

Fusible Cones. — Instead of utilizing the fusion of crystallized substances which pass abruptly from the solid to the liquid state, use may be made of the progressive softening of vitreous matters, that is to say, of mixtures containing an excess of one of the three acids, silicic, boric, or phosphoric. It is necessary in this case to have a definite process for defining a type degree of softening; a definite depression of a prism of given size is taken. These small prisms, formed of vitreous matters, are known under the name of *fusible cones*.

This method was first devised by Lauth and Vogt, who applied it in the manufactures at Sèvres before 1882. But they did not develop it as far as was possible; they were content to construct a small number of fusible cones corresponding to the various temperatures employed in the manufacture of the Sèvres porcelain.

Seger, director of a research laboratory at the royal pottery works of Berlin, published, in 1886, an important memoir on this question. He determined a whole series of fusible cones known as *Seger cones*, of intervals of about 25°, including the interval of temperature from 600° to 1800°. The substances which enter into the composition of these cones are essentially:

Pure quartz sand;
Norwegian feldspar;
Pure carbonate of lime;
Zettlitz kaolin.

The composition of this last is:

SiO ₂	46.9
Al ₂ O ₃	38.6
FeO ₃	0.8
Alkalies.....	1.1
Water.....	12.7

In order to obtain very infusible cones, calcined alumina is added, and for very fusible cones oxide of iron, oxide of lead, carbonate of soda, and boric acid.

The shape of these cones (Fig. 130) is that of triangular pyramids of 15 mm. on a side and 50 mm. high. Under the action of heat, when softening begins, they at first contract without

change of form, then they tip, bending over, letting their apex turn downwards, and finally flattening out completely. One says that the cone has fallen, or that it has melted, when it is bent halfway over, the point directed downwards.

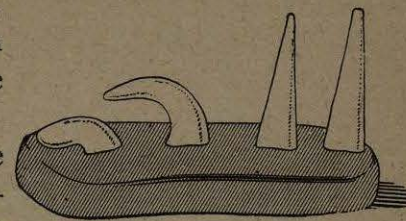


Fig. 130. Seger Cones.

The fusing points of these substances have been determined at the Berlin porcelain works by comparison with the Le Chatelier thermoelectric pyrometer, previously described.

The cones are numbered, for the less fusible, which were first adjusted, from 1 to 38; this last, the least fusible, corresponds to 1980°. The second series, more fusible, and established later, by Cramer and Hecht, is numbered from 01 to 022; this last cone, the most fusible, corresponds to 590°.

If, instead of using the cones of German make, one wishes to make them himself in employing the same formulæ, it is prudent to make a new calibration. The kaolins and feldspars from different sources never have exactly the same compositions, and very slight variations in their amounts of contained alkali may cause marked changes in the fusibility, at least for the less fusible cones. It is also well, on this account, to compare the behavior of new cones with old, even from the same maker.

It is to be noticed that in a great number of cones silica and alumina are found in the proportions Al₂O₃ + 10 SiO₂. This is for the reason that this mixture is more fusible than can be had with silica and alumina alone. It is the starting point to obtain the other cones, the less fusible by the addition of alumina, and the more fusible by the addition of alkaline bases.

The table on pages 371 and 372 gives the list of cones of Seger's scale as they were originally issued.

These cones may be classed in a series of groups, in each of which the compositions of different cones are derived from that of one of them, generally the most fusible, by addition in varying proportions or sometimes by substitution of another substance.

The cones 28 to 38 are derived from the cone 27 by the addition of increasing quantities of Al_2O_3 .

The cones 5 to 28 from the cone 5 by addition of increasing quantities of the mixture $\text{Al}_2\text{O}_3 + 10 \text{SiO}_2$.

The cones 1 to 5 from the cone 1 by substitution of increasing quantities of alumina for the sesquioxide of iron.

The cones 010 to 1 from the cone 1 by the substitution of boric acid for silica.

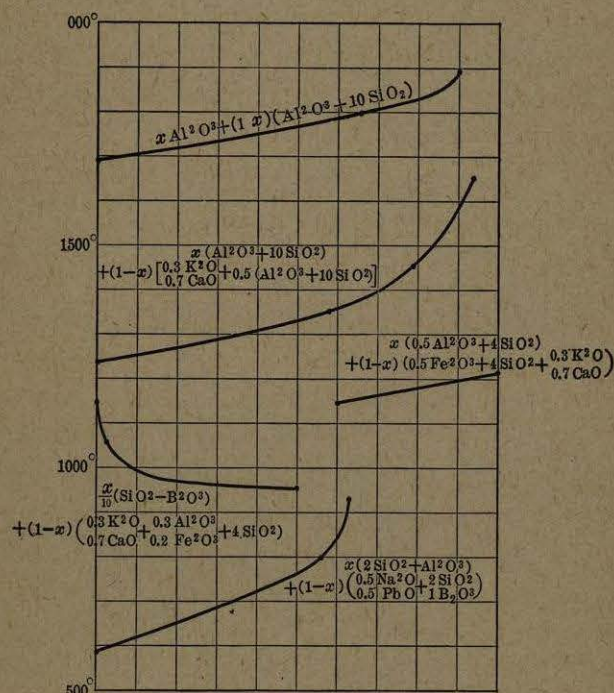


Fig. 131. Composition of Seger Cones.

