CHIMNEY DESIGN AND THEORY

CHAPTER I

INTRODUCTION AND HISTORY

INTRODUCTORY

The most prominent feature to the world at large, of every steam or power plant, and that by which the manufacturing character of a village or city is most easily distinguished, is the chimney.

It is an engineering work which is often given but little thought, so far as the proper size and proportions for the best results are concerned, by those for whom it is to be built.

Nothing in a steam plant is so conducive to great waste of fuel as a badly designed chimney; and it may be made the means of assisting or increasing a high efficiency in the plant, if properly proportioned for the quantity of gases which is to be passed through it.

Chimneys are built of brick, or steel, or stone; steel chimneys being sometimes stayed or guyed with iron rods or wire rope, and sometimes built self-sustaining; in all cases chimneys are set on heavy masonry foundations.

In the following pages the adjuncts and various types of chimneys will be treated separately.

Historical Notes.

According to Tomlinson, chimneys were probably in use in England before those of Padua, of which the earliest record is the year 1368, when Carrara, Lord of Padua, introduced them in Rome.

The use of the curfew-bell in preceding centuries indicates their absence, as the ringing of the bell was the signal to cover the fires (couvre-few), which were made in pits, for the night.

In Venice, chimneys were common in the fourteenth century, a number being overthrown by the earthquake of January 25, 1347.

Of the nations of antiquity little in this direction is known.

No traces of chimneys have been found in the ruins of Pompeii or Herculaneum.

Charcoal has been found, it being used, no doubt, in the portable furnaces discovered in the rooms.

Roman houses were frequently heated by means of hot air, which was brought in pipes from a furnace below.

In the dwellings of the Greeks there were no chimneys, the smoke escaping through a hole in the roof.

The Persians still retain their ancient custom of making fires in a hole in their earthen floors, in an iron vessel, and thus heat their apartments, which plan is said to give very satisfactory results. A low table is placed over the heater, with a thick quilted cloth reaching to the floor, and no provision is made for the escape of the products of combustion.

There is no evidence of chimney-shafts in England earlier than the twelfth century.

Leland, speaking of Bolton Castle, says, " . . . was fyniched or Kynge Richard the 2 dyed . . . one thynge I much notyed in the hawle of Bolton, how chimneys were conveyed by tunnells made in the syds of the walls betwixt the lights in the hawle, and by this means, and by no covers, is the smoke of the harthe in the hawle wonder strangely conveyed."

For centuries afterward chimneys remained luxuries for the houses of the great.

At the beginning of the sixteenth century, chimneys were almost unknown; the fire was kindled against a hob of clay called the *rere dosse*, in the back or centre of the room, which was filled with smoke, from the wood (which was the only fuel used), that found its way out by an opening or lantern in the roof.

The houses built at Amboy, N. J., in 1683 are described usually thirty feet long, sixteen feet wide, ten feet between joints, with double chimneys of timber and clay, "as the manner of this country is to build," and cost about fifty pounds each ($250).

The chimney in its present sense of a funnel from the hearth or fireplace to the roof of the house, is a modern invention.

In 1785, Mr. Watt procured a patent for obviating the smoke of steam-engines by placing the coal in an upright conical tube or hopper fixed in the brickwork of the boiler, immediately behind the furnace door, and causing a stream of air to rush through the furnace door for maintaining combustion.

In Mr. John Bourne's "Treatise on the Steam-engine," p. 51, he shows a boiler and furnace designed by John Smith, of Kingston near Dublin, which has a vertical chimney, designed probably about 1825.

Rev. D. Lardner, "The Steam-engine," p. 128, speaks of the gases passing about the boiler and in immediate contact with it, and finally issuing into the chimney; but he says nothing about the design of the chimney.

