Copper Development Association

COPPER
the professional choice
for plumbing
and heating systems

COPPER TUBES IN DOMESTIC HEATING SYSTEMS

Pipe Sizing: Basic Principles

Introduction

Tube diameters for central heating circuits should be selected so that there is sufficient volume of water flowing at a high enough temperature. This will enable each heat emitter to deliver its manufacturer's rated heat output, without the water velocity exceeding the tube manufacturer's recommended limits.

For many domestic heating system designers and installers, pipe sizing is a matter of choosing tube diameters, that have proved to give satisfactory results. However, this can result in problems due to incorrect water flow velocity. Where the chosen diameter is too large, so that the velocity is less then 0.5 m/s, then sludge can settle in the piping. Conversely, if the diameter chosen is too small, with a velocity greater than 1.5 m/s, the water flow will be loud and disruptive, particularly if the pump output is increased to compensate for this. Furthermore, pipe walls will erode if the heating water velocity exceeds 2.5 m/s.

This article will describe the principles that need to be understood to select correct tube diameters for two-pipe and microbore wet central heating systems.

Simple trial and error can be used to calculate tube diameters; estimate the diameter and then calculate flow resistances to determine the accuracy of the estimate. If it is not accurate, repeat the process with a different tube diameter.

Flow rates

Water is a good heat carrying medium: and its high **specific heat capacity** of 4.2 kJ/kg/°C means that relatively small volumes of water flow can carry significant quantities of heat energy. This means that

Table 1 Fitting resistance's as equivalent straight lengths of copper tube (m)

	Tube Diameter (mm)						
Fitting type	6	8	10	12	15	22	28
Straight pattern valve	0.07	0.11	0.15	0.20	0.30	0.40	0.60
Angle pattern valve	0.90	1.00	1.50	1.80	2.00	4.30	6.00
Minimum radius bend	0.08	0.12	0.16	0.20	0.26	0.41	0.58
Capillary elbow	0.10	0.16	0.21	0.28	0.37	0.60	0.83
Compression elbow	0.16	0.24	0.33	0.42	0.60	1.00	1.30
Square tee	0.17	0.27	0.37	0.49	1.00	1.60	2.00
Manifold connection	0.60	0.60	1.00	1.20	-	-	-

smaller diameter tubes are able to supply large output heat emitters.

For design purposes, the water flow temperature can usually be taken to be 82°C. The water volume required depends on the **heat emitter output** and the **temperature drop** across the circuit. The temperature drop is usually taken to be 11°C, and so we can determine the water volume or **mass flow rate** required by each heat emitter by using the formula:

Mass flow rate required =
Heat emitter output ÷ specific heat
capacity x temperature drop

Because the specific heat capacity of water is a constant at 4.2 kJ/kg/°C and (for two-pipe layouts) if we use a standardised temperature drop of 11°C around the circuit, then the mass flow rate required (measured in kg/s) can be found by dividing the heat emitter output in watts by 46.

For example: A radiator rated heat output of 5 kW, (5000 W) would require a mass flow rate of:

5 ÷ 46 = 0.109 kg/s

Table 2 Resistance to flow (m head per m run of copper tube)

Flow rate	Tube Diameter x Wall Thickness (mm)						
(kg/s)	6 x 0.6	8 x 0.6	10 x 0.6	12 x 0.6	15 x 0.7	22 x 0.9	28 x 0.9
0.005	0.047	0.007	0.002	0.001			
0.010	0.114	0.022	0.006	0.003	0.001	Oversized	
0.015	0.231	0.044	0.013	0.005	0.002	(velocity	
0.020	0.389	0.073	0.022	0.008	0.003	too low)	
0.025	0.566	0.111	0.032	0.012	0.004	0.001	
0.030		0.151	0.044	0.017	0.006	0.001	
0.035		0.197	0.058	0.020	0.007	0.001	
0.040		0.243	0.072	0.025	0.009	0.001	
0.045		0.300	0.089	0.032	0.011	0.002	0.001
0.050		0.362	0.108	0.039	0.014	0.002	0.001
0.060			0.148	0.055	0.018	0.003	0.001
0.070			0.192	0.072	0.024	0.004	0.001
0.080			0.247	0.092	0.030	0.005	0.001
0.090				0.110	0.037	0.006	0.002
0.100				0.134	0.044	0.007	0.002
0.120				0.183	0.061	0.009	0.003
0.140					0.080	0.013	0.004
0.160					0.102	0.016	0.005
0.180		Undersized			0.125	0.019	0.006
0.200		(velocity		0.152	0.023	0.007	
0.250		too high)			0.034	0.010	
0.300						0.047	0.014
0.350						0.062	0.018
0.400						0.079	0.023
0.500							0.034
0.600							0.047
0.700							0.062

