Chimney Sizing

Project Name:

Location:

Type Appliance: Boiler
Hot Water Heater
Incinerator

Type Fuel: Natural Gas
LP Gas
#2 Oil
#6 Oil
Wood/Coal
Waste (Type________)

Appliance Input: BTU
Hp
Lbs/hr

Height Above Seal Level, ft
Flue Gas Temperature, °F
Ambient Temperature, °F
Appliance Outlet Diameter, inches
Total Footage of Pipe, feet (this includes length of breeching and stack)
Height of Stack, feet Effective Draft (Tee centerline to Outlet)
Number/Type of Fittings:
90° Elbows
45° Elbows
45° Tees
90° Tees
Barometric Damper
Spark Arrestor
Allowable Back Pressure, inches in H_2O

Breeching Description/Notes:

Theoretical Draft

Chimney design involves balancing forces, which tend to produce flow (friction). The force producing the flow in gravity or natural draft chimneys is termed theoretical draft, defined as the static pressure resulting from the differences in densities between a stagnant column of hot flue gases and an equal column of ambient air.

Theoretical draft can be calculated using the following equation:

$$D_t = .2554\ B\ H \left(\frac{1}{T_o} - \frac{1}{T_m} \right)$$

Where:
D_t = theoretical draft, inches of water
B = barometric pressure, inches of mercury
H = effective height of chimney, feet
T_o = outside temperature, (ºF + 460)
T_m = mean chimney temperature, (ºF + 460)

Refer to Table 1 for Barometric Pressure vs. Altitude
Refer to Table 2 for Appliance Outlet Temperatures

For more simplified calculation, Table 3 can be used to determine theoretical draft assuming the density of chimney gas is the same as that of air, the barometric pressure is at sea level and the ambient temperature is 60ºF.

Barometric Pressure vs. Altitude

Table 1

ALTITUDE (Feet)	**PRESSURE (Inches of Mercury)**
Sea Level	29.92
2000	27.8
4000	25.8
6000	24.0
8000	22.3
10,000	20.6

Theoretical Draft Per Foot of Chimney Height

Table 2

Mean Chimney Temperature of T_m	Theoretical Draft Inches of Water D_t	Mean Chimney Temperature of T_m	Theoretical Draft Inches of Water D_t
100	0.00105	850	0.00886
150	0.00217	900	0.00907
200	0.00312	950	0.00927
250	0.00393	1000	0.00946
300	0.00464	1050	0.00963
350	0.00526	1100	0.00979
400	0.00581	1200	0.01009
450	0.00629	1300	0.01035
500	0.00673	1400	0.01058
550	0.00713	1500	0.01079
600	0.00748	1600	0.01098
650	0.00780	1700	0.01115
700	0.00810	1800	0.01135
750	0.00837	1900	0.01145
800	0.00862	2000	0.01158

Appliance Outlet Temperatures

Table 3

Appliance Type	Outlet Temperature, ºF
Natural gas-fired heating appliance with draft hood	360
LP gas-fired heating appliances with draft hood	360
Gas-fired heating appliance, no draft hood	460
Oil-fired heating appliances residential	560
Oil-fired heating appliances, forced draft over 400,000 BTU/hr	360
Conventional incinerator	1400
Controlled air incinerator	1800 – 2400
Pathological incinerator	1800 – 2800
Turbine exhaust	900 – 1400
Diesel exhaust	900 – 1400
Ceramic kilns	1800 - 2400

Mass Flow of Combustion Products

Mass flow in a chimney or venting system may differ from that in the appliance depending on the type of draft control, or number of appliances operating in a multiple system. The use of mass flow is preferable (rather than cubic feet) because it remains constant in any continuous portion of the system regardless of changes in temperature or pressure. For the chimney gases resulting from any combustion process, mass flow w, in pounds per hour, can be expressed as:

$$W = I\ M$$

Where: I = appliance heat input BTU/hr
M = mass flow input ratio, pounds of combustion products per 1000 BTU of fuel burned

Table 4 lists mass flow input ratio values for various fuels and appliances. If a BTU input rating is not given for the appliance, Table 5 lists conversion factors for other appliance ratings.