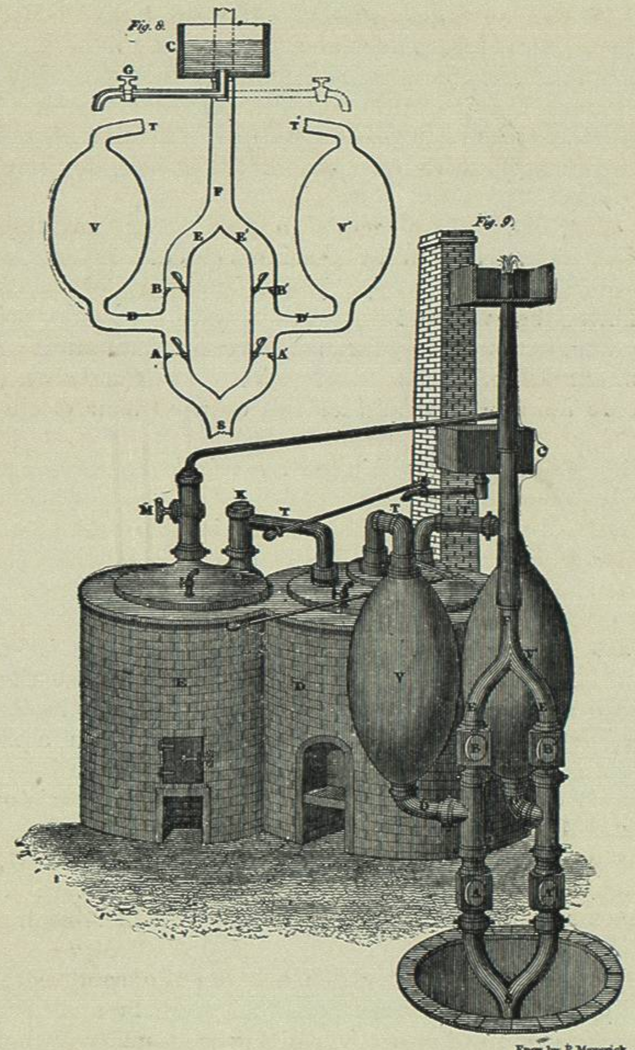
In the same book, in an illustration of Savery's steam-engine, 1702, a brick chimney is shown. This is also the first illustration in Dr. R. H. Thurston's "Growth of the Steam-engine," of a chimney-shaft in connection with a steam-boiler.

The following is abstracted from Bishop's "History of American Manufactures":

Gawen Lawrie, settler of East New Jersey in 1684, says "the country farm-houses they build very cheap, . . . the chimneys are stone." Bricks were used by some.—Volume I., page 226.

"Stone and bricks, of which last ten thousand were sent from London to Massachusetts in 1629, were first used in the construction of the fireplaces, which were usually of the most ample dimensions."—Volume II., page 219.

"In 1789 the first steam-engine for cotton spinning was



ILLUS. No. 1.

SAVERY'S STEAM ENGINE AND BOILER, 1702.

From "The Steam Engine," by Rev. Dionysius Lardner, LL.D., F.R.S.

erected at Manchester, England." It must have been used with a boiler and chimney.—Volume II., page 19.

"Rooseveldt, in connection with James Sullivan, took out a U. S. Patent, May 31, 1798, for a double steam-engine, and soon after constructed probably the first effective steam-engine, after those of Fitch, ever built in America."—Volume II., page 80.

"He completed one in 1800, with a wooden boiler, through which long cylindrical flues, or heaters, wound several times before entering the chimney." It was for the use of the Philadelphia, Pa., Water-works.

A great many chimneys having but one thickness of brick, and the exterior bonded together with hoop-iron bands, were erected at the Potteries during the years 1847–1867 by Mr. Scrivenor, of Hawley, England.

CHAPTER II

THEORY OF CHIMNEY-DRAFT

FURNACE or chimney-draft is produced by one of the following methods:

I. By a natural draft due to the unbalanced pressure of a column of heated gases against a heavier column of outside air.

II. By the use of a steam-jet in the chimney, inducing draft, using either live or exhaust steam from the engine.

III. By a forced draft from a steam blower in the furnace of a boiler setting or a fan feeding through pipes to the furnace.

IV. By induced draft from blowers placed between boiler setting and chimney flue, blowers being usually placed at the base of the chimney.

What follows is abstracted from a paper by Professor De-Volson Wood, in the Transactions of the American Society of Mechanical Engineers, Vol. XI.

Peclet's and Rankine's hypotheses are :

1. A certain amount of air must pass through the grate and the body of the coal on the grate to secure combustion.

2. Since the openings for the admission of air are fixed mechanically the requisite amount of air must be supplied at a definite velocity.

3. The required velocity may be produced by the pressure of a column of atmospheric air, which pressure will be the difference of the pressure of the external air and that within the furnace. The height of such a column is called a "head."

4. That, to the head described in the preceding condition, a head must be added sufficient to overcome the resistance offered by the coal to the passage of the air through it; and

another head for the resistance offered by the flues and chimney to the passage of the gases produced by combustion.

