to grind and temper the wet, raw clay in one operation. A charge varies from 500 to 1500 pounds, and no effort is made to size the material. The clay is shoveled in to the pan or delivered by a spout, and removed by a long handled shovel while the pan is in motion. Wet pans are widely used in this way in the fire brick industry, where 30 to 45 minutes are often used in tempering a single charge, and in pottery, sewer piper, and terra cotta plants. In many cases<sup>2</sup> the wet pan is used to wet grind and temper material that has previously been ground in the dry pan. This is done to eliminate the chance of small lumps escaping the wheel and passing through unground.

Wet grinding rolls are identical in construction to the dry grinding rolls. But being used on wet clay their action is to shred the clay and throw out the pebbles rather than to grind or crush the clay. Wet grinding rolls constitute the simplest method for crushing soft plastic clays and are widely used for this purpose throughout the State.

The chaser mill was formerly widely used in the Akron district of Ohio but is now rarely found. It is somewhat similar to the wet pan except that the pan is stationary while the narrower grinding wheels describe a circular spiral course around the central driving shaft. The appearance of the wheels chasing each other gives the machine its name. The chaser is slow, costly, and not thorough, but seems to develop the cohesion and toughness of the clay in a way that is not done by any other equipment. This is probably due to the peculiar method of working and grinding of the clay giving a product of dense structure composed of a variety of different sized grains.

*Slipping.* For making pottery the clay is thoroughly disintegrated and mixed with water in a blunger. This consists simply of a circular vat containing revolving mixing arms which work the clay and water into a cream-like slip. This suspension is run through a fine screen of 100 to 150 meshes to the inch, into a cistern where it is slowly agitated to prevent settling. The slip is pumped from the cistern and filter pressed to remove the excess water, then worked in a pug mill and wedged before molding. Frequently the clay is aged after pugging to develop to the full extent its plastic qualities.

*Heat Treatment.* Some clays are very sticky when moistened and develop cracks on drying due to excessive shrinkage. Bleiningger and

<sup>1</sup>H. Hardinge, J. Am. Cer. Soc. 6, p. 548 (1923) describes layouts for continuous grinding of feldspar, flint, etc.

<sup>2</sup>Roofing tile industry, Geol. Survey Ohio, Series IV., Bull. 11 (1910).