The cones 022 to 011 from the cone 022 by the addition of increasing quantities of the mixture $\text{Al}_2\text{O}_3 + 2 \text{SiO}_2$.

Fig. 131 gives the graphical representation of these data; the ordinates are temperatures, and the abscissæ are values of x from the table.

These fusible cones of Seger are pretty generally used in the ceramic industry; they are very convenient in all intermittent furnaces whose temperature has to increase constantly up to a

certain maximum, at which point the cooling off is allowed to commence. It is sufficient, before firing up, to place a certain number of fusible cones opposite a draft hole closed by a glass, through which they may be watched. In seeing them fall successively, one knows at what moments the furnace takes on a series of definite temperatures.

In continuous furnaces, the cones may be put into the furnace during the process, but that is more delicate. It is necessary to place them on little earthenware supports that are moved into the desired part of the furnace by an iron rod. When, on the contrary, they are put in place at the start in the cold furnace, they are held in place by a small lump of clay.

THE ORIGINAL SEGER CONE SCALE.

Nos.	Deg. C.	Composition.	X	Formulae.
38	1800	1 $\text{Al}_2\text{O}_3 + 1 \text{SiO}_2$	0	$X \text{Al}_2\text{O}_3 + (1-X)(\text{Al}_2\text{O}_3 + 10 \text{SiO}_2)$
36	1850	1 " +1.5 "	8	
35	1830	1 " +2 "		
34	1810	1 " +2.5 "		
33	1790	1 " +3 "		
32	1770	1 " +4 "		
31	1750	1 " +5 "		
30	1730	1 " +6 "		
29	1710	1 " +8 "		
28	1690	1 " +10 "		
27	1670	1 $\left\{\begin{matrix} 0.3 \text{K}_2\text{O} \\ 0.7 \text{CaO} \end{matrix} + 20(\text{Al}_2\text{O}_3 + 10 \text{SiO}_2)\right\}$	0	$X(\text{Al}_2\text{O}_3 + 10 \text{SiO}_2) + (1-X)\left\{\begin{matrix} 0.3 \text{K}_2\text{O} \\ 0.7 \text{CaO} \end{matrix}\right\}$
26	1650	1 " +7.2 "	93	
25	1630	1 " +6.6 "		
24	1610	1 " +6 "		
23	1590	1 " +5.4 "		
22	1570	1 " +4.9 "		
21	1550	1 " +4.4 "		
20	1530	1 " +3.9 "		
19	1510	1 " +3.5 "		
18	1490	1 " +3.1 "		
17	1470	1 " +2.7 "		
16	1450	1 " +2.4 "		
15	1430	1 " +2.1 "		
14	1410	1 " +1.8 "		
13	1390	1 " +1.6 "		
12	1370	1 " +1.4 "		
11	1350	1 " +1.2 "		
10	1330	1 " +1 "		
9	1310	1 " +0.9 "		
8	1290	1 " +0.8 "		
7	1270	1 " +0.7 "		
6	1250	1 " +0.6 "		
5	1230	1 " +0.5 "		
4	1210	1 " +0.5 $\text{Al}_2\text{O}_3 + 4 \text{SiO}_2$	0	$X(0.5 \text{Al}_2\text{O}_3 + 4 \text{SiO}_2) + (1-X)\left\{\begin{matrix} 0.5 \text{Fe}_2\text{O}_3 \\ 4 \text{SiO}_2 + 0.7 \text{CaO} \end{matrix}\right\}$
3	1190	1 " + $\left\{\begin{matrix} 0.45 \text{Al}_2\text{O}_3 \\ 0.05 \text{Fe}_2\text{O}_3 \end{matrix} + 4 \text{SiO}_2\right\}$	1	
2	1170	1 " + $\left\{\begin{matrix} 0.4 \text{Al}_2\text{O}_3 \\ 0.1 \text{Fe}_2\text{O}_3 \end{matrix} + 4 \text{SiO}_2\right\}$		
1	1150	1 " + $\left\{\begin{matrix} 0.3 \text{Al}_2\text{O}_3 \\ 0.2 \text{Fe}_2\text{O}_3 \end{matrix} + 4 \text{SiO}_2\right\}$		

THE ORIGINAL SEGER CONE SCALE (Continued).