The law representing these conditions is given in the form of an equation by Peclet thus:

$$(1)\quad h=\frac{u^2}{2g}\left(1+G+\frac{fl}{m}\right),$$

in which

u is the required velocity of gases *in the chimney*,

G, a constant to represent the resistance to the passage of air through the coal,

l, the length of the flues and chimney,

m, the mean hydraulic depth or the area of a cross-section divided by the perimeter,

f, a constant depending upon the nature of the surfaces over which the gases pass, whether smooth, or sooty and rough.

If now

A, be the section of the chimney in square feet,

H, the height of the chimney in feet,

$\tau_0 = 461°$ Fahr., absolute (temperature of melting ice),

τ_1, the temperature of the gases in the chimney, absolute,

V_0, the volume of air at the temperature 32° Fahr., supplied per pound of fuel burned on the grate,

w, the pounds of fuel burned *per second*,

n, the ratio of grate area to that of the chimney area,

S, the area of the grate ;

then $$(2)\quad wV_0\frac{\tau_1}{\tau_0} = uA = nuS.$$

The pounds of coal or fuel burned per square foot of grate per hour will be

$$(3)\quad 3600\frac{w}{S} = 3600\frac{nu}{V_0}\cdot\frac{\tau_0}{\tau_1}.$$

Peclet found that when 20 to 24 pounds of coal is burned per hour, the value of G is about 12, and f, for sooty surfaces, equals 0.012.

Professor Wood has assumed 12 for G, except when 16 pounds is burned, when 11 is used.

Neglecting the length of the flue, let $f = 0.015$. Then for square or round chimneys, in which b is the breadth or diameter, we have

$$(4)\quad h = \frac{V_0^2}{2g}\left(\frac{w}{A}\right)^2\left(\frac{\tau_1}{\tau_2}\right)^2\left(13 + \frac{0.060bH}{A}\right).$$

Rankine's determination of the height was for the purpose of deducing the head h. His hypotheses are:

1. The gases in the chimney are uniformly hot;
2. The gases move in parallel sections through the chimney;
3. The density of the gases in the chimney is uniform, and does not differ sensibly from that of air at the same temperature and pressure; in other words, it is assumed that the density varies with the temperature only, the variation of pressure being neglected in determining the density.
4. "The head producing the draft in the chimney is equivalent to the excess of the weight of a vertical column of cool air outside the chimney, and of the same height, above that of a vertical column of equal base of the hot gases within the chimney."
5. That the draft is a maximum when the *weight* of gases discharged is the greatest.

The fourth hypothesis is improperly defined, since the head is defined as a weight, whereas it is a height in feet. Professor Wood defines it as such a height of hot gases as, if added to the column of gases in the chimney, would produce the same pressure at the furnace as a column of outside air, of the same area of base, and a height equal to that of the chimney.

If 24 pounds of air be supplied per pound of fuel the volume of the gaseous product will be $24 \times 12\frac{1}{2} = 300$ cubic feet (nearly), and one cubic foot will weigh $\frac{1}{300} = 0.0033$ of a pound at 32° Fahr., which, added to the weight of a cubic foot of air at 32° Fahr., gives $0.0807 + 0.0033 = 0.084$ of a pound; and if τ_2 be the temperature of the external air, we have at once from the fourth principle as amended,

$$(5)\quad h = \frac{\frac{\tau_0}{\tau_2}(0.0807)}{\frac{\tau_0}{\tau_1}(0.084)}H - H = \left(0.96\frac{\tau_1}{\tau_2} - 1\right)H;$$

which is the formula given by Rankine. From this we find

$$(6)\quad H = \frac{13\frac{V_0^2}{2g}\left(\frac{w}{n\delta}\right)^2\left(\frac{\tau_1}{\tau_0}\right)^2}{0.96\frac{\tau_1}{\tau_2} - 1 - \frac{0.06b}{2gA}\left(V_0^2\frac{w}{n\delta}\frac{\tau_1}{\tau_0}\right)^2}.$$

This gives the height of chimney for burning w pounds of coal per second.

