

Substituting these values in Equation 1 and reducing:

$$D_a = 2.96 \times 200 \times 29.92 \times \left(\frac{0.0863}{522} - \frac{0.09}{960} \right) - \frac{0.00126 \times 100^2 \times 960 \times 0.016 \times 200}{10^4 \times 29.92 \times 0.09}$$

$$= 1.27 - 0.14 = 1.13 \text{ in.}$$

Fig. 4 shows the variation in the available draft of a typical 200 ft by 10 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 1.27 in. of water, the theoretical intensity. As the amount of gases flowing increases, the available intensity decreases until it becomes zero at a gas flow of 297 lb per second at which point the draft loss due to friction is equal to the theoretical intensity. The draft-capacity curve corresponds to the head-capacity curve of centrifugal pump characteristics and the dynamic-head-capacity curve of a fan. 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 1 and then plotting the results in the manner shown in Fig. 4.

Energy Output and Input

The efficiency of a natural draft chimney is the thermodynamical ratio of the energy output to the energy input. The energy output is the total work done by the chimney in moving the gases and corresponds to the water horsepower of a centrifugal pump, or the total work done by a fan in moving the gases. The energy input is equal to the theoretical amount of power generated by the chimney and corresponds to the power input of the driving unit of a centrifugal pump or a fan. The thermodynamical efficiency is given by the equation:

$$E_t = \frac{K_a W D_a}{A \sqrt{H}} \quad (2)$$

where

K_a = a constant depending upon the temperature of the gases, the atmospheric temperature, the elevation of the plant, and the density and specific heat of the gases. For average operating conditions, $K_a = 0.0065$.

Fig. 4 shows the variation in the efficiency of the chimney under consideration for the operating conditions noted. This curve rises from zero at shut-off draft to a maximum for a certain draft and its corresponding capacity and then drops again to zero at the wide open point. The point of maximum efficiency is located by the point on the draft-capacity curve equal to two-thirds of the theoretical draft intensity. In Example 1 the maximum efficiency is at an available draft intensity of $\frac{2}{3} (1.27) = 0.85$ in. of water and the corresponding capacity of 175 lb per second.

Efficiency Curve of Natural Draft Chimney

The efficiency curve of a natural draft chimney corresponds to the efficiency curves of a centrifugal pump and a fan and serves the same general use in that it locates the region of most economical operation. In substituting the values for the various factors in Equation 1, care should be exercised that the selections be as near the actual conditions as is practically possible. The following notes will serve as a guide for these selections:

1. The *barometric pressure* varies inversely as the altitude of the plant above sea level. Fig. 5 gives the barometric pressure corresponding to various elevations as computed from the equation:

$$E_1 = 62,737 \log \frac{29.92}{B_0} \quad (3)$$

where

E_1 = altitude of plant above sea level, feet.

Roughly speaking, the barometric pressure decreases approximately 0.1 in. of mercury per 100 ft increase in elevation.

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

$$W_c = 0.131CO_2 + 0.095 O_2 + 0.083 N_2 \quad (4)$$

in which CO_2 , O_2 and N_2 represent the percentages of the parts by weight of the carbon dioxide, oxygen and nitrogen content, respectively, of the gas analysis. For ordinary operating conditions, the value of W_c may be assumed at 0.09.

3. The *atmospheric temperature* is the actual observed temperature of the outside 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* does not vary appreciably from the gas temperature as it leaves the breeching and enters the chimney. For average operating conditions, the chimney gas temperature will vary between 500 F and 650 F except in the case when economizers and recuperators are used when the temperature will vary between 300 F and 450 F. If a chimney has been properly constructed, properly lined and has no air infiltration due to open joints, the temperature of the gases throughout the chimney will not differ appreciably from the foregoing figures. In most up-to-date heating plants, the temperature may be read from instruments or ascertained from a pyrometer.

5. The *coefficient of friction* between the chimney gases and a sooted surface has been found to be approximately 0.016. This factor, of course, will be much less for a new unlined steel stack than for a brick or brick-lined chimney, but in time the inside surface of all chimneys regardless of the material of which they are constructed becomes covered with a layer of soot and the coefficient of friction should be the same for all types of chimneys.

6. The *length of the friction duct* is the vertical distance between the bottom of the breeching opening and the top of the chimney. Ordinarily this distance is approximately equal to the height of the chimney above the grate level.

7. The *amount of gases flowing and being discharged* is, of course, equal to the amount of gases generated in the combustion chamber of the boiler. The total products of combustion may be computed from the equation:

$$W = \frac{C_g G W_{tp}}{3600} \quad (5)$$