Nos.	Deg. C.	Composition.	X	Formula.
01	1130	$1 \left\{ \begin{array}{l} 0.3 \text{ K}_2\text{O} \\ 0.7 \text{ CaO} \end{array} \right\} + \left\{ \begin{array}{l} 0.3 \text{ Al}_2\text{O}_3 \\ 0.2 \text{ Fe}_2\text{O}_3 \end{array} \right\} + \left\{ \begin{array}{l} 3.95 \text{ SiO}_2 \\ 0.05 \text{ B}_2\text{O}_3 \end{array} \right\}$	1.05	$\frac{X}{10}(\text{SiO}_2 - \text{B}_2\text{O}_3)$ $+ (1-X) \left\{ \begin{array}{l} 0.3 \text{ K}_2\text{O} \\ 0.7 \text{ CaO} \end{array} \right\}$ $+ \left\{ \begin{array}{l} 0.3 \text{ Al}_2\text{O}_3 \\ 0.2 \text{ Fe}_2\text{O}_3 \end{array} \right\} + 4 \text{ SiO}_2$
02	1110	$1 \left\{ \begin{array}{l} 3.90 \text{ SiO}_2 \\ 0.10 \text{ B}_2\text{O}_3 \end{array} \right\}$		
03	1090	$1 \left\{ \begin{array}{l} 3.85 \text{ SiO}_2 \\ 0.15 \text{ B}_2\text{O}_3 \end{array} \right\}$		
04	1070	$1 \left\{ \begin{array}{l} 3.80 \text{ SiO}_2 \\ 0.20 \text{ B}_2\text{O}_3 \end{array} \right\}$		
05	1050	$1 \left\{ \begin{array}{l} 3.75 \text{ SiO}_2 \\ 0.25 \text{ B}_2\text{O}_3 \end{array} \right\}$	1.25	
06	1030	$1 \left\{ \begin{array}{l} 3.70 \text{ SiO}_2 \\ 0.30 \text{ B}_2\text{O}_3 \end{array} \right\}$		
07	1010	$1 \left\{ \begin{array}{l} 3.65 \text{ SiO}_2 \\ 0.35 \text{ B}_2\text{O}_3 \end{array} \right\}$		
08	990	$1 \left\{ \begin{array}{l} 3.60 \text{ SiO}_2 \\ 0.40 \text{ B}_2\text{O}_3 \end{array} \right\}$		
09	970	$1 \left\{ \begin{array}{l} 3.55 \text{ SiO}_2 \\ 0.45 \text{ B}_2\text{O}_3 \end{array} \right\}$		
010	950	$1 \left\{ \begin{array}{l} 3.5 \text{ SiO}_2 \\ 0.5 \text{ B}_2\text{O}_3 \end{array} \right\}$	5	
011	920	$1 \left\{ \begin{array}{l} 0.5 \text{ Na}_2\text{O} \\ 0.5 \text{ PbO} \end{array} \right\} + 0.8 \text{ Al}_2\text{O}_3 + \left\{ \begin{array}{l} 3.6 \text{ SiO}_2 \\ 1.0 \text{ B}_2\text{O}_3 \end{array} \right\}$	0.62	$X(2 \text{ SiO}_2 + \text{Al}_2\text{O}_3)$ $+ (1-X) \left\{ \begin{array}{l} 0.5 \text{ Na}_2\text{O} \\ 0.5 \text{ PbO} \end{array} \right\}$ $+ \left\{ \begin{array}{l} 2 \text{ SiO}_2 \\ 1 \text{ B}_2\text{O}_3 \end{array} \right\}$
012	890	$1 \left\{ \begin{array}{l} 3.5 \text{ SiO}_2 \\ 1.0 \text{ B}_2\text{O}_3 \end{array} \right\} + 0.75 \text{ Al}_2\text{O}_3$		
013	860	$1 \left\{ \begin{array}{l} 3.4 \text{ SiO}_2 \\ 1.0 \text{ B}_2\text{O}_3 \end{array} \right\} + 0.70 \text{ Al}_2\text{O}_3$		
014	830	$1 \left\{ \begin{array}{l} 3.3 \text{ SiO}_2 \\ 1.0 \text{ B}_2\text{O}_3 \end{array} \right\} + 0.65 \text{ Al}_2\text{O}_3$		
015	800	$1 \left\{ \begin{array}{l} 3.2 \text{ SiO}_2 \\ 1.0 \text{ B}_2\text{O}_3 \end{array} \right\} + 0.60 \text{ Al}_2\text{O}_3$	0.57	
016	770	$1 \left\{ \begin{array}{l} 3.1 \text{ SiO}_2 \\ 1.0 \text{ B}_2\text{O}_3 \end{array} \right\} + 0.55 \text{ Al}_2\text{O}_3$		
017	740	$1 \left\{ \begin{array}{l} 3.0 \text{ SiO}_2 \\ 1.0 \text{ B}_2\text{O}_3 \end{array} \right\} + 0.50 \text{ Al}_2\text{O}_3$		
018	710	$1 \left\{ \begin{array}{l} 2.8 \text{ SiO}_2 \\ 1.0 \text{ B}_2\text{O}_3 \end{array} \right\} + 0.40 \text{ Al}_2\text{O}_3$		
019	680	$1 \left\{ \begin{array}{l} 2.6 \text{ SiO}_2 \\ 1.0 \text{ B}_2\text{O}_3 \end{array} \right\} + 0.30 \text{ Al}_2\text{O}_3$		
020	650	$1 \left\{ \begin{array}{l} 2.4 \text{ SiO}_2 \\ 1.0 \text{ B}_2\text{O}_3 \end{array} \right\} + 0.20 \text{ Al}_2\text{O}_3$		
021	620	$1 \left\{ \begin{array}{l} 2.2 \text{ SiO}_2 \\ 1.0 \text{ B}_2\text{O}_3 \end{array} \right\} + 0.10 \text{ Al}_2\text{O}_3$		
022	590	$1 \left\{ \begin{array}{l} 2.0 \text{ SiO}_2 \\ 1.0 \text{ B}_2\text{O}_3 \end{array} \right\}$	0	