If δ be the weight of a cubic foot of the gases in the chimney, and

N, the number of pounds of air required per pound of coal (about 24 pounds), then will the weight of gases passed up the chimney be

$$(7)\quad 2\delta V_o\frac{\tau_1}{\tau_o}\delta = 0.0807Nw \text{ nearly};\qquad \therefore \delta = \frac{0.0807N\tau_o}{V_o\tau_1}.$$

The weight per second will also be δ times the volume, or $Au\delta$; hence

$$(8)\quad Au\delta = \frac{0.0807N\tau_oA\sqrt{2gH}\sqrt{0.96\frac{\tau_1}{\tau_2} - 1}}{V_o\tau_1\left(1 + G + \frac{0.06bH}{A}\right)}.$$

Observing that $N \div V_o$ will be constant, this expression will be a maximum for a given chimney when the function

$$(9)\quad \frac{\sqrt{0.96\frac{\tau}{\tau_2} - 1}}{\tau\left(1 + G + \frac{0.06bH}{A}\right)}$$

is a maximum. If G be a variable, the maximum cannot be found unless it be a known function of the temperature. Little, however, is known of its value in special cases, and the law of variation cannot be assigned. If it be considered constant, as in the assumptions of Peclet and Rankine, the function for a maximum reduces to

$$\frac{0.96\tau - \tau_2}{\tau_2},$$

which is the function considered by Rankine, and gives

$\tau = 2\frac{1}{12}\tau_2$, a maximum ; and if the temperature of the external air be 60°, then will the temperature of the gases be 622°.

From the foregoing rules Professor Wood has calculated the following table :

TABLE No. 1.

SHOWING THE HEIGHTS OF CHIMNEY AND CORRESPONDING HEADS FOR BURNING GIVEN AMOUNTS OF COAL.

τ_2	τ_1 Absolute.	24 lbs. coal per sq. ft. grate area.		20 lbs. coal per sq. ft. grate area.		16 lbs. coal per sq. ft. grate area.	
		Head, h ft.	Height, H ft.	Head, h ft.	Height, H ft.	Head, h ft.	Height, H ft.
520° Absolute or 59° Fahr.	600	128.001	1207.57	52.76	497.73	14.02	132.33
	700	72.75	250.87	45.70	157.61	19.65	67.76
	800	82.76	172.42	55.58	115.80	26.71	55.66
	1000	125.22	149.08	83.97	99.97	40.89	48.68
	1100	153.22	148.76	101.87	98.91	49.61	48.17
	1200	182.34	151.97	121.03	100.86	58.87	49.06
	1400	252.51	159.86	161.92	105.65	80.89	51.20
	1600	334.38	168.83	219.68	110.95	105.96	53.52
	2000	555.53	206.52	355.61	132.20	169.47	63.007

It will be seen that the required heads equal the height of the chimney when the temperature in the chimney-flue is about 620° Fahr., the external air being assumed to be 60° Fahr.

The many different conditions found in the United States, and the complexity of the above equations, prevent their use to any great extent.

Those who wish to investigate more thoroughly the theory of chimney-draft will find material in the Trans. A. S. M. E., Vol. XI.

D. K. Clark deduces the following formula for force of draft in inches of water :

$$(10) \quad w = H\left(.0146 - \frac{7.66}{T'}\right).$$

w = force of draft in inches of water.
H = height of chimney in feet.
T' = absolute temperature, Fahr., of hot gases in chimney.
If H = 135 feet, and $T' = 550° + 461° = 1011°$ then,

$$(11) \quad w = 135\left(.0146 - \frac{7.66}{1011}\right) = 0.945 \text{ inch.}$$

Force of Intensity of Draft.—In this particular case 0.88 inch draft has been observed. The force of the draft is equal to the difference between the weight of the column of hot gases inside of the chimney and the weight of a column of the external air of the same height. It is measured by a draft-gauge, usually a U-tube partly filled with water, one leg connected by a pipe to the interior of the flue, and the other open to the external air.

If D is the density of air outside, d the density of the hot gas inside, in pounds per cubic foot, H the height of the chimney in feet, and .192 the factor for converting pressure in pounds per square foot into inches of water column, then the formula for the force of draft expressed in inches of water is

$$(12) \quad F = .192H(D - d).$$

The density varies with the absolute temperature (see Rankine),

$$(13) \quad d = \frac{\tau_0}{\tau_1} 0.085 \text{; see foot-note.}$$

$$(14) \quad D = 0.0807\frac{\tau_0}{\tau_2};$$

where τ_0 is the absolute temperature at 32° Fahr., = 493°, τ_1 the absolute temperature of the chimney gases, and τ_2 that of the external air.

