## CHAPTER IV

### CHIMNEY TABLES, WIND-PRESSURE, AIR-SPACE IN GRATES

#### RATE OF COMBUSTION

THE results of 45 tests of boilers with anthracite and Welsh steam coal give only 5 instances where the rate of combustion was greater than 13 pounds of coal per square foot of grate per hour, and all of the tests showed the rate of evaporation from and at 212° Fahr. per pound of combustible to be 8.11 pounds to 14.23 pounds.

The same quantity of coal as used in the above tests, burned on a smaller grate, evaporated more water per pound.

Averages of 15 tests by Isherwood give the following data:

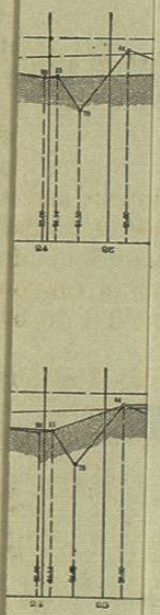
| | Coal per sq. ft. of grate per hour. | Evaporation from and at 212° F. per lb. coal. |
|---|---|---|
| Anthracite coal ..... | 12.75 | 8.90 |
| Semi-bituminous coal ..... | 10.95 | 10.14 |
| Bituminous coal .. ..... | 12.43 | 9.31 |

Another case—Average of 15 boilers tested gives 13.87 pounds of coal to square foot of grate per hour, while only 7 tests exceed 13 pounds (capacity trials).

For economy trials we have the average of 15 tests, giving 9.77 pounds of coal per square foot of grate per hour; none being over 13 pounds.—Clark, Volume I.

Thurston—"Steam Engine and Boiler Trials," p. 17, says the "efficiency of fuel falls off at 50 to 60 pounds of fuel burned per square foot of grate" (per hour).

In the plotted tests of the writer, PLATE I, all regularity ceases after 37 pounds of coal burned per square foot of grate is reached.



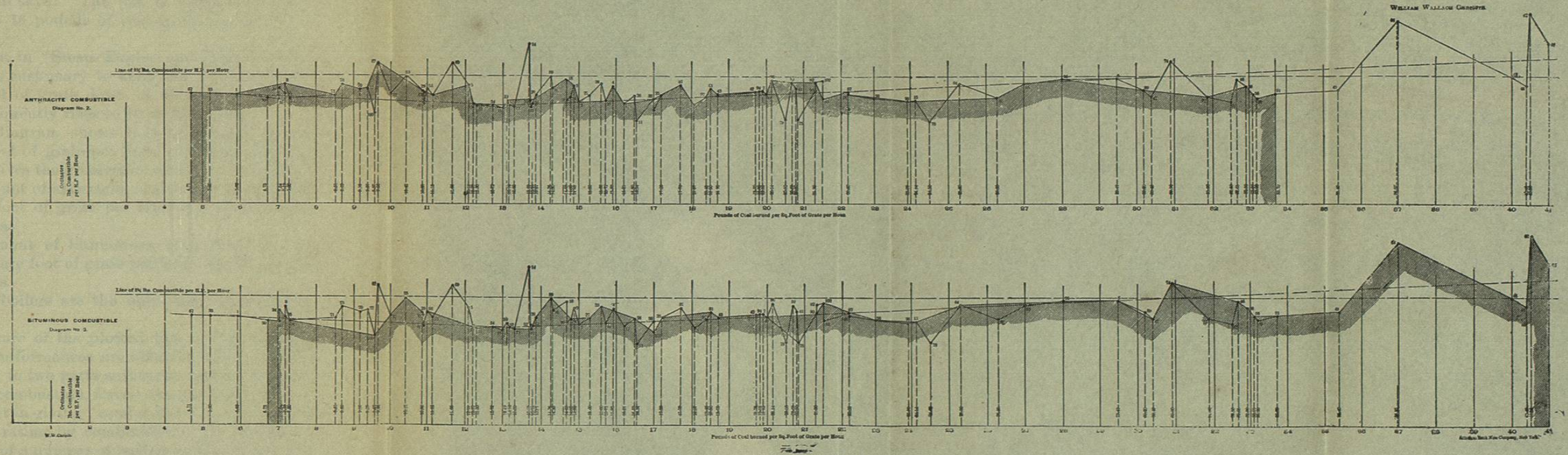

ANTHRACITE COMBUSTIBLE
Diagram No. 2.
Pounds of Coal burned per Sq. Foot of Grate per Hour
BITUMINOUS COMBUSTIBLE
Pounds of Coal burned per Sq. Foot of Grate per Hour

PLATE No. 1.

The following averages are from over 100 tests collated by the writer:

| | |
|---|---|
| Pounds of coal per horse-power developed per hour..... | 3.64 |
| Pounds of combustible per horse-power developed per hour | 3.04 |
| Pounds of coal burned per square foot of grate per hour.. | 18.16 |

Professor Rankine says: "The rate of combustion in factory boilers is 12 to 16 pounds of coal to the square foot of grate."

Dr. Thurston says, in "Steam Engine and Boiler Trials": "In land boilers it is customary to keep the rate of combustion per square foot of grate down to about 8 pounds per hour. although it frequently rises to 10 or 12 pounds."

The preceding diagram shows that 13 pounds of coal burned per square foot of grate per hour of either anthracite or bituminous coal gives the greatest economy in evaporation.

The greatest amount of anthracite coal found to have been burned per square foot of grate per hour was 33.70 pounds; the least, 4.70 pounds.

The greatest amount of bituminous coal found to have been burned per square foot of grate per hour was 57 pounds; the least, 6.70 pounds.

Land stationary boilers are the only ones considered in these statements.

A noticeable feature of the plotted data is that the most economical boiler performances are obtained when a mixture of one part soft coal to two parts anthracite dust is burned at quite a high rate of combustion, forced draught being used.