Mass flow within incinerator chimneys must account for the probable heating value of the waste, plus its moisture content, plus the use of additional fuel to initiate or sustain combustion. Where constant burner operation accompanies the combustion of waste, the additional quantity of products due to the additional fuel should be considered in the design process. For incinerator chimneys, mass flow can be calculated using a slightly different formula.

W = (# waste burned) x (# combustion products)
(per hour) (per # waste)

Table 6 gives the values for # combustion products based on the type of waste being burned.

In order to determine the losses in the chimney, the velocity must first be calculated. Velocity can be computed using the following equation.

$$V = \frac{W}{P_m x 19.635 x d^2}$$

Where: V = velocity, feet/second
W = mass flow, pounds/hour
P_m = flue gas density, pounds/cu. ft.
d = diameter, inches

If the diameter is unknown, a reasonable estimate can be determined using a velocity of 17 feet per second.

If the volume of flow in the chimney is required, possibly for fan selection, the following formula can be used.

$Q = A\,V$

Where: Q = cubic feet per minute
A = area, square feet
V = velocity, feet/minute

Mass Flow Input Ratio

Table 4

Fuel	Appliance	Mass Flow Input Ratio
Natural Gas	Draft Hood	1.60
Natural Gas	No Draft Hood	0.90
LP Gas	Draft Hood	1.64
Oil	All	1.24
Oil #2	Over 400,000 BTU/hr	0.85
Oil #6	Over 400,000 BTU/hr	0.86
Coal (Bituminous)	All	1.54

Conversion Factors

Table 5

BTU/hr Input =	Boiler Horsepower @100% efficiency x 33475
“	Boiler Horsepower @ 80% efficiency x 42000
“	Boiler Horsepower @75% efficiency x 44500
“	Boiler Horsepower @70% efficiency x 47800
“	Gallons per hour oil (#1 & #2) x 140,000
“	Gallons per hour oil (#4, #5, & #6) x 150,000
“	Cubic feet per hour natural gas x 1000
“	Pounds per hour coal x 13,000
“	Watts x 3.412
“	Pounds of steam x .9704 x 1000

Mass Flow for Incinerator Chimneys

Table 6

		Combustion Products	
Type of Waste	**BTU/lb Waste**	**CFM/lb Waste @1400ºF**	**lb/hr per lb Waste**
Type 0	8500	10.74	13.76
Type 1	6500	8.40	10.80
Type 2	4300	5.94	7.68
Type 3	2500	4.92	6.25
Type 4	1000	4.14	5.33

System Losses

Flow losses due to friction may be estimated by means of several methods using formulas for flow in pipes or ducts. These include the equivalent length method and the loss coefficient or velocity head method. Primary emphasis will be placed in this treatment on the loss coefficient method, because in chimney systems, fittings usually cause the greater portion of system pressure drop, and conservative loss coefficients (which are practically independent of piping size) provide an adequate basis for system designs.

Using the velocity head method for resistance losses, a fixed numerical coefficient (independent of velocity) or k factor is assigned to every turn in the flow circuit, and to piping as well. Table 7 offers design values for the resistance loss coefficient for various fittings.

Once the loss coefficients for the system have been evaluated, the system losses can be calculated using the following formula.

$$\Delta p = \frac{{}^{kp}m^{V2}}{5.2\,(2g)}$$

Where: Δp = system loss, inches of water
K = loss coefficient
${}^{p}m$ = density of flue gas, pounds/cubic foot
V = chimney velocity, feet/second
g = gravitational constant, 32 feet/second

Refer to Table 8 for Density vs. Temperature

To determine the losses in a rectangular system, an equivalent circular diameter for equal friction and capacity can be used. A sample of these equivalent diameters is given in Table 9.