Recent investigations on Seger cones, in view of their improvement, have been carried out mainly by the staff of the Laboratorium für Tonindustrie, and at the Reichsanstalt, and consequently there have been changes in their composition, melting point, and numbering. The improvements have been mainly in increasing the sharpness of melting points, elimination in so far as possible of the lag due to rate of heating, and finding components that are uninfluenced by the usual ceramic furnace atmosphere. This has resulted in the elimination of lead and iron compounds. Cones Nos. 21 to 25 have been dropped, as their melting points were too close together; and four new

cones, Nos. 39 to 42, the most refractory of all, have been added.

In the following table are given the melting points of the cones according to the Tonindustrie Zeitung circulars for 1910, together with their compositions when the latter differ from the original series.

1910 SCALE OF SEGER CONES.

No.	Deg. C.	Composition.
42	2000	Al_2O_3
41	1960	$\text{Al}_2\text{O}_3 \text{ o. } 13 \text{ SiO}_2$
40	1920	$\text{Al}_2\text{O}_3 \text{ o. } 33 \text{ SiO}_2$
39	1880	$\text{Al}_2\text{O}_3 \text{ o. } 66 \text{ SiO}_2$
38	1850	No. Deg. C. No. Deg. C.
37	1825	28 1630 14 1410
36	1790	27 1610 13 1380
35	1770	26 1580 12 1350
34	1750	20 1530 11 1320
33	1730	19 1520 10 1300
32	1710	18 1500 9 1280
31	1690	17 1480 8 1250
30	1670	16 1460 7 1230
29	1650	15 1435

No.	Deg. C.	Composition.
6a	1200	$\left. \begin{array}{l} 0.013 \text{ Na}_2\text{O} \\ 0.288 \text{ K}_2\text{O} \\ 0.685 \text{ CaO} \\ 0.014 \text{ MgO} \end{array} \right\} 0.693 \text{ Al}_2\text{O}_3 \left\{ \begin{array}{l} 6.801 \text{ SiO}_2 \\ 0.026 \text{ B}_2\text{O}_3 \end{array} \right.$
5a	1180	$\left. \begin{array}{l} 0.028 \text{ Na}_2\text{O} \\ 0.274 \text{ K}_2\text{O} \\ 0.666 \text{ CaO} \\ 0.032 \text{ MgO} \end{array} \right\} 0.684 \text{ Al}_2\text{O}_3 \left\{ \begin{array}{l} 6.565 \text{ SiO}_2 \\ 0.056 \text{ B}_2\text{O}_3 \end{array} \right.$
4a	1160	$\left. \begin{array}{l} 0.043 \text{ Na}_2\text{O} \\ 0.260 \text{ K}_2\text{O} \\ 0.649 \text{ CaO} \\ 0.048 \text{ MgO} \end{array} \right\} 0.676 \text{ Al}_2\text{O}_3 \left\{ \begin{array}{l} 6.339 \text{ SiO}_2 \\ 0.086 \text{ B}_2\text{O}_3 \end{array} \right.$
3a	1140	$\left. \begin{array}{l} 0.059 \text{ Na}_2\text{O} \\ 0.244 \text{ K}_2\text{O} \\ 0.630 \text{ CaO} \\ 0.067 \text{ MgO} \end{array} \right\} 0.667 \text{ Al}_2\text{O}_3 \left\{ \begin{array}{l} 6.083 \text{ SiO}_2 \\ 0.119 \text{ B}_2\text{O}_3 \end{array} \right.$
2a	1120	$\left. \begin{array}{l} 0.085 \text{ Na}_2\text{O} \\ 0.220 \text{ K}_2\text{O} \\ 0.599 \text{ CaO} \\ 0.096 \text{ MgO} \end{array} \right\} 0.652 \text{ Al}_2\text{O}_3 \left\{ \begin{array}{l} 5.687 \text{ SiO}_2 \\ 0.170 \text{ B}_2\text{O}_3 \end{array} \right.$
1a	1100	$\left. \begin{array}{l} 0.109 \text{ Na}_2\text{O} \\ 0.198 \text{ K}_2\text{O} \\ 0.571 \text{ CaO} \\ 0.122 \text{ MgO} \end{array} \right\} 0.639 \text{ Al}_2\text{O}_3 \left\{ \begin{array}{l} 5.320 \text{ SiO}_2 \\ 0.217 \text{ B}_2\text{O}_3 \end{array} \right.$