The writer's object in giving "combustible" per square foot of grate is that the rating by combustible is the best way of comparing the tests of a number of boilers under which different coals are burned, and is a more reasonable criterion than that of coal only.

It will be readily seen from the averages that less than 4 pounds of coal in the majority of cases is that which is required to be burned per hour to produce one horse-power; and as 13 pounds of coal burned per square foot of grate is a most economical rate of combustion, 13 divided by 4, or 3.25 horse-power per square foot of grate per hour, is most economically attainable.

The above is for anthracite coal. For bituminous coal, as 23.8 pounds burned per square foot of grate is an economical rate of combustion, 23.8 divided by 4, or 5.95 horse-power per square foot of grate per hour, is economically attainable.

The average of 13 and 23.8 is 18.4, which is very nearly 18.16, the average of all the 108 tests; which confirms the correctness of common practice, as to rates of combustion.

## CHIMNEYS.

The writer has found that a relation exists between the coal burned per square foot of grate, with efficient chimney draft, for anthracite and bituminous coal, and by assuming that

$$\text{coefficient} \times A\sqrt{H} = \text{coal per hour in pounds,}$$

then $\text{coefficient} \times A\sqrt{H} = G \times$ coal per square foot of grate per hour, we find that for anthracite coal the coefficient equals the coal burned per square foot of grate, and that for bituminous coal the coefficient equals the coal burned per square foot of grate divided by 1.83.

The following tables, figured by formulæ given, will give satisfactory results to any who may use them; should any special modification be needed, the user must use his own judgment with regard to them.

Table No. 6. Grate area for a rate of combustion of 13 pounds per square foot of grate per hour.

Table No. 7. Grate area for a rate of combustion of 23.8 pounds per square foot of grate per hour.

Table No. 8. Coal capacity of chimney.

Table No. 9. Horse-power of boilers.

Table No. 10. Horse-power of chimneys, when two pounds of coal per hour burned furnishes one indicated horse-power at engine. Should the engine horse-power be known, and the chimney size wanted, great care should be exercised in determining it.

The last table is intended only for the one case. The writer has put himself on record as being decidedly in favor of rating chimneys at their coal capacity and not by horse-power.



The 23.8 is a derived constant obtained by multiplying 13 × 1.83; 1.83 confirms Mr. Harris's rule for grate area for bituminous coal burned with natural draft, 23.8 is an economical rate of combustion for bituminous coal.

A horse-power is understood throughout these tables to be the American Society of Mechanical Engineers' standard of 34½ pounds of water evaporated per hour from and at 212° Fahr.

TABLE No. 6.

| DIAM. | AREA (A) | HEIGHT OF CHIMNEY | | | | | | | | | | | | EQUIV. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 50′ | 60′ | 70′ | 80′ | 90′ | 100′ | 110′ | 125′ | 150′ | 175′ | 200′ | 225′ | 250′ | 300′ | Sq. Chim. |
| Inches. | Sq. Ft. | Grate Area ($G$)=$A\sqrt{H}$ for a rate of combustion of 13 lbs. | | | | | | | | | | | | | | Side of Sq. |
| 18 | 1.77 | 13 | 14 | 15 | 16 | | | | | | | | | | | 16″ |
| 21 | 2.41 | 17 | 19 | 20 | 21 | | | | | | | | | | | 19 |
| 24 | 3.14 | 22 | 24 | 26 | 28 | 30 | | | | | | | | | | 22 |
| 27 | 3.98 | 28 | 31 | 33 | 35 | 38 | | | | | | | | | | 24 |
| 30 | 4.91 | 35 | 38 | 41 | 44 | 47 | 49 | | | | | | | | | 27 |
| 33 | 5.94 | | 46 | 50 | 53 | 56 | 59 | 62 | | | | | | | | 30 |
| 36 | 7.07 | | 55 | 59 | 63 | 67 | 70 | 74 | 79 | | | | | | | 32 |
| 39 | 8.30 | | | 69 | 74 | 79 | 83 | 87 | 93 | | | | | | | 35 |
| 42 | 9.62 | | | 81 | 88 | 91 | 96 | 102 | 108 | 120 | | | | | | 38 |
| 48 | 12.57 | | | | 112 | 119 | 126 | 132 | 141 | 157 | 210 | | | | | 43 |
| 54 | 15.90 | | | | | 151 | 159 | 167 | 178 | 199 | 266 | | | | | 48 |
| 60 | 19.64 | | | | | 186 | 196 | 206 | 220 | 246 | 329 | | | | | 54 |
| 66 | 23.76 | | | | | | 238 | 249 | 266 | 297 | 397 | 536 | | | | 59 |
| 72 | 28.27 | | | | | | 283 | 296 | 317 | 353 | 472 | 637 | 424 | 626 | 666 | 64 |
| 78 | 33.18 | | | | | | | 346 | 371 | 415 | 553 | 747 | 498 | 735 | 785 | 70 |
| 84 | 38.48 | | | | | | | 403 | 431 | 481 | 642 | 867 | 577 | 853 | 911 | 76 |
| 90 | 44.18 | | | | | | | | 495 | 552 | 738 | 996 | 663 | 980 | 1047 | 80 |
| 96 | 50.27 | | | | | | | | 563 | 628 | 840 | 1134 | 754 | 1115 | 1191 | 86 |
| 102 | 56.75 | | | | | | | | 636 | 709 | 948 | 1280 | 851 | 1259 | 1345 | 91 |
| 108 | 63.62 | | | | | | | | 712 | 795 | 1063 | 1435 | 954 | 1411 | 1507 | 96 |
| 114 | 70.88 | | | | | | | | | 886 | 1184 | 1599 | 1063 | 1572 | 1679 | 101 |
| 120 | 78.54 | | | | | | | | | 982 | 1313 | 1772 | 1178 | 1742 | 1860 | 107 |
| 132 | 95.03 | | | | | | | | | 1188 | 1589 | 2145 | 1425 | 2108 | 2252 | 117 |
| 144 | 113.10 | | | | | | | | | 1414 | 1891 | 2553 | 1697 | 2509 | 2680 | 128 |