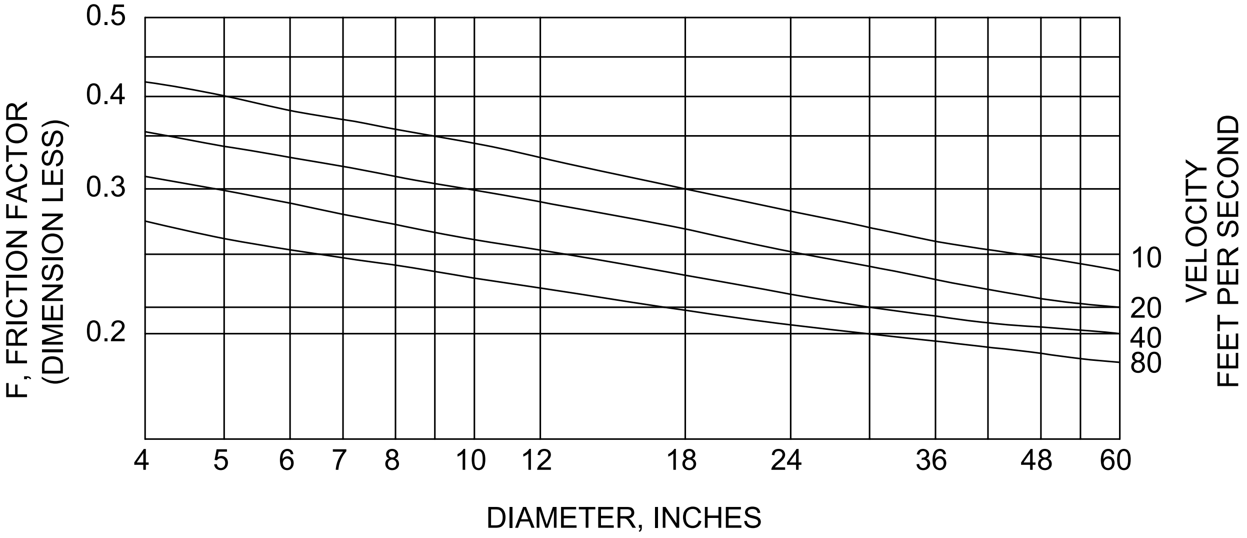
Resistance Loss Coefficients

(Velocity Heads, Dimensionless)
Table 7

Component	Suggested Design Value	Estimated Span/Notes
Inlet-acceleration		
Gas vent with draft hood	1.5	1.0 – 3.0
Barometric regulator	0.5	0.0 – 0.5
Direct connection	0.0	Also dependent on blocking damper position
Round elbow, 90º	0.75	0.5 – 1.5
Round elbow, 45º	0.3	-
Tee or 90º breeching	1.25	1.0 – 4.0
Y breeching	0.75	0.5 – 1.5
Cap top		
Open straight	0.0	-
Low resistance (UL)	0.5	0.0 – 1.5
Other	-	1.5 – 4.5
Spark Screen	0.5	-
Converging exit cone	$(d_1/d_2)^4-1$	System designed using d_1
Tapered reducer $({}^{d}{}_{1}$ to ${}^{d}{}_{2})$	$1-(d_2/d_1)^4$	System designed using d_2
Piping	$0.4\,\frac{L,\ \text{ft}}{d,\ \text{in}}$	Numerical coefficient from 0.2 – 0.5
See Figure 1 for friction factors		

Friction Factor for Piping

Figure 1



Density vs. Temperature

Table 8

Temperature ºF	Density #/cu. ft.	Temperature ºF	Density #/cu. ft.
60	0.07656	300	0.05237
70	0.07512	350	0.04914
80	0.07373	400	0.04628
90	0.07238	450	0.04374
100	0.07109	500	0.04146
110	0.06984	550	0.03940
120	0.06864	600	0.03754
130	0.06747	650	0.03585
140	0.06635	700	0.03431
150	0.06526	800	0.03158
175	0.06269	900	0.02926
200	0.06031	1000	0.02725
225	0.05811	1500	0.02030
250	0.05606	2000	0.01617
275	0.05415		