1910 SCALE OF SEGER CONES (Continued).

No.	Deg. C.	Composition.
01a	1080	$\left. \begin{array}{l} 0.134 \text{ Na}_2\text{O} \\ 0.174 \text{ K}_2\text{O} \\ 0.541 \text{ CaO} \\ 0.151 \text{ MgO} \end{array} \right\} 0.625 \text{ Al}_2\text{O}_3 \left\{ \begin{array}{l} 4.931 \text{ SiO}_2 \\ 0.268 \text{ B}_2\text{O}_3 \end{array} \right.$
02a	1060	$\left. \begin{array}{l} 0.157 \text{ Na}_2\text{O} \\ 0.153 \text{ K}_2\text{O} \\ 0.513 \text{ CaO} \\ 0.177 \text{ MgO} \end{array} \right\} 0.611 \text{ Al}_2\text{O}_3 \left\{ \begin{array}{l} 4.572 \text{ SiO}_2 \\ 0.314 \text{ B}_2\text{O}_3 \end{array} \right.$
03a	1040	$\left. \begin{array}{l} 0.182 \text{ Na}_2\text{O} \\ 0.130 \text{ K}_2\text{O} \\ 0.484 \text{ CaO} \\ 0.204 \text{ MgO} \end{array} \right\} 0.598 \text{ Al}_2\text{O}_3 \left\{ \begin{array}{l} 4.199 \text{ SiO}_2 \\ 0.363 \text{ B}_2\text{O}_3 \end{array} \right.$
04a	1020	$\left. \begin{array}{l} 0.204 \text{ Na}_2\text{O} \\ 0.109 \text{ K}_2\text{O} \\ 0.458 \text{ CaO} \\ 0.229 \text{ MgO} \end{array} \right\} 0.586 \text{ Al}_2\text{O}_3 \left\{ \begin{array}{l} 3.860 \text{ SiO}_2 \\ 0.407 \text{ B}_2\text{O}_3 \end{array} \right.$
05a	1000	$\left. \begin{array}{l} 0.229 \text{ Na}_2\text{O} \\ 0.086 \text{ K}_2\text{O} \\ 0.428 \text{ CaO} \\ 0.257 \text{ MgO} \end{array} \right\} 0.571 \text{ Al}_2\text{O}_3 \left\{ \begin{array}{l} 3.467 \text{ SiO}_2 \\ 0.457 \text{ B}_2\text{O}_3 \end{array} \right.$
06a	980	$\left. \begin{array}{l} 0.247 \text{ Na}_2\text{O} \\ 0.069 \text{ K}_2\text{O} \\ 0.407 \text{ CaO} \\ 0.277 \text{ MgO} \end{array} \right\} 0.561 \text{ Al}_2\text{O}_3 \left\{ \begin{array}{l} 3.197 \text{ SiO}_2 \\ 0.493 \text{ B}_2\text{O}_3 \end{array} \right.$
07a	960	$\left. \begin{array}{l} 0.261 \text{ Na}_2\text{O} \\ 0.055 \text{ K}_2\text{O} \\ 0.391 \text{ CaO} \\ 0.293 \text{ MgO} \end{array} \right\} 0.554 \text{ Al}_2\text{O}_3 \left\{ \begin{array}{l} 2.984 \text{ SiO}_2 \\ 0.521 \text{ B}_2\text{O}_3 \end{array} \right.$
08a	940	$\left. \begin{array}{l} 0.279 \text{ Na}_2\text{O} \\ 0.038 \text{ K}_2\text{O} \\ 0.369 \text{ CaO} \\ 0.314 \text{ MgO} \end{array} \right\} 0.543 \text{ Al}_2\text{O}_3 \left\{ \begin{array}{l} 2.691 \text{ SiO}_2 \\ 0.559 \text{ B}_2\text{O}_3 \end{array} \right.$
09a	920	$\left. \begin{array}{l} 0.336 \text{ Na}_2\text{O} \\ 0.018 \text{ K}_2\text{O} \\ 0.335 \text{ CaO} \\ 0.311 \text{ MgO} \end{array} \right\} 0.468 \text{ Al}_2\text{O}_3 \left\{ \begin{array}{l} 3.087 \text{ SiO}_2 \\ 0.671 \text{ B}_2\text{O}_3 \end{array} \right.$
010a	900	$\left. \begin{array}{l} 0.338 \text{ Na}_2\text{O} \\ 0.011 \text{ K}_2\text{O} \\ 0.338 \text{ CaO} \\ 0.313 \text{ MgO} \end{array} \right\} 0.423 \text{ Al}_2\text{O}_3 \left\{ \begin{array}{l} 2.626 \text{ SiO}_2 \\ 0.675 \text{ B}_2\text{O}_3 \end{array} \right.$
011a	880	$\left. \begin{array}{l} 0.349 \text{ Na}_2\text{O} \\ 0.340 \text{ CaO} \\ 0.311 \text{ MgO} \end{array} \right\} 0.4 \text{ Al}_2\text{O}_3 \left\{ \begin{array}{l} 2.38 \text{ SiO}_2 \\ 0.68 \text{ B}_2\text{O}_3 \end{array} \right.$
012a	855	$\left. \begin{array}{l} 0.345 \text{ Na}_2\text{O} \\ 0.341 \text{ CaO} \\ 0.314 \text{ MgO} \end{array} \right\} 0.365 \text{ Al}_2\text{O}_3 \left\{ \begin{array}{l} 2.04 \text{ SiO}_2 \\ 0.68 \text{ B}_2\text{O}_3 \end{array} \right.$