## TABLE No. 7.

| DIAM | AREA (A) | HEIGHT OF CHIMNEY. | | | | | | | | | | | | | EQUIV. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 50′ | 60′ | 70′ | 80 | 90′ | 100′ | 110′ | 125′ | 150′ | 175′ | 200′ | 225′ | 250′ | 300′ | Sq. Chim. |
| Inches. | Sq. Ft. | Grate Area ($G_1$) = $A\sqrt{H} \div 1.83$ for a rate of combustion of 23.8 lbs. | | | | | | | | | | | | | | Side of Sq. |
| 18 | 1.77 | 7 | 7.6 | 8.1 | 8.7 | | | | | | | | | | | 16″ |
| 21 | 2.41 | 9 | 10 | 11 | 12 | | | | | | | | | | | 19 |
| 24 | 3.14 | 12 | 13 | 14 | 15 | 16 | | | | | | | | | | 22 |
| 27 | 3.98 | 15 | 17 | 18 | 19 | 21 | | | | | | | | | | 24 |
| 30 | 4.91 | 19 | 21 | 23 | 24 | 26 | 27 | | | | | | | | | 27 |
| 33 | 5.94 | | 25 | 27 | 29 | 30 | 32 | 34 | | | | | | | | 30 |
| 36 | 7.07 | | 30 | 32 | 34 | 36 | 38 | 40 | 43 | | | | | | | 32 |
| 39 | 8.30 | | | 38 | 40 | 43 | 45 | 47 | 51 | | | | | | | 35 |
| 42 | 9.62 | | | 44 | 47 | 50 | 53 | 56 | 59 | 66 | | | | | | 38 |
| 48 | 12.57 | | | | 60 | 65 | 69 | 72 | 77 | 86 | | | | | | 43 |
| 54 | 15.90 | | | | | 83 | 87 | 91 | 97 | 109 | 115 | | | | | 48 |
| 60 | 19.64 | | | | | 102 | 107 | 113 | 120 | 134 | 142 | | | | | 54 |
| 66 | 23.76 | | | | | | 130 | 136 | 145 | 162 | 172 | 184 | | | | 59 |
| 72 | 28.27 | | | | | | 155 | 162 | 173 | 193 | 204 | 219 | 232 | | | 64 |
| 78 | 33.18 | | | | | | | 190 | 203 | 227 | 245 | 256 | 272 | 297 | | 70 |
| 84 | 38.48 | | | | | | | 220 | 236 | 263 | 278 | 297 | 315 | 332 | 364 | 75 |
| 90 | 44.18 | | | | | | | | 270 | 302 | 319 | 341 | 362 | 381 | 472 | 80 |
| 96 | 50.27 | | | | | | | | 308 | 343 | 353 | 389 | 412 | 434 | 476 | 86 |
| 102 | 56.75 | | | | | | | | 347 | 388 | 410 | 439 | 465 | 490 | 537 | 91 |
| 108 | 63.62 | | | | | | | | 389 | 434 | 459 | 492 | 521 | 550 | 602 | 96 |
| 114 | 70.88 | | | | | | | | | 484 | 512 | 548 | 581 | 612 | 671 | 101 |
| 120 | 78.54 | | | | | | | | | 536 | 567 | 607 | 647 | 679 | 743 | 107 |
| 132 | 95.03 | | | | | | | | | 650 | 686 | 735 | 778 | 831 | 899 | 117 |
| 144 | 113.10 | | | | | | | | | 772 | 817 | 874 | 927 | 977 | 1070 | 128 |

## TABLE No. 8.

| DIAM. | AREA (A) | HEIGHT OF CHIMNEY. | | | | | | | | | | | | | EQUIV. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 50′ | 60′ | 70′ | 80′ | 90′ | 100′ | 110′ | 125′ | 150′ | 175′ | 200′ | 225′ | 250′ | 300′ | Sq. Chim. |
| nches. | Sq. Ft. | Horse Power = 3.25 $A\sqrt{H}$; 4 lbs. of coal burned considered 1 H. P. | | | | | | | | | | | | | | Side of Sq. |
| 18 | 1.77 | 42 | 46 | 49 | 52 | | | | | | | | | | | 16″ |
| 21 | 2.41 | 55 | 62 | 65 | 68 | | | | | | | | | | | 19 |
| 24 | 3.14 | 72 | 78 | 85 | 91 | 98 | | | | | | | | | | 22 |
| 27 | 3.98 | 91 | 101 | 107 | 114 | 124 | | | | | | | | | | 24 |
| 30 | 4.91 | 114 | 124 | 133 | 143 | 153 | 159 | | | | | | | | | 27 |
| 33 | 5.94 | | 149 | 163 | 172 | 182 | 192 | 202 | | | | | | | | 30 |
| 36 | 7.07 | | 179 | 192 | 205 | 218 | 228 | 241 | 257 | | | | | | | 32 |
| 39 | 8.30 | | | 224 | 241 | 257 | 270 | 283 | 302 | | | | | | | 35 |
| 42 | 9.62 | | | 263 | 282 | 296 | 312 | 332 | 351 | 390 | | | | | | 38 |
| 48 | 12.57 | | | | 364 | 387 | 410 | 429 | 458 | 510 | | | | | | 43 |
| 54 | 15.90 | | | | | 491 | 517 | 543 | 579 | 647 | 683 | | | | | 48 |
| 60 | 19.64 | | | | | 605 | 637 | 669 | 715 | 797 | 845 | | | | | 54 |
| 66 | 23.76 | | | | | | 774 | 809 | 865 | 965 | 1021 | 1092 | | | | 59 |
| 72 | 28.27 | | | | | | 920 | 962 | 1051 | 1147 | 1215 | 1300 | 1378 | | | 64 |
| 78 | 33.18 | | | | | | | 1131 | 1206 | 1349 | 1459 | 1524 | 1619 | 1706 | | 70 |
| 84 | 38.48 | | | | | | | 1310 | 1401 | 1563 | 1654 | 1768 | 1875 | 1976 | 2165 | 75 |
| 90 | 44.18 | | | | | | | | 1609 | 1794 | 1898 | 2031 | 2155 | 2269 | 2488 | 80 |
| 96 | 50.27 | | | | | | | | 1830 | 2041 | 2161 | 2311 | 2451 | 2584 | 2831 | 86 |
| 102 | 56.75 | | | | | | | | 2067 | 2304 | 2434 | 2607 | 2766 | 2915 | 3195 | 91 |
| 108 | 63.62 | | | | | | | | 2314 | 2584 | 2734 | 2925 | 3101 | 3269 | 3578 | 96 |
| 114 | 70.88 | | | | | | | | | 2879 | 3045 | 3257 | 3455 | 3643 | 3991 | 101 |
| 120 | 78.54 | | | | | | | | | 3191 | 3374 | 3611 | 3829 | 4037 | 4420 | 107 |
| 132 | 95.03 | | | | | | | | | 3861 | 4082 | 4368 | 4631 | 4882 | 5350 | 117 |
| 144 | 113.10 | | | | | | | | | 4596 | 4859 | 5200 | 5515 | 5811 | 6367 | 128 |



