Table 3 .... Results of Field Survey on Chimney Damage

Type of Construction	Number of Chimneys	Number Reported Damaged	Percent Damaged
Chimneys without liners	4720	562	11.9
Chimneys with sewer tile construction	8410	104	1.2
Wilder metal coated with asphalt chromate emulsion	5185	291	5.6
Steel coated with plastic	9200	1928	21.0
Vitreous enamel on steel	614	No record	—
Aluminum	50,000	228	0.45

AVAILABLE DRAFT FOR THE INDUSTRIAL CHIMNEY

The available draft, D_a, *for large chimneys and stacks* has been estimated with apparent satisfaction in the past by means of formulas which in effect deduct an estimated friction loss from a theoretical draft determined as in Equation 2. The friction loss can be estimated by means of one of the formulas available for ducts, such as the Fanning equation. This procedure results in formulas for the available draft as follows:

The first terms represent the theoretical draft and the second terms represent the friction loss.

For a *cylindrical* stack:

$$D_a = 2.96\,HB_a\left(\frac{\rho_a}{T_a} - \frac{\rho_c}{T_c}\right) - \frac{0.00126W^2T_cfL}{d^5B_a\rho_c} \tag{2}$$

and for a *rectangular* stack:

$$D_a = 2.96\,HB_a\left(\frac{\rho_a}{T_a} - \frac{\rho_c}{T_c}\right) - \frac{0.000388W^2T_cfL(x+y)}{(xy)^3B_a\rho_c} \tag{3}$$

where

D_a = available draft, inches water.
H = height of chimney above inlet, feet.
B_a = existing barometric pressure, inches of mercury.
ρ_a = density of air at 0 F, 1 atmosphere pressure.
ρ_c = density of flue gas at 0 F, 1 atmosphere pressure.
T_a = temperature of atmosphere, Fahrenheit, absolute.
T_c = average temperature of flue gas, Fahrenheit, absolute.
W = flue gas flow rate, pounds per second.
f = coefficient of friction.
L = length of friction duct (approximately equal to H), feet.
d = minimum diameter of round chimney, feet.
x and y = length and width of cross-section of rectangular chimney, feet.

The following notes facilitate the use of Equations 2 and 3.

1. The *barometric pressure*, represented by B_a, is the actual pressure at the site of the chimney and not the pressure reduced to sea level datum.

In general, the barometric pressure decreases approximately 0.1 in. Hg per 100 ft increase in elevation.

2. The *unit weight of a cubic foot* of chimney gases at 0 F and sea level barometric pressure is given by the equation:

$$\rho_c = 0.131CO_2 + 0.095O_2 + 0.083N_2 \tag{4}$$

In this equation, CO_2, O_2, and N_2 represent the percentages of the parts by volume of the carbon dioxide, oxygen, and nitrogen content, respectively. For ordinary operating conditions, the value of ρ_c may be assumed at 0.09.

The effect on the chimney gas density of superheated water vapor resulting from moisture and hydrogen in the fuel, or of any air infiltration in the chimney proper, is disregarded. Although water vapor content is not disclosed by Orsat analysis, its presence tends to reduce the actual weight per cubic foot of chimney gases.

3. The *atmospheric temperature* is the actual observed temperature of the outdoor air at the time the analysis of the operating chimney is made. The mean atmospheric temperature in the temperate zone is approximately 62 F.

4. The *chimney gas temperature* decreases from the breeching connection to the top of the chimney. This drop in temperature depends upon the material and construction of the chimney, its tightness or freedom from leaks, its area, its height, and the velocity of the gases through it. The same chimney will suffer different temperature losses, depending upon the capacity under which it is working and the variable atmospheric conditions. No general equation covering all these variables has been suggested. It has been assumed by some authorities that the temperature drop will average about 1 F deg per foot of chimney height in steel chimneys, and ½ to ⅓ F deg per foot of height in brick lined, brick and concrete chimneys.[13]

5. The *coefficient of friction* between the chimney gases and a sooted surface has been taken by many workers in this field as a constant value of 0.016 for the conditions involved. This value, of course, would be less for a new, unlined steel chimney than for a brick or brick-lined chimney, but, in time, the inside surface of all chimneys, regardless of the materials of construction, becomes covered with a layer of soot. Therefore, the coefficient of friction has been assumed the same for all types of chimneys, and generally constant for all conditions of operation. For reasons of simplicity and convenience to the reader, this constant value of 0.016 has been employed in the development of the various special equations and charts shown in this chapter.

In important large chimney design, especially when the construction or the materials are unusual, it is recommended that use be made of the Reynolds number[16] in determining the friction factor, f.

The following problem illustrates the use of Equation 2.

Example 1: Determine the available draft of a natural draft chimney 80 ft in height and 3 ft in diameter, operating under the following conditions: atmospheric temperature, 62 F; chimney gas temperature, 500 F; sea level atmospheric pressure, B_a = 29.92 in. Hg; atmospheric and chimney gas density, 0.0863 and 0.09, respectively; coefficient of friction, 0.016; length of friction duct, 80 ft. The chimney discharges 3.15 lb of gases per second.