1910 SCALE OF SEGER CONES (Continued).

No.	Deg. C.	Composition.
013a	835	$\left. \begin{array}{l} 0.343 \text{ Na}_2\text{O} \\ 0.343 \text{ CaO} \\ 0.314 \text{ MgO} \end{array} \right\} 0.34 \text{ Al}_2\text{O}_3 \left\{ \begin{array}{l} 1.78 \text{ SiO}_2 \\ 0.69 \text{ B}_2\text{O}_3 \end{array} \right.$
014a	815	$\left. \begin{array}{l} 0.385 \text{ Na}_2\text{O} \\ 0.385 \text{ CaO} \\ 0.230 \text{ MgO} \end{array} \right\} 0.34 \text{ Al}_2\text{O}_3 \left\{ \begin{array}{l} 1.92 \text{ SiO}_2 \\ 0.77 \text{ B}_2\text{O}_3 \end{array} \right.$
015a	790	$\left. \begin{array}{l} 0.432 \text{ Na}_2\text{O} \\ 0.432 \text{ CaO} \\ 0.136 \text{ MgO} \end{array} \right\} 0.34 \text{ Al}_2\text{O}_3 \left\{ \begin{array}{l} 2.06 \text{ SiO}_2 \\ 0.86 \text{ B}_2\text{O}_3 \end{array} \right.$
016	750	Bf. * $0.31 \text{ Al}_2\text{O}_3 \left\{ \begin{array}{l} 1.61 \text{ SiO}_2 \\ \text{B}_2\text{O}_3 \end{array} \right.$
017	730	Bf. $0.2 \text{ Al}_2\text{O}_3 \left\{ \begin{array}{l} 1.4 \text{ SiO}_2 \\ \text{B}_2\text{O}_3 \end{array} \right.$
018	710	Bf. $0.13 \text{ Al}_2\text{O}_3 \left\{ \begin{array}{l} 1.26 \text{ SiO}_2 \\ \text{B}_2\text{O}_3 \end{array} \right.$
019	690	Bf. $0.08 \text{ Al}_2\text{O}_3 \left\{ \begin{array}{l} 1.16 \text{ SiO}_2 \\ \text{B}_2\text{O}_3 \end{array} \right.$
020	670	Bf. $0.04 \text{ Al}_2\text{O}_3 \left\{ \begin{array}{l} 1.08 \text{ SiO}_2 \\ \text{B}_2\text{O}_3 \end{array} \right.$
021	650	Bf. $0.02 \text{ Al}_2\text{O}_3 \left\{ \begin{array}{l} 1.04 \text{ SiO}_2 \\ \text{B}_2\text{O}_3 \end{array} \right.$
022	600	

* Bf = $\left\{ \begin{array}{l} 0.50 \text{ Na}_2\text{O} \\ 0.25 \text{ CaO} \\ 0.25 \text{ MgO} \end{array} \right.$

It would seem to be well to replace, in so far as possible, these cones by pure compounds and eutectics having definite melting points, as the softening temperatures of the former are influenced considerably, in some cases 100° C. or more, by the rate of heating, as has been remarked by several investigators. Dr. Kanolt of the Bureau of Standards has carried out a series of measurements on some of the "Standard Pyrometric Cones" of Professor Orton of the Ohio State University, corresponding to Nos. 25 to 36 of the Seger series, as well as on this Seger series. His work shows that heating the cones as rapidly as 5° C. per minute, when near their softening temperatures, will give too high values for these temperatures. The rate of heating in the experimental or calibrating furnace must be reduced to more

nearly that which obtains in kiln practice, in order to get a fair calibration of the cones for use in the ceramic industries.

The Seger and Orton cones were found to agree very closely in their behavior. With slow heating, the cones of the series 25-36 were found to soften at temperatures lower by 40° to 70° C. than indicated in the table of 1910, page 373, agreeing closely in this with the results found by Heraeus. Melting in air or in vacuo gave the same results. Kanolt's measurements were made with an optical pyrometer whose scale is represented by Au = 1064°, Pd = 1550°, Pt = 1755° C.

