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 grate level. *These curves may be used for general operating conditions.* For specific conditions, a new chart may be prepared from Equation 4.

DETERMINING INDUSTRIAL CHIMNEY SIZES

If the required performance for a proposed chimney is known, and *if a chimney-gas velocity is assumed*, Equation 3 can be transposed to yield the necessary height, and an equation can be developed for the required diameter. These operations result in the following equations:

$$H = \frac{D_r}{2.96B_o\left(\frac{\rho_o}{T_o} - \frac{\rho_c}{T_c}\right) - \frac{0.184 f\rho_c B_o V^2}{T_c d}} \qquad (7)$$

The weight of gas per second, $W = 12.075\ (dVB_o\rho_c/T_c)$

$$d = 0.288\sqrt{\frac{WT_c}{B_o\rho_c V}} \qquad (8)$$

where

H = required height of chimney above inlet, feet.
d = required minimum diameter of chimney, feet.
V = chimney gas velocity, feet per second.
D_r = total required draft, inches of water.

For large chimneys, it is usual to assume that total construction cost is least when the product Hd (height × diameter) is minimum. On this assumption, the product of Equations 7 and 8 can be differentiated, and the differential set equal to zero to find the minimum. Solution for velocity then *yields the following equation:*

$$V_e = \left(\frac{0.772T_c\left(\frac{\rho_o}{T_o} - \frac{\rho_c}{T_c}\right)\sqrt{\frac{WT_c}{B_o\rho_c}}}{f\rho_c}\right)^{2/5} \qquad (9)$$

where

V_e = economical chimney gas velocity, feet per second.

Equations 7, 8, and 9 can of course be simplified if values are assumed for some of the factors in it. Some typical values for boiler plants are:

Average chimney gas temperature 500 F .... T_c = 960 F absolute
Average atmospheric temperature 62 F . T_o = 522 F absolute
Average coefficient of friction 0.016 . . . . f = 0.016
Average chimney gas density, 0 F, 1 atmosphere .... ρ_c = 0.09 lb per cu ft
Barometer reading, sea level .... B_o = 29.92 in. Hg

When these values are substituted in Equations 7, 8, and 9, respectively, the results are:

$$H = 190D_r \qquad (10)$$

$$d = 1.5W^{2/5} \qquad (11)$$

$$V_e = 13.7W^{1/5} \qquad (12)$$

These equations should be used for general operating conditions only, or where the required data necessary for an exact determination are difficult or impossible to secure. Whenever *it is possible to obtain accurate data, or the anticipated op*erating conditions are fairly well known, the required size should be determined from Equations 7, 8, and 9.

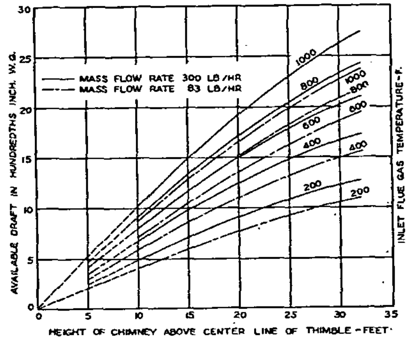


Fig. 4 . . . . Available Draft for 9" x 9" and 9" x 13" Masonry Chimneys

Additional construction data for large industrial chimneys, whether brick, concrete, or steel may be found in *Kent's Mechanical Engineers' Handbook*[4] or the *Handbook of Building Construction.*[5]

RESIDENTIAL CHIMNEYS

Since residential heating appliances depend to a large extent on the natural draft of residential chimneys for satisfactory performance, the chimneys must be of adequate height and of optimum cross-sectional area, reasonably gas tight, and as smooth as practicable internally. They must be of such construction as to create no fire hazard to the building. The height and location of a residential chimney are usually limited by architectural and structural considerations, *and therefore the draft produced* will sometimes be inadequate for satisfactory and efficient operation of the fuel-burning equipment. The basementless house, the one-story ranch or rambler type, and the flat-roofed *structure* are usually restrictive, particularly with regard to adequate chimney height. The limitations of chimney height should be carefully considered to determine whether or not the type of heating equipment specified will operate properly. If the available draft of the chimney is less than the draft required for the particular heating equipment specified, auxiliary means such as forced or induced draft should be included.

Until recently most chimneys for residences were constructed of masonry. The *National Building Code* of the National Board of Fire Underwriters specifies a minimum of 4 in. of masonry enclosing a fire clay flue liner. *Within the* past several years, however, the Underwriters' Laboratories have tested and listed as approved *Type A* flues, several chimneys of prefabricated construction. Their advantages, compared with masonry chimneys, are ease of installation, and usually lower cost and a greater degree of safety under abnormal firing conditions. Through the use of insulation or other means to reduce heat transfer through the chimney walls, these *Type A* flues usually operate at a higher mean temperature for a given entering temperature and therefore produce slightly higher drafts.