## TABLE No. 9.

| DIAM. | AREA (A) | HEIGHT OF CHIMNEY. | | | | | | | | | | | | | EQUIV. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 50′ | 60′ | 70′ | 80′ | 90′ | 100′ | 110′ | 125′ | 150′ | 175′ | 200′ | 225′ | 250′ | 300′ | Sq. Chim. |
| Inches. | Sq. Ft. | Horse Power = 6.5 $A\sqrt{H}$. When 2 lbs. coal burned per hour = 1 H. P. | | | | | | | | | | | | | | Side of Sq. |
| 18 | 1.77 | 84 | 92 | 98 | 104 | | | | | | | | | | | 16″ |
| 21 | 2.41 | 110 | 124 | 130 | 136 | | | | | | | | | | | 19 |
| 24 | 3.14 | 144 | 156 | 170 | 182 | 196 | | | | | | | | | | 22 |
| 27 | 3.98 | 182 | 202 | 214 | 228 | 248 | | | | | | | | | | 24 |
| 30 | 4.91 | 228 | 248 | 266 | 286 | 306 | 318 | | | | | | | | | 27 |
| 33 | 5.94 | | 298 | 326 | 344 | 364 | 384 | 404 | | | | | | | | 30 |
| 36 | 7.07 | | 358 | 384 | 410 | 436 | 456 | 482 | 514 | | | | | | | 32 |
| 39 | 8.30 | | | 448 | 482 | 514 | 540 | 566 | 604 | | | | | | | 35 |
| 42 | 9.62 | | | 526 | 564 | 592 | 624 | 662 | 702 | 780 | | | | | | 38 |
| 48 | 12.57 | | | | 728 | 774 | 820 | 858 | 916 | 1020 | | | | | | 43 |
| 54 | 15.90 | | | | | 982 | 1034 | 1086 | 1158 | 1294 | 1366 | | | | | 48 |
| 60 | 19.64 | | | | | 1210 | 1274 | 1338 | 1430 | 1594 | 1690 | | | | | 54 |
| 66 | 23.76 | | | | | | 1548 | 1618 | 1730 | 1930 | 2042 | 2184 | | | | 59 |
| 72 | 28.27 | | | | | | 1840 | 1924 | 2102 | 2294 | 2430 | 2600 | 2756 | | | 64 |
| 78 | 33.18 | | | | | | | 2252 | 2412 | 2698 | 2918 | 3048 | 3238 | 3412 | | 70 |
| 84 | 38.48 | | | | | | | 2520 | 2802 | 3126 | 3308 | 3536 | 3750 | 3952 | 4330 | 75 |
| 90 | 44.18 | | | | | | | | 3218 | 3588 | 3796 | 4062 | 4310 | 4538 | 4972 | 80 |
| 96 | 50.27 | | | | | | | | 3860 | 4082 | 4322 | 4622 | 4902 | 5168 | 5662 | 86 |
| 102 | 56.75 | | | | | | | | 4134 | 4608 | 4858 | 5214 | 5532 | 5830 | 6390 | 91 |
| 108 | 63.62 | | | | | | | | 4628 | 5168 | 5468 | 5850 | 6202 | 6538 | 7156 | 96 |
| 114 | 70.88 | | | | | | | | | 5758 | 6090 | 6514 | 6910 | 7286 | 7982 | 101 |
| 120 | 78.54 | | | | | | | | | 6382 | 6748 | 7222 | 7658 | 8074 | 8840 | 107 |
| 132 | 95.03 | | | | | | | | | 7722 | 8164 | 8736 | 9262 | 9764 | 10700 | 117 |
| 144 | 113.10 | | | | | | | | | 9192 | 9718 | 10400 | 11030 | 11622 | 12734 | 128 |