F. R. Low, in *Power*, February, 1900, says: The weight per cubic foot of chimney gas will vary with its composition.

Carbon dioxide is heavier than air, nitrogen and aqueous vapor is lighter; so it is easily seen that the density of the gases will depend upon the proportion of carbon and hydrogen which is being burned and with the excess of air used. For ordinary fuel and 19 pounds of air to one of combustible (20 pounds of gas) the gas will weigh .085 * pounds per cubic foot at 32° Fahr.

Substituting 13 and 14 in equation 12 the formula for force of draft becomes

$$(15) \quad F = .192H\left(\frac{39.79}{\tau_2} - \frac{41.41}{\tau_1}\right) = H\left(\frac{7.64}{\tau_2} - \frac{7.95}{\tau_1}\right),$$

or knowing the force of draft in inches of water it becomes, for obtaining the height of a chimney,

* Rankine, "Steam Engine," gives this decimal as varying from 0.084 to 0.087.

$$(15\text{ A.})\quad H=\frac{F}{\frac{7.64}{T_2}-\frac{7.95}{T_1}}$$

To find the maximum intensity of draft for any given chimney, the heated column being at 600° Fahr., and the external air at 60° Fahr., multiply the height above grate in feet by .0073, and the product is the draft in inches of water.

TABLE No. 1a.

DENSITY OR WEIGHT PER CUBIC FOOT OF AIR, BY FORMULA 14.

t	*D*
0	.086355
5	.085424
10	.084514
15	.083623
20	.082750
25	.081895
30	.081058
32	.080728
35	.080238
40	.079434
45	.078646
50	.077874
55	.077117
60	.076374
65	.075645
70	.074930
75	.074229
80	.073541
85	.072865
90	.072201
95	.071550
100	.070910

TABLE No. 1b.

DENSITY OR WEIGHT PER CUBIC FOOT OF CHIMNEY GAS, BY FORMULA 13.

t	*d*	*t*	*d*	*t*	*d*
200	.063335	430	.046952	660	.037302
210	.062389	440	.046429	670	.036972
220	.061470	450	.045919	680	.036647
230	.060578	460	.045419	690	.036328
240	.059711	470	.044930	700	.036015
250	.058869	480	044451	710	.035707
260	.058051	490	.043983	720	.035404
270	.057255	500	.043525	730	.035106
280	.056480	510	.043076	740	.034814
290	.055726	520	.042636	750	.034526
300	.054992	530	.042205	760	.034242
310	.054277	540	.041782	770	.033964
320	.053580	550	.041368	780	.033690
330	.052901	560	.040962	790	.033420
340	.052239	570	.040564	800	.033155
350	.051594	580	.040174	900	.030715
360	.050964	590	.039791	1000	.028610
370	.050349	600	.039415	1100	.026775
380	.049750	610	.039047	1200	.025161
390	.049163	620	.038685	1300	.023731
400	.048591	630	.038330	1400	.022455
410	.048032	640	.037981	1500	.021308
420	.047486	650	.037639	1800	.018479
				2000	.016976

—F. R. Low, *Power*, 1900.

The readings of all draft-gauges will vary somewhat from the figures in Table No. 2, as the same condition of variation in temperature from bottom to top exists to a greater or less extent in all chimneys.

For any other height of chimney than 100 feet, the height of water-column is found by simple proportion, the height of the water column being directly proportional to the height of the chimney.

The calculations have been made for a chimney 100 feet

high, with various temperatures outside and inside of the flue, and on the supposition that the temperature of the chimney is uniform from top to bottom.

TABLE No. 2.

HEIGHT OF WATER-COLUMN DUE TO UNBALANCED PRESSURE IN CHIMNEY 100 FEET HIGH.