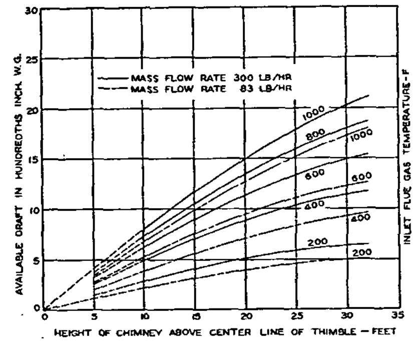


Fig. 5 . . . . Available Draft for 9" x 9" and 9" x 13" Masonry Chimneys

AVAILABLE DRAFT FOR THE RESIDENTIAL CHIMNEY

Equations 3 and 4 cannot readily be used for computing the available draft for residential chimneys because of the relatively *greater importance of friction losses*, cooling of the gases, and soot deposits in small chimneys. Eddy currents and simultaneous flow both upward and downward can occur in a residential chimney for very low flue-gas velocities.

At present, it is best to rely on actual test data for determining the available draft of residential chimneys. Fig. 4 shows the available draft of nominal 9 x 9-in. and 9 x 13-in. masonry chimneys with an ambient temperature of 0 F for a range of effective heights from 5 to 32 ft, a range of entering flue-gas temperatures from 200 to 1000 F, and for mass flow rates of 83 and 300 lb per hr. Fig. 5 shows the same *information for an ambient temperature* of 60 F. The available drafts produced by 9 x 9-in. and 9 x 13-in. masonry chimneys are equal for practical purposes over the range of mass flow from 83 to 300 lb per hr.[6] In *tests of these chimneys* the smaller chimney produced slightly greater drafts in the lower end of the range of mass flow rates whereas the larger chimney produced slightly higher drafts in the upper end of the range.

The chimney height for heating plants that operate on an *on-off* or *high-fire-low-fire* cycle should be selected to produce the desired draft from Fig. 5 since this class of heating system is required to operate at rated input for short periods when the outdoor temperature is 60 F. Heating plants whose fuel-burning rate is gradually increased as the outdoor temperature decreases are not required to operate at rated input except when outdoor temperatures approach design conditions. For such systems, the chimney height should be selected from Fig. 4 which shows the available draft for an outdoor temperature of 0 F since this is likely to be the more critical condition with respect to chimney draft. The available draft for outdoor temperatures between 0 F and 60 F can be obtained by interpolation from Figs. 4 and 5 with only slight error.

Fig. 6 is a graphical representation of the available draft for a 13-ft brick chimney with a nominal 8 x 8-in. flue liner[7] over a wide range of mass flow rates and for inlet flue-gas temperatures ranging from 200 to 1000 F. This family of curves is a typical group of performance curves showing that there is a certain mass flow rate that produces a maximum available draft for any flue-gas temperature.

The following approximate method may alternately be used to determine the available draft for small residential chimneys, *from 10 to 25 ft* in height and with internal cross-section areas from 35 to 55 sq in., with a maximum probable error of ±15 percent at the same flow and temperature conditions. This method is based on the chimney efficiencies[7] shown in Fig. 7 and the ideal draft computed from the chimney inlet temperature. The available draft may be expressed as:

$$D_a = n_e D_i \qquad (13)$$

where

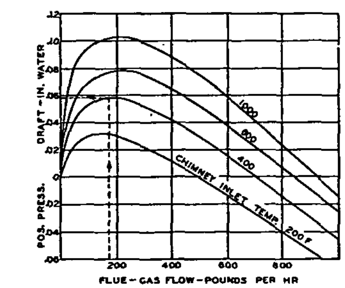
n_e = chimney efficiency taken from Fig. 7 at the desired conditions of temperature and flow.
D_i = ideal draft, calculated from Equation 14, assuming that the barometric pressure is 29.92 in. Hg, and the ambient temperature is 60 F.

$$D_i = 0.2554B_oH\left(\frac{1}{T_o} - \frac{1}{T_i}\right) \qquad (14)$$

where

B_o = barometric pressure, inches of mercury.
H = chimney height, feet.
T_i = chimney inlet temperature, Fahrenheit, absolute.
T_o = ambient air temperature, Fahrenheit, absolute.

The clay-lined brick chimney is the most commonly used chimney, but recently other building materials have been used for reasons of economy or convenience. Investigations have established that the results shown in Figs. 4 and 5 for brick



[a] Square Flue Liner 6¾ x 6¾ in. inside.
[b] Barometric Pressure 29.92 in. Hg. Air Temperature 60 F.

Fig. 6 . . . . Available Chimney Draft for 13 Ft Brick Chimney[a, b]