## TABLE No. 10.

| DIAM. | AREA (A) | HEIGHT OF CHIMNEY. | | | | | | | | | | | | | EQUIV. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 50′ | 60′ | 70′ | 80′ | 90′ | 100′ | 110′ | 125′ | 150′ | 175′ | 200′ | 225′ | 250′ | 300′ | Sq. Chim. |
| Inches. | Sq. Ft. | Pounds of coal burned per Hour. = 13 x G. | | | | | | | | | | | | | | Side of Sq. |
| 18 | 1.77 | 169 | 182 | 195 | 208 | | | | | | | | | | | 16″ |
| 21 | 2.41 | 221 | 247 | 260 | 273 | | | | | | | | | | | 19 |
| 24 | 3.14 | 286 | 312 | 338 | 364 | 390 | | | | | | | | | | 22 |
| 27 | 3.98 | 364 | 403 | 429 | 455 | 494 | | | | | | | | | | 24 |
| 30 | 4.91 | 455 | 494 | 533 | 572 | 611 | 637 | | | | | | | | | 27 |
| 33 | 5.94 | | 598 | 650 | 689 | 728 | 767 | 806 | | | | | | | | 30 |
| 36 | 7.07 | | 715 | 767 | 819 | 871 | 910 | 962 | 1027 | | | | | | | 32 |
| 39 | 8.30 | | | 897 | 962 | 1027 | 1079 | 1131 | 1209 | | | | | | | 35 |
| 42 | 9.62 | | | 1053 | 1128 | 1183 | 1248 | 1326 | 1404 | 1560 | | | | | | 38 |
| 48 | 12.57 | | | | 1453 | 1547 | 1638 | 1716 | 1833 | 2041 | | | | | | 43 |
| 54 | 15.90 | | | | | 1963 | 2067 | 2171 | 2314 | 2587 | 2730 | | | | | 48 |
| 60 | 19.64 | | | | | 2418 | 2548 | 2678 | 2860 | 3198 | 3380 | | | | | 54 |
| 66 | 23.76 | | | | | | 3094 | 3237 | 3458 | 3861 | 4082 | 4368 | | | | 59 |
| 72 | 28.27 | | | | | | 3679 | 3848 | 4121 | 4589 | 4859 | 5200 | 5512 | | | 64 |
| 78 | 33.18 | | | | | | | 4524 | 4823 | 5395 | 5837 | 6097 | 6474 | 6825 | | 70 |
| 84 | 38.48 | | | | | | | 5239 | 5603 | 6253 | 6617 | 7072 | 7501 | 7904 | 8658 | 75 |
| 90 | 44.18 | | | | | | | | 6435 | 7176 | 7592 | 8125 | 8619 | 9074 | 9945 | 80 |
| 96 | 50.27 | | | | | | | | 7319 | 8164 | 8645 | 9243 | 9802 | 10335 | 11323 | 86 |
| 102 | 56.75 | | | | | | | | 8238 | 9217 | 9737 | 10426 | 11063 | 11661 | 12779 | 91 |
| 108 | 63.62 | | | | | | | | 9256 | 10335 | 10933 | 11700 | 12402 | 13078 | 14313 | 96 |
| 114 | 70.88 | | | | | | | | | 11518 | 12181 | 13026 | 13819 | 14573 | 15964 | 101 |
| 120 | 78.54 | | | | | | | | | 12766 | 13494 | 14443 | 15314 | 16146 | 17680 | 107 |
| 132 | 95.03 | | | | | | | | | 15444 | 16328 | 17472 | 18525 | 19526 | 21398 | 117 |
| 144 | 113.10 | | | | | | | | | 18382 | 19435 | 20800 | 22061 | 23244 | 25467 | 128 |

TABLE No. 11.

| Diameter | Area (A) square feet. | HEIGHT OF CHIMNEY. 50′ | 60′ | 70′ | 80′ | 90′ | 100′ | 110′ | 125′ | 150′ | 175′ | 200′ | 225′ | 250′ | 300′ | Equivalent square chimney side of square. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | WATER-HEATING SURFACE IN BOILERS. | | | | | | | | | | | | | | |
| Inches. | | (0.3 lb. of coal per square foot of W. H. S. per hour.) | | | | | | | | | | | | | | Inches. |
| 18 | 1.77 | 563 | 607 | 650 | 693 | .... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 16 |
| 21 | 2.41 | 737 | 823 | 867 | 910 | .... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 19 |
| 24 | 3.14 | 953 | 1040 | 1127 | 1213 | 1300 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 22 |
| 27 | 3.98 | 1218 | 1343 | 1430 | 1517 | 1647 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 24 |
| 30 | 4.91 | 1517 | 1647 | 1777 | 1907 | 2037 | 2123 | .... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 27 |
| 33 | 5.94 | .... | 1993 | 2167 | 2297 | 2427 | 2557 | 2687 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 30 |
| 36 | 7.07 | ..... | 2383 | 2557 | 2730 | 2903 | 3033 | 3207 | 3428 | ..... | ..... | ..... | ..... | ..... | ..... | 32 |
| 39 | 8.30 | .... | .... | 2990 | 3207 | 3423 | 3597 | 3770 | 4030 | ..... | ..... | ..... | ..... | ..... | ..... | 35 |
| 42 | 9.62 | ..... | ..... | 3510 | 3760 | 3943 | 4160 | 4420 | 4680 | 5200 | ..... | ..... | ..... | ..... | ..... | 38 |
| 48 | 12.57 | ..... | ..... | ..... | 4853 | 5157 | 5460 | 5720 | 6110 | 6803 | ..... | ..... | ..... | ..... | ..... | 43 |
| 54 | 15.90 | .... | .... | ..... | ..... | 6545 | 6880 | 7237 | 7713 | 8623 | 9100 | ..... | ..... | ..... | ..... | 48 |
| 60 | 19.64 | .... | .... | ..... | ..... | 8060 | 8498 | 8927 | 9533 | 10660 | 11267 | ..... | ..... | ..... | ..... | 54 |
| 66 | 23.76 | ..... | ..... | ..... | ..... | ..... | 10313 | 10790 | 11527 | 12870 | 13607 | 14562 | ..... | ..... | ..... | 59 |
| 72 | 28.27 | .... | .... | ... | ..... | ..... | 12263 | 12827 | 13737 | 15297 | 16197 | 17333 | 18378 | ..... | ..... | 64 |
| 78 | 33.18 | .... | .... | ..... | ..... | ..... | ..... | 15080 | 16077 | 17983 | 19457 | 20323 | 21580 | 22750 | ..... | 70 |
| 84 | 38.48 | .... | .... | ..... | ..... | ..... | ..... | 17463 | 18677 | 20843 | 22057 | 23573 | 25003 | 26347 | 28860 | 75 |
| 90 | 44.18 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 21450 | 23920 | 25307 | 27083 | 28730 | 30247 | 33150 | 80 |
| 96 | 50.27 | .... | .... | ..... | ..... | ..... | ..... | ..... | 24397 | 27213 | 28817 | 30810 | 32673 | 34450 | 37743 | 86 |
| 102 | 56.75 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 27560 | 30757 | 32457 | 34753 | 36877 | 38871 | 42597 | 91 |
| 108 | 63.62 | .... | .... | ..... | ..... | ..... | ..... | ..... | 30853 | 34450 | 36443 | 39000 | 41340 | 43593 | 47710 | 96 |
| 114 | 70.88 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 38398 | 40603 | 43420 | 46063 | 48910 | 53213 | 101 |
| 120 | 78.54 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 42558 | 44980 | 48143 | 51047 | 53820 | 58983 | 107 |
| 132 | 95.03 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 51480 | 54427 | 58240 | 61750 | 65087 | 71327 | 117 |
| 144 | 113.10 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 61278 | 64783 | 69333 | 73537 | 77480 | 84890 | 128 |