Temperature in the chimney.	Temperature of external air.—Barometer 14.7.										
	0	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°
200	.453	.419	.384	.353	.321	.292	.263	.234	.209	.182	.157
210	.470	.436	.401	.371	.338	.309	.280	.251	.227	.200	.175
220	.488	.453	.419	.388	.355	.326	.298	.269	.244	.217	.192
230	.505	.470	.436	.405	.372	.344	.315	.286	.261	.234	.209
240	.520	.488	.451	.421	.388	.359	.330	.301	.276	.250	.225
250	.537	.503	.468	.438	.405	.376	.347	.319	.294	.267	.242
260	.555	.528	.484	.453	.420	.392	.363	.334	.309	.282	.257
270	.568	.534	.499	.468	.436	.407	.378	.349	.324	.298	.273
280	.584	.549	.515	.482	.451	.422	.394	.365	.340	.313	.288
290	.597	.563	.528	.497	.465	.436	.407	.379	.353	.326	.301
300	.611	.576	.541	.511	.478	.449	.420	.392	.367	.340	.315
310	.624	.589	.555	.524	.492	.463	.434	.405	.380	.353	.328
320	.637	.603	.568	.538	.505	.476	.447	.419	.394	.367	.342
330	.651	.616	.582	.551	.518	.489	.461	.432	.407	.380	.355
340	.662	.638	.593	.563	.530	.501	.472	.443	.419	.392	.367
350	.676	.641	.607	.576	.543	.514	.486	.457	.432	.405	.380
360	.687	.653	.618	.588	.555	.526	.497	.468	.444	.417	.392
370	.699	.664	.630	.599	.566	.538	.509	.480	.455	.428	.403
380	.710	.676	.641	.611	.578	.549	.520	.492	.467	.440	.415
390	.722	.687	.652	.622	.589	.561	.532	.503	.478	.451	.426
400	.732	.697	.662	.632	.598	.570	.541	.513	.488	.461	.436
410	.743	.708	.674	.643	.610	.583	.553	.524	.499	.472	.447
420	.753	.718	.684	.653	.620	.591	.563	.534	.509	.482	.457
430	.764	.730	.695	.664	.632	.602	.574	.545	.520	.493	.468
440	.774	.739	.705	.674	.641	.612	.584	.555	.530	.503	.478
450	.783	.749	.714	.684	.651	.622	.593	.564	.540	.513	.488
460	.793	.758	.724	.694	.660	.632	.603	.574	.549	.522	.497
470	.802	.768	.733	.703	.670	.641	.612	.584	.559	.532	.507
480	.810	.776	.741	.710	.678	.649	.620	.591	.566	.540	.515
490	.820	.785	.751	.720	.687	.659	.630	.601	.576	.549	.524
500	.829	.791	.760	.730	.697	.669	.639	.610	.586	.559	.534

This is the basis on which all calculations respecting the draft-power of chimneys have been made by Rankine and others, but it is very far from the truth in most cases.

The difference will be shown by comparing the reading of the draft-gauge with the table given. In one case a chimney 122 feet high showed a flue temperature at the base of 320° Fahr., and at the top 230° Fahr., while the table considers the temperature uniform.

Box gives this table: internal air at 552° Fahr., external air at 62° Fahr.; damper nearly closed.

TABLE No. 3.

DRAFT-POWERS OF CHIMNEYS.

Height of chimney—feet.	Draft in inches of water.	Theoretical velocity—feet per second.	
		Cold air entering.	Hot air at exit.
10	.073	17.8	35.6
20	.146	25.3	50.6
30	.219	31.0	62.0
40	.292	35.7	71.4
50	.365	40.0	80.0
60	.438	43.8	87.6
70	.511	47.3	94.6
80	.585	50.6	101.2
90	.657	53.7	107.4
100	.730	56.5	113.0
120	.876	62.0	124.0
150	1.095	69.3	138.6
175	1.277	74.3	148.6
200	1.460	80.0	160.0

TABLE No. 4.

VOLUME, DENSITY, AND PRESSURE OF AIR AT VARIOUS TEMPERATURES.

Fahr.	Volume at atmos. pressure.		Density lbs. per cubic foot at atmos. pressure.	Pressure at constant volume.	
	Cubic ft. in 1 lb.	Comparative volume.		Lbs. per sq. in.	Comparative pressure.
0	11.583	.881	.086331	12.96	.881
32	12.387	.943	.080728	13.86	.943
40	12.586	.958	.079439	14.08	.958
50	12.840	.977	.077884	14.36	.977
62	13.141	1.000	.076097	14.70	1.000
70	13.342	1.015	.074950	14.92	1.015
80	13.593	1.034	.073565	15.21	1.034
90	13.845	1.054	.072230	15.49	1.054
100	14.096	1.073	.070942	15.77	1.073
110	14.344	1.092	.069721	16.05	1.092
120	14.592	1.111	.068500	16.33	1.111
130	14.846	1.130	.067361	16.61	1.130
140	15.100	1.149	.066221	16.89	1.149
150	15.351	1.168	.065155	17 19	1.168
160	15.603	1.187	.064088	17.50	1.187
170	15.854	1.206	.063089	17.76	1.206
180	16.106	1.226	.062090	18.02	1.226
200	16.606	1.264	.060210	18.58	1.264
210	16.860	1.283	.059313	18.86	1.283
212	16.910	1.287	.059135	18.92	1.287