Masonry Chimney Liner Dimensions with Circular Equivalents

Table 9

Nominal Liner Size, in.	Inside Dimensions of Liner, in.	Inside Diameter or Equivalent Diameter, in.	Equivalent Area, sq. in.	Typical Outside Dimensions of Casing, in.
4 x 8	2 ½ x 6 ½	4	12.2	
		5	19.6	
		6	28.3	
		7	38.5	
8 x 8	6 ¾ x 6 ¾	7.4	42.7	16 x 16
		8	50.3	
8 x 12	6 ½ x 10 ½	9	63.6	16 x 21
		10	78.5	
12 x 12	9 ¾ x 9 ¾	10.4	83.3	21 x 21
		11	95.0	
12 x 16	9 ½ x 13 ½	11.8	107.5	21 x 25
		12	113.0	
		14	153.9	
16 x 16	13 ¼ x 13 ¼	14.5	162.9	25 x 25
		15	176.7	
16 x 20	13 x 7	16.2	206.1	15 x 29
		18	254.4	
20 x 20	16 ¾ x 16 ¾	18.2	260.2	29 x 29
		20	314.1	
20 x 24	16 ½ x 20 ½	20.1	314.2	29 x 34
		22	380.1	
24 x 24	20 ¼ x 20 ¼	22.1	380.1	34 x 34
		24	452.3	
24 x 28	20 ¼ x 24 ¼	24.1	456.2	34 x 38
28 x 28	24 ¼ x 24 ¼	26.4	543.3	38 x 38
		27	572.5	
30 x 30	25 ½ x 25 ½	27.9	607.0	48 x 48
		30	706.8	
30 x36	25 ½ x 31 ½	30.9	749.9	48 x54
		33	855.3	
36 x 36	31 ½ x 31 ½	34.4	929.4	54 x 54
		36	1017.9	

Balancing The System

Equipment or appliances can be placed in three broad categories: Negative Pressure appliances which require a negative pressure at the outlet to induce combustion air flow into the combustion zone, Atmospheric appliances which require a neutral pressure at the outlet without need for chimney draft, for example, draft hood type of gas appliances in which the combustion process is isolated from chimney flow variations, and Forced Draft appliances which operate at above atmospheric pressure and have sufficient pressure to force the products of combustion through the appliance resulting in either a slight positive pressure or a zero pressure at the outlet.

Depending on the type of appliance, a different formula is needed to balance the system.

Appliance Type	**Pressure Equation (Loss = Draft Requirements)**	**Notes**
Negative Pressure	$\Delta p = D_t - D_o$	D_o is the amount of negative pressure needed
Atmospheric	$\Delta p = D_t$	Neutral pressure at outlet
Forced Draft	$\Delta p = D_t + D_o$	D_o is the amount of positive pressure at the outlet due to the force draft system (if any)

Where: Δp = system losses, inches of water
D_t = theoretical draft, inches of water
D_o = appliance outlet pressure, inches of water

The values previously calculated for the system should be evaluated using these equations. In all three cases, if the system losses exceed the draft requirements, the system will not properly exhaust the combustion products. At this point, using an interactive process, the stack and breeching diameters should be increased (or decreased) until the system balances. Another solution for an undersized system would be the inclusion of a draft inducer in the chimney system. For a system with a draft inducer, the static pressure supplied by the inducer should be added to the draft requirements in the pressure equation.

In reverse, a draft inducer can be selected based on the additional draft required to balance the pressure equation. Knowing the volume of flow in the system and the static pressure required, the fan selection for the inducer is simplified.

Multiple Systems

The most common configuration is the individual vent, stack, or chimney, where one continuous system carries the products from appliance to terminus. Other configurations include the combined vent serving a pair of appliances, the manifold serving several, and branched system with two or more lateral manifolds connected to a common vertical system.

For the configurations where one system is used to vent several appliances, the sizing procedure involves the summation of losses through out the various branches of the system. The system should be divided into sections based on the number of appliances venting into that portion of the system. The velocity and loss coefficient are calculated separately for each branch. Using these values, the losses in each section can be computed.

The draft requirements of each appliance need individual consideration. A pressure equation for each appliance should be formulated to assure that the system balances at each connection. If the system does not balance at any point, either a branch size or the vertical stack size must be changed. Once a size is changed, the pressure equations should be reformulated to determine if the change leaves the system balanced.