At the Reichsanstalt, Hoffmann and Meissner find (1911) similar differences between softening temperatures in ceramic kilns for a time of heating of about sixty hours and in the electric furnace.

SOFTENING TEMPERATURES OF SEGER CONES.

Cone number.	In electric furnace.	In ceramic kiln.	Difference.
4	1225	1160	65
6	1260	1200	>60
7	1285	1180	105
8	1305	<1200	105
9	1335	1225	110
10	1345	1235	110
13	1395	1315	80
14	1415	1375	40
16	1460	1405	55
17	1480	1410	70

On the whole, it may be said that the Seger cone series give reliable relative temperatures to about 25° C. at the higher temperatures for any given method of procedure, but too much reliance should not be placed on the numerical values of the temperatures apparently measured.

Wiborgh's Thermophones. — Another cheap, discontinuous pyroscope has been put on the market by Wiborgh. His thermophones are refractory earth cylinders 2.5 cm. long and 2 cm. in diameter, containing an explosive. A thermophone is quickly deposited in the region whose temperature is sought, and the time noted to the fifth of a second until the cylinder bursts. A table then gives the temperature. Very concordant results are

obtained if the thermophones are kept dry, different cylinders of the same set agreeing to one-fifth second, or 20° C. at 1000° C.

Dilution Pyrometers. — If a current of liquid or gas is kept flowing through a heated space, it is evidently possible to estimate the temperature of the latter by observing the inlet and outlet temperatures of the fluid. Carnelly and Burton constructed such a pyrometer, using water flowing at constant head from a tank kept at constant temperature. The graduation of such a pyrometer is purely empirical, and may be effected, for a given

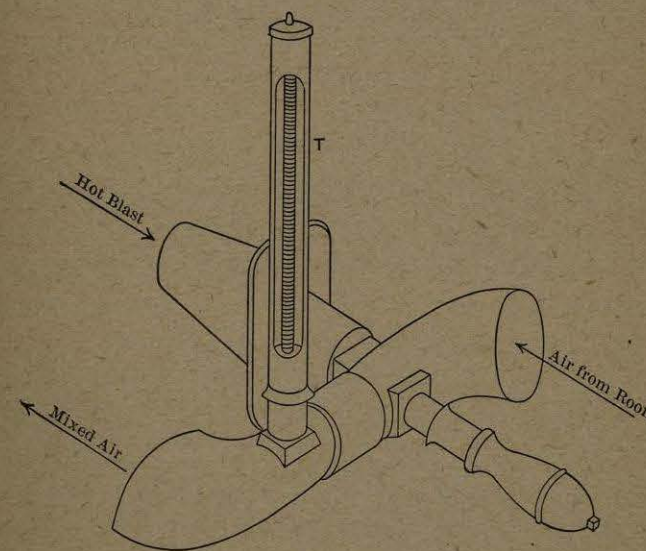


Fig. 132. Hot-blast Pyrometer.

heat and temperature of supply, by taking the inlet and outlet temperatures for three or more known temperatures of the furnace. For every different head and temperature of source the graduation will be different. Such a pyrometer evidently requires a somewhat cumbersome, permanent installation, and has the further disadvantages of not being direct-reading and having its indications change with difficultly controllable factors.

For determining hot-blast temperatures air-dilution pyrometers have been used, air from the outside entering the blast, mixing with it, and the temperature of the outcoming mixture

being taken with a mercury thermometer, and then the temperature of the blast computed from an empirical calibration. But very uncertain results can be obtained in this way, as they will depend on the speed of the blast, the size of openings, and the temperature of the diluting air. Such a pyrometer is illustrated in Fig. 132.

Pyrometers, such as Carnelly's, have also been based on the circulation of a water stream whose inlet and outlet temperatures could be taken.

Transpiration Pyrometers.— Various attempts have been made to construct pyrometers based on the variation of the viscosity of gases with temperature, and this subject has been thoroughly studied by Holman, Barus, and Callendar; but, owing to the complexity of the viscosity temperature relation for small tubes, no simple pyrometer based on this relation alone, not requiring an arbitrary calibration, has been devised. This method may perhaps serve, as first suggested by Barus, as an independent one for extending the temperature scale beyond the region reached by other forms of gas thermometer.

Job has shown that if a short piece of platinum wire be inserted in the end of a porcelain tube of less than 1 mm. diameter and a constant current of gas, as from an electrolytic cell or blower, be passed through this capillary, the back pressure developed will be proportional to the temperature, or $T = k(H - h_0)$, where H is given by a manometer inserted between the cell or blower and the porcelain capillary, and h_0 is the initial pressure. This simple relation holds very exactly up to temperatures as high as 1500° C., and the method may be made very sensitive by a proper choice of manometer liquid and initial pressure h_0 . The indications, however, vary with the depth of immersion of the capillary, and they depend not alone upon the viscosity of the gas, but also upon the relative expansion of platinum and porcelain.

