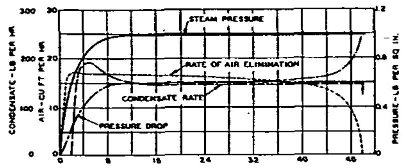


Fig. 21 . . . . Relation Between Elapsed Time, Steam Pressure, Condensate and Air Elimination Rates

rate is obtained when the system steam pressure is lower than that existing during a period of constant condensing rate. It will also be noted that the peak rate of air elimination does not coincide with the higher condensing rate.

Steam Flow

The rate of flow of dry steam, or steam with a small amount of water flowing in the same direction, is in accordance with the general laws of gas flow, and is a function of the length and diameter of the pipe, the density of the steam, and the pressure drop through the pipe. This relationship, developed by Unwin and later by Babcock, has been used for years as a means of determining steam flow through pipes. The new charts for weight-flow rate, pressure drop, and velocity presented in this chapter take into account the Reynolds number and its effect on friction loss, two items which were not considered when using the Unwin or Babcock formulas.

The data presented in Figs. 22, 23, 24, 25, 26 and Table 5, in later sections of this chapter, are based on the Moody Friction Factor where the absolute roughness of the internal pipe surface is that of new commercial steel or wrought iron. The Reynolds number, as expressed by Equation 9, Chapter 4, is

$$N_{Re} = \frac{dV\rho}{\mu} \tag{1}$$

where

V = velocity of the steam, feet per second.
d = internal diameter of the pipe, feet.
ρ = density of saturated steam at a specified saturation pressure, pounds per cubic foot.
μ = absolute viscosity, pounds per foot-second.

Table 2 . . . . Pressure Drops in Common Use for Sizing Steam Pipe[a]
(For Corresponding Initial Steam Pressures)

Initial Steam Pressure, Psig	*Pressure Drop Per 100 Ft, Psi*	*Total Pressure Drop in Steam Supply Piping, Psi*
Subatmos. or vacuum return	2-4 oz	1-2 psi
0	½ oz	1 oz
1	2 oz	1-4 oz
2	2 oz	8 oz
5	4 oz	1½ psi
10	8 oz	3 psi
15	1 psi	4 psi
30	2 psi	5-10 psi
50	2-5 psi	10-15 psi
100	2-5 psi	15-25 psi
150	2-10 psi	25-30 psi

[a] Equipment, control valves, etc., must be selected on the basis of delivered pressures.

The velocity is determined by the equation

$$V = \frac{W}{3600\rho A} \tag{2}$$

where

W = given weight-flow rate, pounds per hour.
A = internal pipe area, square feet.

The values used for the absolute viscosity of saturated steam are those of Lieb, published in *Combustion*, December, 1940. The relative roughness of the internal pipe surface is obtained by dividing the absolute surface roughness by the internal pipe diameter. The values for absolute roughness are those presented by L. F. Moody in *Mechanical Engineering*, Vol. 69, 1947, p. 1005, and appear in Table 1, Chapter 4. From the Reynolds number and relative roughness, the friction factor f is obtained from the Moody Friction Factor Chart, Fig. 4 of Chapter 4.

The head loss in feet is given by the equation

$$h = \frac{fLV^2}{2gd} \tag{3}$$

where

f = friction factor.
L = length of pipe (100 ft).
g = acceleration due to gravity, 32.174 feet per (second) (second).

Table 3 . . . . Comparative Capacity of Steam Lines at Various Pitches for Steam and Condensate Flowing in Opposite Directions[a]
(Pitch of Pipe in Inches per 10 Ft. Velocity in Ft per Sec)

Pitch of Pipe . .	*¼ in.*		*½ in.*		*1 in.*		*1½ in.*		*2 in.*		*3 in.*		*4 in.*		*5 in.*	
Pipe Size Inches	*Capacity*	*Max. Vel.*	*Capacity*	*Max. Vel.*	*Capacity*	*Max. Vel.*	*Capacity*	*Max. Vel.*	*Capacity*	*Max. Vel.*	*Capacity*	*Max. Vel.*	*Capacity*	*Max. Vel.*	*Capacity*	*Max. Vel.*
	Capacity Expressed in Pounds per Hour															
¾	6.3	12	7.6	14	9.3	18	10.1	19	10.6	20	11.5	21	11.9	22	12.3	23
1	11.5	12	13.2	15	15.8	17	17.5	20	18.8	22	20.8	23	22.0	25	22.6	26
1¼	26.2	18	29.3	20	33.3	23	36.1	25	38.5	27	41.3	28	43.2	29	44.6	31
1½	35.7	18	39.8	21	45.3	23	49.1	25	52.3	27	56.0	28	58.7	30	60.7	31
2	59.0	19	65.9	20	74.9	23	81.4	25	86.6	27	92.4	28	97.1	29	100.3	30

[a] From The American Society of Heating and Air-Conditioning Engineers Research Laboratory.

