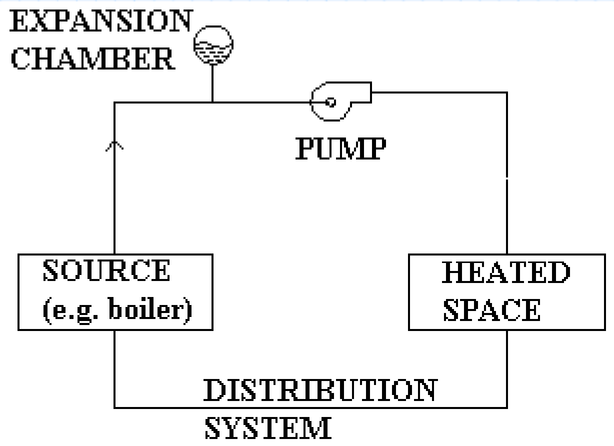
CHAPTER 11 HEATING — HYDRONIC SYSTEM SIZING

11.1 Boiler, Piping System, and Pump

A closed hydronic system contains a few major components; in the case of heating the system usually consists of a heat source such as a boiler, piping and distribution system (including radiators, baseboards etc.), expansion tank to accommodate water volume changes, and a pump to circulate the water.



HYDRONIC SYSTEM - MAJOR COMPONENTS

The sizing of a hydronic heating system and its components follows a number of steps as follows:

1. Determine the peak load for each zone (area in which a heat distribution device such as a radiator is to be located) using a technique such as the one given in section 9.2. This should be the output of the radiators (or other device) in each zone.

2. The sum of the peak loads from the zones Qh , plus standby losses from the boiler (e.g. 1-3%) and losses from piping Qp is equal to the boiler output Qout.

$$Qout = Qh + Qp$$

3. The ratio of the energy output Qout to the energy input Qin (calorific value of fuel) is the efficiency Eff of the boiler.

$$Eff = \frac{Qout}{Qin}$$

4. In general, if we oversize the radiators by about 10-20%, then Qout and Qh may be assumed to be equal for design purposes. The **pump flow rate** Qv required to deliver the hot water is determined from the following equation:

$$Qv = \frac{Qh}{\rho \cdot c \cdot (Tsup - Tret)}$$

where ρ = density
c = specific heat capacity of water
Tsup = supply water temperature
Tret = return water temperature

5. The basic pressure drop equation (Darcy-Weisbach) for Newtonian fluids is:

$$\Delta p = f \cdot \frac{L}{D} \cdot \rho \cdot \frac{V^2}{2}$$

V is velocity — *f* is friction factor

D is diameter — L is length

Head form: $$\Delta h = \frac{\Delta p}{\rho \cdot g}$$

The friction factor f depends on the Reynolds dimensionless number and the roughness of the pipe. The friction factor may be determined from the Moody Chart or from correlation equations such as the Hazen-Williams equation used below.

Pressure losses in valves and fittings may be expressed as an equivalent length of pipe or using a loss coefficient k:

$$\Delta p = k \cdot \rho \cdot \frac{V^2}{2}$$

We typically select pipe sizes based on the desired flow rate and the available or allowable pressure drop.

Piping System Calculations

The Hazen-Williams equation is used in calculating pressure drops in pipes:

$\rho := 983\ \frac{kg}{m^3}$ density of water at 60 degC $g := 9.81\ \frac{m}{s^2}$

$C := 140$ roughness constant for copper pipe and plastic pipe

$$p(L,V,D) := 6.819 \cdot L \cdot \left(\frac{\frac{V}{\frac{m}{s}}}{C}\right)^{1.852} \cdot \left(\frac{1}{\left(\frac{D}{m}\right)^{1.167}}\right) \cdot \rho \cdot g$$