Widening the Top of Chimney Flue.—The effect of widening the chimney flue at the top or mouth is, according to Dubois-Weisbach, as follows: strictly speaking, according to the principles of hydraulics (Vol. I., § 425), in the formula $Q = 0.47S\sqrt{\frac{(t_1 - t)hd}{30d + 0.05h}}$ we should insert for S not the mean cross-section, but that at the mouth, hence, other things being equal, a chimney which gradually widens toward the mouth or top can discharge more gas and smoke than one which diminishes.

Q = cubic feet of gas per second.
d = diameter, in feet.
h = height in feet.
t = temperature of outer air.
t_1 = temperature of escaping gases in the flue.

From Weisbach, we find that Q is a maximum when $t_1 - t = 273°$ Cent., and we have $v = 1.32\sqrt{h}$ in feet; $S = \frac{0.76Q}{\sqrt{h}}$ in feet. If outer temperature is 32° Fahr. then gases are 555° Fahr.

Except in cases where the gases have a very high velocity, as in the locomotive chimney, the writer fails to find any advantage in widening the mouth of chimneys; in locomotive practice it has been proven, however, that the taper stack with diverging sides is the most efficient type.

Illustration No. 35 is of a chimney whose flue widens toward the top or mouth.

Pyrometers.—The high temperatures and peculiar currents of gases in the chimney make it very difficult to ascertain definitely what the temperature is. The clock-face pyrometers made for general use, and whose indications depend on the unequal expansions of metals in their stem, are not considered very reliable, particularly as the zero point is subject to change during the handling of the instrument.

The most satisfactory type of pyrometer is that in which a thermo-electric couple is made use of, but this type has not come into general use; the metal pyrometers just described being considered sufficiently accurate for commercial purposes.

CHAPTER III

CHIMNEY FORMULÆ

Professor H. B. Gale gives this handy rule, that the sectional area of the chimney in square feet should be equal to the number of pounds of fuel to be burned per minute. This would make the velocity of chimney gases betwcen 7 and 11 feet per second.*

Mr. Gale also suggests the following rules:

(17) Flue area in square feet $= A = .07\ F^{\frac{1}{2}}$

(18) Height of chimney in feet $= H = 100 \frac{K}{t}\left(\frac{F}{A}\right)^2$

where a may be considered $\frac{1}{3}$ of grate area in square feet.

K may be approximately taken as 0.2.

$F =$ pounds of fuel burned per hour.

$G =$ grate area in square feet $= 3a$.

$t =$ temperature of chimney gases.

$$(19)\quad H = \frac{180}{t}\left(\frac{F}{G}\right)^2;$$

$$(20)\quad F = \frac{a}{10}\sqrt{\frac{Ht}{K}};$$

$$(21)\quad a = 10F\sqrt{\frac{K}{Ht}};$$

which enables us to calculate the openings in the grate for the admission of air.

Professor Gale has calculated Table No. 5, the temperature of gases in a chimney being taken as 500° Fahr. The heights obtained by calculation are said to agree fairly well with American practice.

* Only for chimneys of small dimensions.

TABLE No. 5.

GALE'S CHIMNEY TABLE.

H. P.	Coal per hour, F.	Coal per sq. ft. grate, R.	Area grate, G. $\left(=\frac{F}{R}.\right)$	Area opening, a. $(=0.4\ G.)$	Height, $H = 100\frac{K}{t}\left(\frac{F}{a}\right)^2$
	lbs.	lbs.	sq. ft.	sq. ft.	ft.
20	100	13	7.7	3	44
60	300	15	20	8	56
100	500	17	30	12	70
200	1000	19	53	21	90
400	2000	21	95	38	111
600	3000	23	130	52	133
1000	5000	25	200	80	156

Chimney Rules.

Adams gives:

Chimney for one boiler: area $= \frac{1}{8}$ of fire-grate.

Chimney under 150 feet high for more than one boiler: area $= \frac{1}{10}$ fire-grate area.

Chimney over 150 feet high for more than one boiler: area $= \frac{1}{15}$ fire-grate area.