Solution: Substituting these values in Equation 2 and reducing,

$$D_a = 2.96 \times 80 \times 29.92 \times \left(\frac{0.0863}{522} - \frac{0.09}{960}\right) - \frac{0.00126 \times 3.15^2 \times 960 \times 0.016 \times 80}{3^5 \times 29.92 \times 0.09}$$

$$= 0.507 - 0.024 = 0.483$$

Fig. 6 shows the variation in the available draft of a typical 80 ft by 3 ft chimney operating under the general conditions noted in *Example 1*. When the chimney is under static conditions and no gases are flowing, the available draft is equal to 0.507 in. of water, the theoretical intensity. As the amount of gases flowing increases, the available draft decreases until it becomes zero at a gas flow of 14.6 lb per second, at which point the draft loss, due to friction, is equal to the theoretical intensity. The point of maximum draft and zero capacity is called shut-off draft, or point of impending delivery, and corresponds to the point of shut-off head of a centrifugal pump. The point of zero draft and maximum capacity is called the wide open point, and corresponds to the wide open point of a centrifugal pump. A set of operating characteristics may be developed for any size chimney operating under any set of conditions by substituting the proper values in Equation 2 and then plotting the results in the manner shown in Fig. 6.

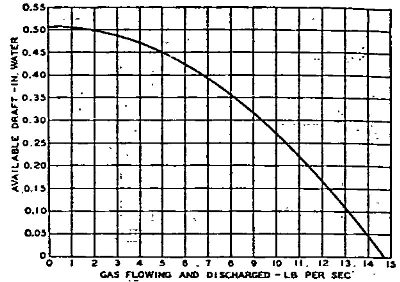
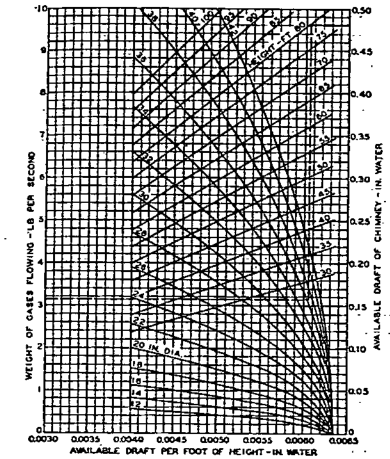


Fig. 6 .... Typical Set of Operating Characteristics of a Natural-Draft Chimney



To solve a typical example: Proceed horizontally from a Weight Flow Rate point to intersection with diameter line; from this intersection follow vertically to chimney height line; from this intersection follow horizontally to the right to Available Draft scale. Starting from a point of Available Draft, take steps in reverse order.

Fig. 7 .... Chimney Performance Chart

Fig. 7 is a typical chimney performance chart, giving the available draft for various gas flow rates and sizes of chimney. This chart is based on an atmospheric temperature of 62 F, an average chimney gas temperature of 500 F, a unit chimney gas weight of 0.09 lb per cu ft, sea level atmospheric pressure, a coefficient of friction of 0.016, and a friction duct length equal to the height of the chimney above the point of entry of the flue gases. These curves may be used for general operating conditions. For specific conditions, a new chart may be prepared from Equation 2.

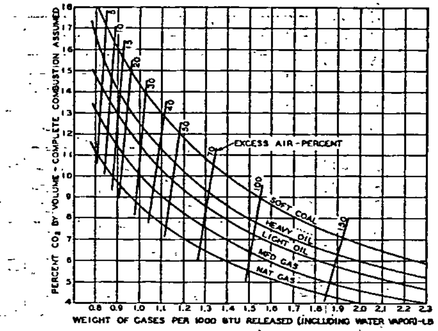
The usual problem encountered by the designer is the selection of a chimney size, as illustrated by Example 2.

Example 2: Select a natural draft chimney for a boiler with fuel input 73 gph of 151,000 Btu per gal heavy oil, burned at 12 percent CO_2. The draft tension required in the firebox is 0.12 in.; draft loss through the boiler is 0.28 in., and the draft loss in the breeching is 0.08 in., making a total draft requirement of 0.48 in. water. The average stack temperature is 500 F, and the ambient temperature is 62 F.

Solution: From Fig. 8, using the heavy oil curve, determine 1.03 lb gases per 1000 Btu released at 12 percent CO_2. Then:

$$\frac{73 \times 151{,}000 \times 1.03}{1000 \times 3600} = 3.15\ \text{lb}$$

flue gases produced per second. Several combinations of chimney diameter and height can satisfy the draft and flue gas flow requirements. The dashed line in Fig. 7 indicates that a 36 in. diameter stack 80 ft high will be satisfactory. The use of a



Heavy Oil (by wt)	Light Oil (by wt)	Soft Coal (by wt)
C=0.856 S=0.023 H=0.097 $\frac{N+O_2}{2}$=0.020 Ash=0.0012	C=0.834 S=0.006 O=0.013 N=0.147	C=0.6958 S=0.0396 O=0.1069 H=0.0519 N=0.0120 Ash=0.0938
Btu/lb=18,300	Btu/lb=19,580	Btu/lb=12,847
Nat Gas (by vol)	**Mfd Gas[a] (by vol)**	**Notes**
CH_4=0.9416 C_2H_6=0.0030 H=0.0170 CO=0.0055 CO_2=0.0029 O=0.0030 N=0.0270	CH_4=0.282 H=0.252 CO=0.139 Ill=0.047 CO_2=0.053 N=0.221	[a] Do not use Mfd Gas data for any gas except with analysis similar to that shown. [b] Specific gravity =0.678.
Btu/lb=22,330	Btu/lb=10,010[b]	

Fig. 8 .... Graphical Evaluation and Rate of Flue Gas Flow from Percent CO_2 and Fuel Rate