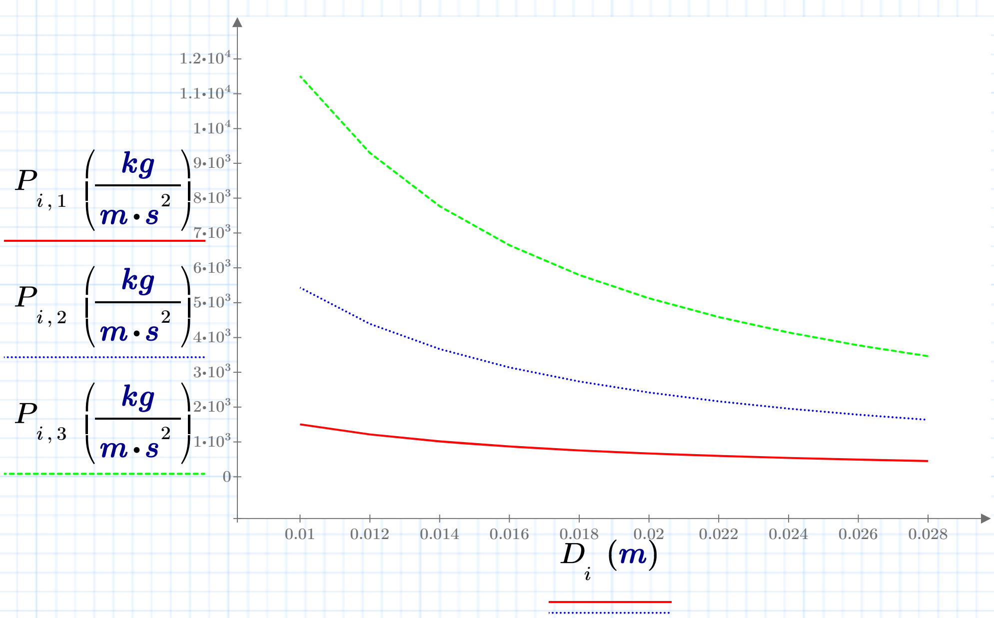
pressure drop (Pa) in pipe with internal diameter D (m) length L (m) and average flow velocity V (m/s)

$L := 1\ m$ $i := 1,2..10$ $j := 1,2..4$

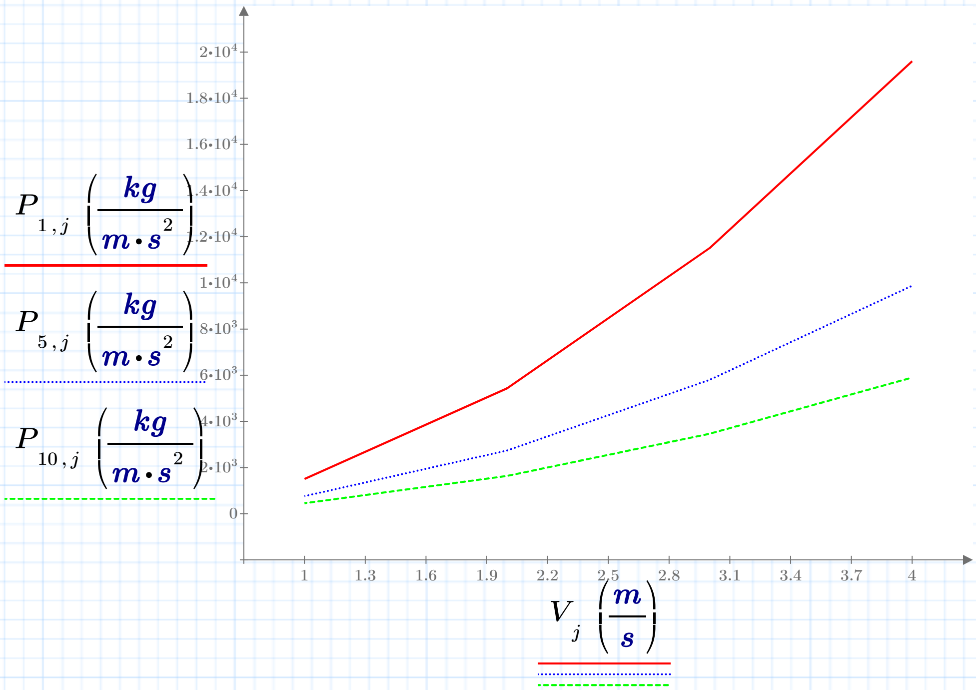
$D_i := (0.008 + i \cdot 0.002) \cdot m$ $V_j := j \cdot \frac{m}{s}$

$P_{i,j} := p\left(L, V_j, D_i\right)$ pressure drop as a function of length, velocity and diameter

VARIATION OF P WITH DIAMETER



VARIATION OF P WITH VELOCITY



Example: For a pipe of diameter 20 mm and water flow velocity 1 m/sec:

$D_6 = 0.02\ m$ $\qquad V_1 = 1\ \frac{m}{s}$ $\qquad P_{6,1} = 669.903\ Pa$

Compare with the following parameters:

$D := 0.025 \cdot m$ $\qquad V := 1.5 \cdot \frac{m}{s}$ $\qquad p(L,V,D) = \left(1.094 \cdot 10^3\right)\ Pa$

$Qv := \pi \cdot \frac{D^2}{4} \cdot V$ $\qquad Qv = 0.736\ \frac{liter}{s}$ $\qquad$ ..flow rate

Pump and Piping System Calculations

ASHRAE (1996) recommends a range of friction loss 100 - 400 Pa/m for piping. A value of 250 Pa/m is the usual design average. The recommended velocity limit to reduce piping noise is 1.2 m/s. Minimum velocities of about 0.5 m/s are recommended to avoid cavitation. Pipe diameter needs to be selected before detailed calculation of influence of fittings. A common design rule-of-thumb is that actual piping length is 50-100% longer than actual to account for fitting losses.