This table has been calculated by D. K. Clark's rules.

TABLE No. 12.

| Height. | Diameter of Flue. | Top sectional area of flue in feet. | | Coal per hour. | Area of grate. |
|---|---|---|---|---|---|
| | | Area. | Per lb. coal per hour. | | |
| Feet. | Inches. | | | Pounds. | Square feet. |
| 40 | 16 | 1.39 | 1.41 | 142 | 9.5 |
| 45 | 18 | 1.77 | 1.34 | 190 | 12 7 |
| 50 | 20 | 2.19 | 1.27 | 248 | 16.5 |
| 55 | 22 | 2.63 | 1.21 | 314 | 20.9 |
| 60 | 24 | 3.14 | 1.16 | 390 | 26.0 |
| 65 | 26 | 3.69 | 1.11 | 477 | 31.7 |
| 70 | 28 | 4.26 | 1.07 | 574 | 38.3 |
| 75 | 30 | 4.91 | 1.04 | 682 | 45.5 |
| 80 | 32 | 5.60 | 1.00 | 801 | 53 4 |
| 85 | 34 | 6 29 | .97 | 932 | 62.1 |
| 90 | 36 | 7.09 | .95 | 1076 | 71.7 |
| 95 | 38 | 7.89 | .92 | 1231 | 82.1 |
| 100 | 40 | 8.71 | .90 | 1394 | 93.0 |
| 105 | 42 | 9.62 | .88 | 1582 | 105.5 |
| 110 | 44 | 10.57 | .86 | 1777 | 118.4 |
| 115 | 46 | 11.52 | .84 | 1985 | 132.3 |
| 120 | 48 | 12.86 | .82 | 2208 | 147.2 |
| 125 | 50 | 13 65 | .80 | 2446 | 163.1 |
| 130 | 52 | 14.73 | .79 | 2698 | 179.8 |
| 135 | 54 | 15 90 | .77 | 2964 | 197.6 |
| 140 | 56 | 17.12 | .76 | 3247 | 216.4 |
| 145 | 58 | 18.32 | .74 | 3544 | 236.2 |
| 150 | 60 | 19.63 | .73 | 3858 | 257.2 |
| 155 | 62 | 20.99 | .72 | 4187 | 279.1 |
| 160 | 64 | 22.31 | .71 | 4533 | 302.3 |
| 165 | 66 | 23.76 | .70 | 4896 | 326.4 |
| 170 | 68 | 25.24 | .69 | 5275 | 351.6 |
| 175 | 70 | 26.69 | .68 | 5672 | 378 1 |
| 180 | 72 | 28.27 | .67 | 6086 | 405.7 |
| 185 | 74 | 29.90 | .66 | 6517 | 434 5 |
| 190 | 76 | 31.47 | .65 | 6967 | 464.5 |
| 195 | 78 | 33.18 | .64 | 7434 | 495.6 |
| 200 | 80 | 34.94 | .63 | 7920 | 526.6 |

### RATE OF COMBUSTION DUE TO HEIGHT OF CHIMNEY.

Trowbridge's "Heat and Heat Engines" gives the following table showing the heights of chimneys for producing certain rates of combustion per square foot of section of the chimney-flue. It is best adapted to chimneys where a good grade of large-sized anthracite coal is used.

TABLE No. 13.

| Height of chimney in feet. | Lbs. of coal burned per hour per square foot of section of chimney flue. | Lbs. of coal burned per square foot of grate, the ratio of grate area to chimney flue area being 8 to 1. | Height of chimney in feet. | Lbs. of coal burned per hour per square foot of section of chimney flue. | Lbs. of coal burned per square foot of grate, the ratio of grate area to chimney flue area being 8 to 1. |
|---|---|---|---|---|---|
| 20 | 60 | 7.5 | 70 | 126 | 15.8 |
| 25 | 68 | 8.5 | 75 | 131 | 16.4 |
| 30 | 76 | 9.5 | 80 | 135 | 16.9 |
| 35 | 84 | 10.5 | 85 | 139 | 17.4 |
| 40 | 93 | 11.6 | 90 | 144 | 18.0 |
| 45 | 99 | 12.4 | 95 | 148 | 18.5 |
| 50 | 105 | 13.1 | 100 | 152 | 19.0 |
| 55 | 111 | 13.8 | 105 | 156 | 19.5 |
| 60 | 116 | 14.5 | 110 | 160 | 20.0 |
| 65 | 121 | 15.1 | ..... | ..... | ..... |

Dr. R. H. Thurston's rule for the rate of combustion for a given height of chimney (Trans. A. S. M. E., vol. xi., p. 991) is: Subtract one from twice the square root of the height, and the result is the rate of combustion in pounds per square foot of grate per hour, for anthracite coal; or rate $= 2\sqrt{H} - 1$, in which $H$ is the height of chimney in feet.