A pyrometer depending upon the change in pressure produced in a current of gas or vapor passing through a small orifice A (Fig. 133), at high temperature has been developed by Uhling and

Steinbart, using a steam-jacket aspirator D to produce a steady flow. It is essential that the air pass through the apertures B and A at a constant pressure, as measured by Q , that all the air become heated to a uniform temperature at A , that the apertures, which are but pinholes, remain perfectly clear, that the temperature of the colder aperture B remain constant, and that there are no leaks. The hot end CA is inclosed within a tube of platinum or nickel and the air is filtered before passing into A .

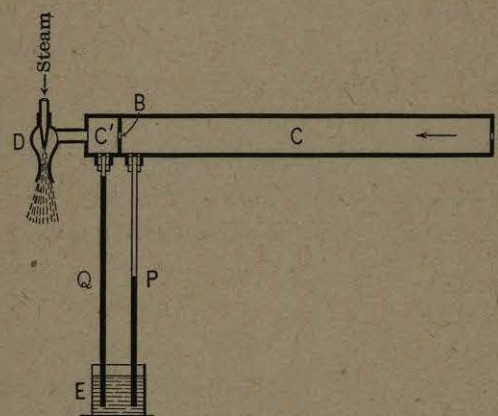


Fig. 133. Uhling-Steinbart Pyrometer.

Although simple in principle, the apparatus as constructed is very complicated and costly. It is made direct-reading and also recording. The calibration is empirical and the apparatus is so constructed that temperatures are read off the water-manometer column, P . The elaborateness of construction of such a pressure apparatus renders it liable to deteriorate with time and use, and it requires a source of steam for its operation.

In Threw's pyrometer, air under constant pressure is forced through a coiled tube in the heated region, and the back pressure developed between a hot and cold orifice is measured on a water column in much the same way as in Uhling's apparatus. Both these instruments have been used considerably in blast-furnace practice.

Vapor-pressure Pyrometers.— Use is made of the fact that the pressure of a saturated vapor, or one in the presence of its liquid, depends only on the temperature of the vapor, and is independent of its volume. Readings of such a pyrometer may reduce to those of a pressure gauge. There is an apparent advantage over the gas thermometer, in that the volume of the containing vessel plays no part. This vessel must be gas-tight, however, in both types. For relatively low temperatures, where ether or water may be used, to 350° C. for water, several industrial forms using this principle have been developed, that have given satisfaction in special installations, notably the thalpotassimeter of Schaffer and Budenberg and the instruments of Fournier.

The difficulty of rendering them gas-tight and permanent when mercury or other substance suitable for higher temperatures is used appears to be a serious obstacle to the general introduction of this type of instrument as a pyrometer.

Other Pyrometric Methods.— We have by no means exhausted the list of methods for measuring high temperatures that have been suggested or tried. Without dwelling on any of them, we may mention a few that may possibly be of service in particular cases. The variation of boiling point with pressure of such substances as naphthaline, benzophenone, and sulphur, first studied in detail by Crafts, in 1882, will give a continuous temperature scale of very great range, although a relatively complicated pressure apparatus is necessary. Again, the velocity of sound in any medium is a function of its temperature; and, as early as 1837, a method of temperature measurement using this principle was devised by Cagniard-Latour with dry air as the medium. Other phenomena of less promise which have been made use of or suggested, are: heat conduction, rotary polarization, magnetic moment, dissociation, conductivity of gases and vapors, the corpuscular emission in vacuo from current-bearing metals, and an application of Clapeyron's Equation.

CHAPTER X.

RECORDING PYROMETERS.

AMONG the different methods for the measurement of high temperatures, some of them may be made continuously recording. This is as useful for industrial applications as for scientific investigations. In research laboratories one endeavors as much as possible to take observations automatically, escaping the influence either of preconceived ideas or of carelessness of the observer; in industrial works the use of such processes gives continuous control over the work of the artisans, such as the presence of no foreman can replace.

In recent years, one of the most important practical advances that have been made in pyrometry is the development of several types of simple, convenient, and reliable instruments for the registration of temperatures in industrial operations. It will be impossible to describe them all here, but we shall pass in review several, as well as calling attention to the historical development of the subject. Forms of temperature-recording apparatus, suitable for laboratory investigations of problems involving temperature changes, but too complicated for any but the most elaborate technical installations, have been in existence for a good many years, and the recent introduction of more simple apparatus has greatly stimulated technical research as well as afforded means for the exact control of a great many industrial operations that were heretofore left to chance.

Forms of Temperature Records.— There are several ways in which the change of temperature with time may be recorded, and the method adopted will depend upon the problem in hand. The simplest and the one of most universal application and general utility both in the works and laboratory is the *time-temperature* curve; that is, the time appears as one coördinate,