The Fireplace Chimney

Fireplaces, with natural draft chimneys, obey the same gravity fluid flow law as gas vents and thermal flow ventilation systems. Mass flow of hot flue gases up to some limiting value is induced in a vertical pipe as a function of rate of heat release, and is regulated by chimney area, height, and system pressure loss coefficient. A fireplace may be treated analytically as a gravity duct inlet fitting, have a characteristic entrance loss coefficient, and an internal heat source. Proper functioning of a fireplace (prevention of smoking) is achieved by producing adequate intake or face velocity across those critical portions of the frontal opening in order to nullify effects of external drafts or internal convection effects.

A minimum mean frontal inlet velocity of 0.8 fps should control smoking adequately, in conjunction with a chimney gas temperature at least 300 to 500ºF above ambient. For a reasonably conservative design, a frontal inlet velocity of 1.0 fps and a temperature of 350ºF can be used.

To determine the volume of air entering the fireplace at 70ºF, the following equation can be used.

$$Q_f = V_c \times A_f$$

Where: Q_f = volume of air entering the fireplace @ 70ºF, cu. ft./min.
V_c = capture velocity, fpm
A_f = fireplace frontal area, sq. ft.

The volume of flue gas in the chimney can be calculated using the following equation:

$$Q_c = \frac{Q_f}{DCF}$$

Where: Q_c = volume of gas entering the chimney at the average chimney temperature, cu. ft./min.
Q_f = volume of air entering fireplace @70ºF, cu. ft./min.
DCF = density correction factor (see Table 10)

The velocity in the chimney is determined by:

$$V_c = \frac{Q_c}{A_c}$$

Where: V_c = velocity in chimney, fpm
Q_c = volume of gas entering the chimney at the average chimney temperature, cu. ft./min.
A_c = area of chimney, sq. ft.

In most applications, the area of the chimney will fall between 1/10th and 1/12th of the fireplace frontal area.

Once the velocity's computed, the system losses can be calculated following the procedure previously described. For a fireplace application, there are additional loss coefficients, which need to be considered. These values can be found in Table 11.

The procedures for calculating theoretical draft and balancing the system follow the previous sections. Draft inducers can also be used on fireplace chimneys to supplement the theoretical draft if needed to help prevent smoking.

Density Correction Factor

Table 10

Temperature ºF	Altitude, Feet above Sea Level						
	0	**1000**	**2000**	**3000**	**4000**	**5000**	**6000**
0	1.15	1.11	1.07	1.03	0.99	0.95	0.91
70	1.00	0.96	0.93	0.89	0.86	0.83	0.80
100	0.95	0.92	0.88	0.85	0.81	0.78	0.75
150	0.87	0.84	0.81	0.78	0.75	0.72	0.69
200	0.80	0.77	0.74	0.71	0.69	0.66	0.64
250	0.75	0.72	0.70	0.67	.064	0.62	0.60
300	.070	0.67	0.65	0.62	0.60	0.58	0.56
350	0.65	0.62	0.60	0.58	0.56	0.54	0.52
370	0.64	0.61	0.59	0.57	0.55	0.53	0.51
400	0.62	0.60	0.57	0.55	0.53	0.51	0.49
450	0.58	0.56	0.54	0.52	0.50	0.48	0.46
500	0.55	0.53	0.51	0.49	0.47	0.45	0.44
550	0.53	0.51	0.49	0.47	0.45	0.44	0.42
600	0.50	0.48	0.46	0.45	0.43	0.41	0.40
650	0.48	0.46	0.44	0.43	0.41	0.40	0.38
700	0.46	0.44	0.43	0.41	0.39	0.38	0.37
750	0.44	0.42	0.41	0.39	0.38	0.36	0.35
800	0.42	0.40	0.39	0.37	0.36	0.35	0.33
850	0.40	0.38	0.37	0.36	.034	0.33	0.32
900	0.39	0.37	0.36	0.35	0.33	0.32	0.31
950	0.38	0.36	0.35	0.34	0.33	0.31	0.30
1000	0.36	0.35	0.33	0.32	0.31	0.30	0.29

System Loss Coefficients

Table 11

Loss	k factor
Loss to initiate flow	1.0
Inlet loss	
Cone type fireplace	0.5
Masonry damper throat = 2 x flue area	1.0
Masonry damper throat = flue area	2.5