This rule gives the following table:

| $H =$ | 50 | 60 | 70 | 80 | 90 | 100 | 110 | 125 | 150 | 175 | 200 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $2\sqrt{H} - 1 =$ | 13.14 | 14.49 | 15.73 | 16.89 | 17.97 | 19 | 19.97 | 21.36 | 23.49 | 25.45 | 27.28 |

The results agree closely with Trowbridge's table given above. In practice, however, the high rates of combustion for high chimneys given by the formulæ are seldom obtained, for the reason that with high chimneys there are long horizontal flues, serving many boilers, and the friction and interference of the currents of gases from the different boilers diminish the intensity of the draft at the boiler from what it was at the chimney.

In a battery of several boilers connected to a chimney 150 feet in height there has been found $\frac{3}{4}$ inch of water draft at the boiler nearest the chimney, and only $\frac{1}{4}$ inch at the boiler farthest from it.

The first boiler was wasting fuel from an excessive temperature of the chimney gases, 900° Fahr., having too large a



grate surface for the draft, and the last boiler was working below its capacity, and with poor economy, on account of poor draft.

Theron Skeel gives the following relative amounts of coal that can be burned in the same time with chimneys of various heights:

| Height in feet | 120 | 100 | 80 | 60 | 40 | 20 |
|---|---|---|---|---|---|---|
| Relative amount of fuel | 100 | 90 | 80 | 70 | 57 | 40 |

J. J. DeKinder finds the best results to be obtained by using chimneys of the following heights:

75 feet for free-burning bituminous coal.
100 feet for free-burning bituminous slack.
115 feet for slow-burning bituminous coal.
125 feet for anthracite pea coal.
150 feet for anthracite buckwheat coal.

with a draft for anthracite coal of 0.75 to 0.88 inch of water.

This agrees with the conclusions of Emery and Hague.

### AIR-SPACE IN GRATES.

The successful performance of a chimney depends upon very many local conditions, among which, and very important, is the amount of air supplied to the burning fuel and allowed to pass through it.

The following list gives the proper size of air-space and thickness of metal in the bar for different fuels.

$\frac{1}{4}$-inch opening and $\frac{3}{8}$-inch iron for screenings.
$\frac{3}{8}$-inch opening and $\frac{3}{8}$-inch iron for buckwheat coal.
$\frac{1}{2}$-inch opening and $\frac{1}{2}$-inch iron for nut or pea coal.
$\frac{5}{8}$-inch opening and $\frac{1}{2}$-inch iron for stove coal.
$\frac{3}{4}$-inch opening and $\frac{1}{2}$-inch iron for egg coal.
$\frac{7}{8}$-inch opening and $\frac{1}{2}$-inch iron for broken coal.
1-inch opening and $\frac{1}{2}$-inch iron for lump coal.
$\frac{1}{4}$-inch opening and $\frac{3}{8}$-inch iron for sawdust.
$\frac{3}{8}$-inch opening and $\frac{3}{8}$-inch iron for sawdust.
$\frac{1}{2}$-inch opening and $\frac{1}{2}$-inch iron for shavings.
$\frac{5}{8}$-inch opening and $\frac{1}{2}$-inch iron for shavings.

For bituminous coal, $\frac{5}{8}$ or $\frac{3}{4}$-inch opening and $\frac{1}{2}$-inch iron.

### VOLUME OF AIR PASSING THROUGH CHIMNEY.

According to Professor H. B. Gale, the velocity for maximum draft in chimneys is between six and fourteen feet per second, depending on the height of the chimney and temperature of the escaping gases; in brick-stacks it sometimes is as low a rate as three feet per second. The exact rate at which the best draft is produced depends on so many variables, such as flue temperatures, grate air-space, kind of conditions of fuel, etc., that it is probably not the same in any two chimneys or power plants.

### VELOCITY OF GASES.

Lang recommends "for velocity of chimney gases, $V_n$, 13.12 feet per second; in sheltered locations 9.84 feet per second.

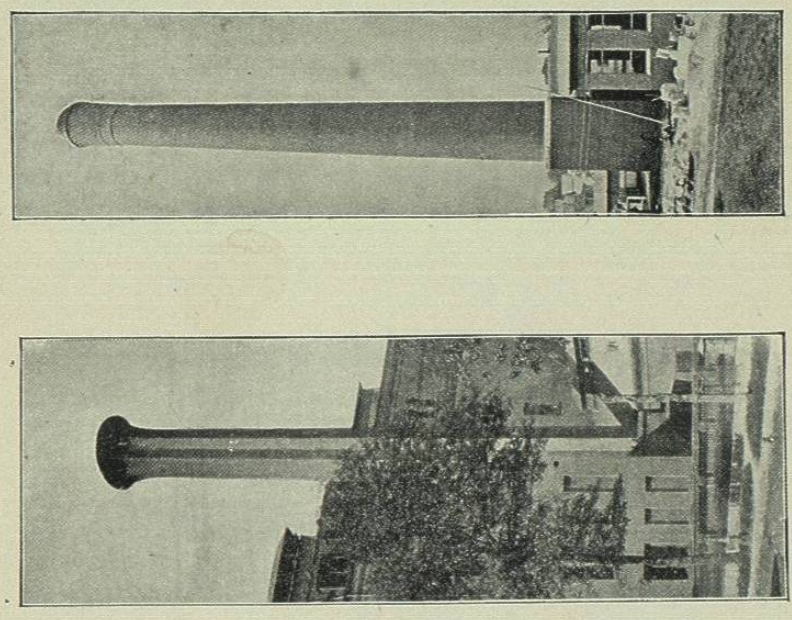
If prevailing winds come over steep mountains and fall on the top of the chimney, then $V_n$ must be correspondingly increased from 19.68 to 22.96 feet per second; or the top of the chimney must be provided with proper covers for such unfavorable directions (wind caps, etc.).