Example: Consider a house with a floor area of 170 sq. m. and a peak load of 21 kW. Its hydronic heating system feeds hot water to nine radiators/convectors and a domestic hot water heater (solar).

$Qh := 21000\ watt$ — total capacity of radiators plus domestic hot water heater (rooftop solar collector)

$c := 4200 \cdot \frac{joule}{kg}$ — specific heat of water

$Tret := 70\ \Delta°C$ $\qquad Tsup := 80\ \Delta°C$

$Qv := \frac{Qh}{\rho \cdot c \cdot (Tsup - Tret)}$ $\qquad Qv = 0.509\ \frac{liter}{s \cdot K}$ — volumetric flow rate to be supplied by pump

Approximate Estimate of Pressure Drops and Velocity in Pipes Based on Required Flow Rates

Portion going to solar heater (3000 watts):

$Qv_{solar} := \frac{3000 \cdot watt}{Qh} \cdot Qv$ $\qquad Qv_{solar} = 0.073\ \frac{liter}{s \cdot K}$

Select pipe diameter to water heater:

$D_{solar} := 0.013\ m$ $\qquad V := \frac{Qv_{solar} \cdot 4}{\pi \cdot D_{solar}^{2}}$

$V = 0.547\ \frac{m}{s \cdot K}$ $\qquad p(L, V, D) = 169.172\ \frac{1}{K^{\frac{463}{250}}}\ Pa$

Pipe diameter - main supply pipe (nominal 28 mm OD)

$D_1 := 0.025\ m$ $\qquad V := \frac{Qv - Qv_{solar}}{0.25 \cdot \pi \cdot D_1^{2}}$

$V = 0.888\ \frac{m}{s \cdot K}$ $\qquad p(L, V, D) = 414.515\ \frac{1}{K^{\frac{463}{250}}} \cdot Pa$

Three 22 mm OD takeoffs from the main pipe:

$D_2 := 0.019\ m$ $\qquad V := \frac{Qv - Qv_{solar}}{\left(0.25 \cdot \pi \cdot D_2^{2}\right) \cdot 3}$

$V = 0.513\ \frac{m}{s \cdot K}$ $\qquad p(L, V, D) = 149.754\ \frac{1}{K^{\frac{463}{250}}} \cdot Pa$

Three 13 mm OD branches from each 22 mm pipe (feeding a total of 9 radiators)

$D_3 := 0.010\ m$

$V := \dfrac{Qv - Qv_{solar}}{\left(0.25 \cdot \pi \cdot {D_3}^2\right) \cdot 9}$

$V = 0.617\ \dfrac{m}{s \cdot K}$

$p(L, V, D) = 210.985\ \dfrac{1}{K^{\frac{463}{250}}} \cdot Pa$

Assuming a reverse return system and each branch having a length of 5m, and doubling the total length to account for fittings (i.e. effective length is 5x2x2=20m for each branch), the total pressure drop that must be overcome by the pump is:

$Ppump := 20 \cdot m \cdot (415 + 150 + 211) \cdot \dfrac{Pa}{m}$

$Ppump = \left(1.552 \cdot 10^4\right)\ Pa$

Therefore the pump must be able to supply Qv-Qvsolar at 15 kPa. A separate pump is chosen in a similar manner for the collector. The pressure that it must overcome is (assuming distance 6x2x2=24m) determined by:

$Ppump := 24 \cdot m \cdot \left(169 \cdot \dfrac{Pa}{m}\right)$

$Ppump = \left(4.056 \cdot 10^3\right)\ Pa$

A more detailed analysis is necessary to evaluate precisely pressure drops and flow rates. We may write a set of nonlinear equations based on pressure drops between nodal (branch-off) points and mass balance at the nodal points. For example:

Qtotal_into_node = Sum of flows out of node

$$Q_{total} = \sum_{branches} \sqrt{\frac{\Delta P_i}{R_i}}$$

where

Q_{total} = total flow into node

R_i = fluid resistance of branch i (flow away from node)

ΔP_i = pressure drop across branch i

The above equation may be written for all the nodes. Then, these equations may be solved to obtain exact flow rates and pressure drops.

References

ASHRAE, 1996, Handbook- Systems and Equipment, Atlanta, GA.