The pressure drop in psi per 100 ft of pipe is

$$\Delta P = \frac{\rho \Delta h}{144} \tag{4}$$

Pipe Sizes

The determination of pipe sizes for a given load in steam heating depends on the following principal factors:

1. The initial pressure and the total pressure drop which may be allowed between the source of supply and at the end of the return system.
2. The maximum velocity of steam allowable for quiet and dependable operation of the system, taking into consideration the direction of condensate flow.
3. The equivalent length of the run from the boiler or source of steam supply to the farthest heating unit.
4. The direction of flow of the condensate, whether against or with the steam.

Initial Pressure and Pressure Drop

Theoretically, there are several factors to be considered such as initial pressure and pressure required at the end of the line, but it is most important that: (1) the total pressure drop does not exceed the initial gage pressure of the system, and in actual practice it should never exceed one-half of the initial gage pressure; (2) the pressure drop is not so great as to cause excessive velocities; (3) there is a constant initial pressure, except on systems specially designed for varying initial pressures, such as the subatmospheric, which normally operate under controlled partial vacuums, and orifice and vapor systems, which at times operate under such partial vacuums as may be obtained due to the condition of the fire; and (4) the rise in water due to pressure drop does not exceed the difference in level, for gravity return systems, between the lowest point on the steam main, the heating units, or the dry-return, and the boiler water line.

Table 2 lists pressure drops in common use with corresponding initial steam pressures for sizing steam piping. It is common practice to limit the total drop in the supply piping to approximately ⅓ of the initial pressure. The allowable pressure per 100 ft is thereby determined by the equivalent length. Designers may utilize total pressure drops up to ½ the initial pressure when steam velocities and operating pressure requirements of the selected equipment will permit. For initial pressures of 30 psig and higher many designers prefer to size steam piping on the velocity method.

The total pressure drop should never exceed one-half of the initial gage pressure when condensate is flowing in the same direction as the steam. Where the condensate must flow counter to the steam, the governing factor is the velocity permissible without interfering with the condensate flow. ASHAE Research Laboratory experiments limit this to the capacities given in Table 3 for horizontal pipes at various grades.

Maximum Velocity

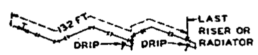
The capacity of a steam pipe in any part of a steam system depends upon the quantity of condensate present, the direction in which the condensate is flowing, and the pressure drop in the pipe. Where the quantity of condensate is limited and is flowing in the same direction as the steam, only the pressure drop need be considered. When the condensate must flow against the steam, even in limited quantity, the velocity of the steam must not exceed limits above which the disturbance between the steam and the counter-flowing water may produce objectionable sounds, such as water hammer, or may result in the retention of water in certain parts of the system until the steam flow is reduced sufficiently to permit the water to pass. The velocity at which such disturbances take place is a function of (1) the pipe size, whether the pipe runs horizontally or vertically; (2) the pitch of the pipe if it runs horizontally; (3) the quantity of condensate flowing against the steam; and (4) freedom of the piping from water pockets which under certain conditions act as a restriction in pipe size.

Table 4 . . . . Length in Feet of Pipe to be Added to Actual Length of Run—Owing to Fittings—To Obtain Equivalent Length

Size of Pipe Inches	*Length in Feet to be Added to Run*				
	Standard Elbow	*Side Outlet Tee[b]*	*Gate Valve[a]*	*Globe Valve[a]*	*Angle Valve[a]*
½	1.3	3	0.3	14	7
¾	1.8	4	0.4	18	10
1	2.2	5	0.5	23	12
1¼	3.0	6	0.6	29	15
1½	3.5	7	0.8	34	18
2	4.3	8	1.0	46	22
2½	5.0	11	1.1	54	27
3	6.5	13	1.4	66	34
3½	8	15	1.6	80	40
4	9	18	1.9	92	45
5	11	22	2.2	112	56
6	13	27	2.8	136	67
8	17	35	3.7	180	92
10	21	45	4.6	230	112
12	27	53	5.5	270	132
14	30	63	6.4	310	152

[a] Valve in full open position.
[b] Values given apply only to a tee used to divert the flow in the main to the last riser.

Example of length in feet of pipe to be added to actual length of run.



Measured Length	=	132.0 ft
4 in. Gate Valve	=	1.9 ft
4-4 in. Elbows	=	36.0 ft
2-4 in. Tees	=	36.0 ft
Equivalent	=	205.9 ft

Reaming Important

It is extremely important that the ends of all pipe be reamed or filed. This insures full pipe area and minimizes disturbance of the steam or condensate stream.

Equivalent Length of Run

All tables for the flow of steam in pipes, based on pressure drop, must allow for the friction offered by the pipe, as well as for the additional resistance of the fittings and valves. These resistances generally are stated in terms of straight pipe; in other words, a certain fitting will produce a drop in pressure equivalent to the stated number of feet of straight run of the same size of pipe. Table 4 gives the number of feet of straight pipe usually allowed for the more common types of fittings and valves. In all pipe sizing tables in this chapter the *length of run* refers to the *equivalent length of run* as distinguished from the *actual length* of pipe