With good wind caps $V_n$ may be reduced from 4.92 to 5.65 feet a second.

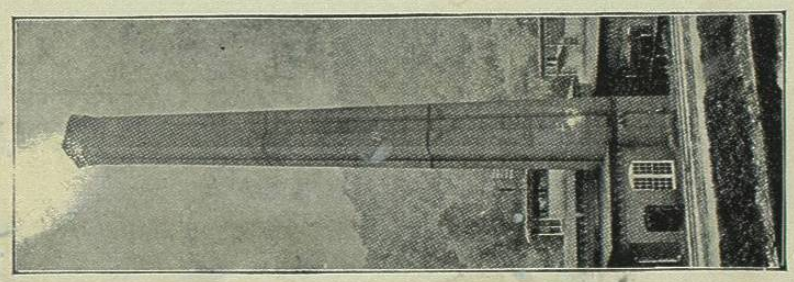
Wind caps, on account of their dangerous position, are only recommended in exceptional cases.

If a number of boiler-furnaces discharge their gases in one and the same chimney, then $V_n$ must be increased for the full working number, so that in case there are less than the whole number of boilers under fire a sufficient exhaust velocity of the gases will still be obtained. In place of the average value of $V_n = 13.12$ feet per second; the following values may be substituted:

For 3 boilers, $V_n = 16.40$ ft. per sec. = 984.0 ft. per minute.
" 7 " $V_n = 19.68$ " " = 1180.8 " "
" 12 " $V_n = 22.96$ " " = 1377.6 " "
" more, $12 + X$ boilers, $V_n = 22.96 + \frac{X \times 3.28}{20}$ ft. a second.



ILLUS. No. 2.
THREE BRICK CHIMNEYS.





### WIND-PRESSURE.

The scale of the Smithsonian Institution at Washington for the estimation and description of the velocity and pressure of the wind, calculated by Smeaton's Rule, is as follows:

Divide the square of the velocity in miles per hour by 200; the quotient is the pressure in pounds per square foot.

TABLE No. 14.

| Grade. | Velocity in miles per hour. | Pressure per square foot in lbs. | Name. |
|---|---|---|---|
| 0 | 0 | 0.0 | Calm. |
| 1 | 2 | 0.02 | Very light breeze. |
| 2 | 4 | 0.08 | Gentle breeze. |
| 3 | 12 | 0.75 | Fresh wind. |
| 4 | 25 | 3.00 | Strong wind. |
| | 30 | 4.50 | |
| 5 | 35 | 6.00 | High wind. |
| | 40 | 8.00 | |
| 6 | 45 | 10.00 | Gale. |
| | 50 | 12.5 | |
| 7 | 60 | 18.00 | Strong gale. |
| 8 | 75 | 28.2 | Violent gale. |
| | 80 | 32.00 | |
| 9 | 90 | 40.5 | Hurricane. |
| 10 | 100 | 50.00 | Most violent hurricane. |

In the United States the general practice is to assume fifty pounds wind-pressure per square foot as the highest to be considered.

No record of such a high pressure has been heard of, or is likely to be, except in the extreme hurricane, with cyclonic conditions present, as in the East St. Louis, Mo., tornado of 1896, when the brick chimney of the Electric Light Station was partially destroyed and blown down.

From calculations made since the occurrence, the force of the wind must have been about ninety pounds per square foot.

During the Galveston, Tex., tornado of September, 1900, the barometer dropped to 27.3 inches, and the velocity of the wind was reported by a United States Engineer to have been as high as 100 miles per hour.

The *Engineer*, London, says: the pressure of the wind on plane surfaces has been found by experiments to be approximately:

$$q = \frac{v^2}{430} \cos i.$$

$v$ = velocity of wind in feet per second.
$i$ = angle between the normal to the plane and the direction of the wind.
$q$ = pressure in pounds per square foot of plane.

The above, of course, does not apply to curved surfaces.

## CHAPTER V

### FOUNDATION MATERIALS. BRICK CHIMNEY MATERIALS

Logically and from an engineering stand-point, the first detail of chimney construction is the foundation.

Before considering this topic, a brief statement of the qualities and strengths of various soils, with reference to their ability to support foundations, is requisite.

#### BEARING POWER OF SOILS.

The building laws of New York City allow 4 tons per square foot as a safe load for "good solid natural earth."

The laws of Chicago specify 1¾ tons for pure clay, fifteen feet or more thick; 2 tons for pure dry sand, fifteen feet or more thick; and 1½ tons for a mixture of clay and sand of the same depth.

Ordinary practice gives the following:

200 tons per square foot for solid bed rock.

5 to 25 tons per square foot for rock broken, but well compacted.

4 tons per square foot for pure clay fifteen feet or more thick.

1 ton per square foot for soft wet clay.

8 tons per square foot for gravel well packed and confined.

4 tons per square foot for pure dry sand well packed and confined.

2 tons per square foot for pure dry sand in its natural bed.

½ ton per square foot for quicksands and marshy soils.

#### PILING.

Piling must be resorted to when the soil is very sandy or loose.