Rankine gives, "Rules and Tables," p. 29:

Area of grate = .10 to .04 square feet per pound of fuel burned per hour.

Area of grate in furnaces with forced draft by blast-pipe from .04 to .01 square foot per pound of fuel burned per hour.

Area of chimney = .10 area of grate.

D. K. Clark, "Thurston's Manual of Steam-engineering," Vol. II., p. 201:

Sectional area of tubes, inside $= \frac{1}{6}$ grate surface.

Sectional area of chimney $= \frac{1}{15}$ grate surface.

Sectional area blast orifices $= \frac{1}{66}$ grate surface.

Height of chimney in feet = its diameter in inches multiplied by 4.

2

Transactions of the "American Society of Mechanical Engineers," Vol. XV., p. 607, gives:

$$A = \frac{C}{12\sqrt{H}} \div 1.076.$$

1.076 is constant for a horizontal flue 50 feet long.

Nystrom gives:

$$H = \frac{C^2}{4G^2} - 2 \qquad A = \frac{HP}{1.45\sqrt{H}}$$

$$H = \frac{(HP^2)}{2.1A^2} \qquad G = \frac{C}{2\sqrt{H+2}}$$

$$C = 2G\sqrt{H+2}$$

Jones and Laughlin give:

$$A = \frac{C}{10\sqrt{H}} \qquad A = \frac{1.04HP}{\sqrt{H}}$$

Another formula is

$$HP = \sqrt{S \times G}$$

$$S = \frac{(HP)^2}{G} \qquad G = \frac{(HP)^2}{S}$$

Molesworth gives:

$$A = \frac{HP}{1.28\sqrt{H}} \qquad A = \frac{C}{12\sqrt{H}}$$

Adams, p. 155, "Hand-book for Mechanical Engineers," gives:

$$A = \frac{C}{14\sqrt{H}} \qquad H = \left(\frac{C}{14A}\right)^2$$

$$C = 14A\sqrt{H}.$$

G = square feet of grate surface.
S = square yards of heating surface.
C = pounds coal per hour.
H = height of chimney in feet.
A = area of chimney-flue in square feet.
HP = horse-power of boilers.

William Kent gives the following, assuming a commercial horse-power to demand the consumption of 5 pounds of coal per hour:

Let A = actual section of chimney-flue in square feet.
Let HP = boiler horse-power.

(22) $E = \frac{0.3HP}{\sqrt{H}} = A - 0.6\sqrt{A}$ = effective section in square feet.
(23) $HP = 3.33E\sqrt{H}$ = horse-power.
(24) $d = 13.54\sqrt{E} + 4''$ = diameter of round flue in inches.
(25) $S = 12\sqrt{E} + 4''$ = side of square flue in inches.
(26) $H = \left(\frac{0.3HP}{E}\right)^2$ = height of chimney in feet.

After numerous examples and discussion, D. K. Clark, in Vol. I. of "The Steam-engine," constructs the following formulæ:

Working maximum consumption of coal per hour, for a chimney of a given height: diameter at the top, one-thirtieth of the height; temperature in the flue, 600° Fahr.

(27) $C = .014H^2\sqrt{H}.$

C = coal consumed per hour in pounds.
H = height of chimney in feet.
G = area of grate in square feet.

Taking as an average rate of combustion 15 pounds of coal per square foot of grate per hour, we have: Total grate area for a chimney of a given height; conditions as above:

(28) $G = \frac{H^2\sqrt{H}}{1071}$ or: $H = 16.3\frac{2.5}{\sqrt{G}}.$

Another formula has been quite widely published, which applies to about the same conditions as were assumed by Mr. Kent, and agreeing well with Isherwood's experiments on anthracite coal is given by Dr. R. H. Thurston. Subtract one from twice the square root of the height, and the result is the rate of combustion for anthracite. For low-grade soft coals the result is to be multiplied by 1.5—for general use we may use the mean of the figures for best anthracite and low-grade bituminous coal, or a multiplier of 1.25. Mr. Nagle * examined a good many chimneys, varying from 300 to 1,000 horse-power, to see if there existed any common ratio between these two elements. Where a smaller ratio than 1½ square inches of area to 1 pound of coal burned per hour existed, much dissatisfaction existed as to the draft of the chimney; when it reached 2 square inches very satisfactory results were obtained.

* Transactions of the American Society of Mechanical Engineers.