Flow resistance

Turbulence is created as water circulates around the system - changes of direction caused by elbows, bends tees and valves. This friction causes a loss of pump pressure. Ordinary panel type convector radiators and traditional boilers with large cast iron heat exchangers offer very low resistance to flow and so can usually be ignored. Modern low water content boilers with finned tube heat exchangers can offer significant resistance to the water flow; in this case the manufacturer's data sheet can be consulted to ascertain the extent of this.

Resistance to flow caused by fittings is best dealt with by adding their "**equivalent lengths**" of straight tube to the actual length of tube needed for each section. When selecting tube diameters for simple domestic type installations the resistance of "full-way" valves and water passing straight through tees can be ignored. Table 1 gives equivalent lengths of straight copper tube for a variety of fitting patterns.

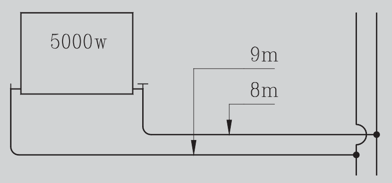

Figure 1

For example: take a 17m run (9 + 8 m flow and return) of 12 mm diameter tube, including 2 angle pattern valves 2 bends and 2 square tee connections, as shown in Figure 1.

The total equivalent length will be:

17 + 1.8 + 1.8 + 0.2 + 0.2
+ 0.49 + 0.49 = 21.98 m

Flow resistance per unit length of tube

Once the mass flow rate is known and the diameter of tube estimated, the resistance to flow per unit length of tube can be found by referring to Table 2. Use the first column to find a figure equal to or slightly above that required, then trace along that row for the corresponding number. This will give the minimum tube diameter necessary. If you find that this resistance is too great, choose a larger diameter; this will result in a lower resistance.

Returning to our example: if the mass flow rate required by the heat emitter is 0.109 kg/s and the tube diameter chosen is 12 mm, then (from Table 2, and using 0.120 kg/s, as the closest value above that required) the resistance to flow will be found to be 0.183 metres head/metre run of tube.

Total resistance

Once the resistance to flow per unit run of tube is obtained, the figure can be multiplied by the equivalent length of tube to give the total resistance in metres head for the section:

Total resistance of section =
equivalent length (m) x resistance to
flow (m head / m run of tube)

Returning to our example:

21.98 m x 0.183 m head / m run
= 4.022 m

Pump performance

This is a high resistance, due to the relatively long run of tube needed for a fairly high flow rate. In a case like this, you may find that the pump chosen cannot produce the required head. The pump performance graph (illustrated in figure 2) shows that this particular pump would not be able to satisfy the flow rate needed at the required pressure. This is because the operating point is above the line for its maximum setting (5). We must therefore choose a larger diameter tube and recalculate the resistance.

So, in our example the new total equivalent length for 15 mm diameter tube will be:

17 + 2.0 + 2.0 + 0.26 + 0.26
+ 1.0 + 1.0 + = 23.52 m.

The mass flow rate remains at 0.109 kg/s, but the resistance to flow for the run drops to 0.061 m head / m run. This results in a total resistance of 23.52 x 0.061 = 1.43 m head which is now well within the capacity of the pump.

Index circuit

The circuit with the greatest total resistance (this usually includes the most remote heat emitter) is known as the "index circuit". If the pump can deliver pressure needed for this section of the system at the volume flow rate required, the pipes are adequately sized, and all the system will circulate correctly after balancing and commissioning.

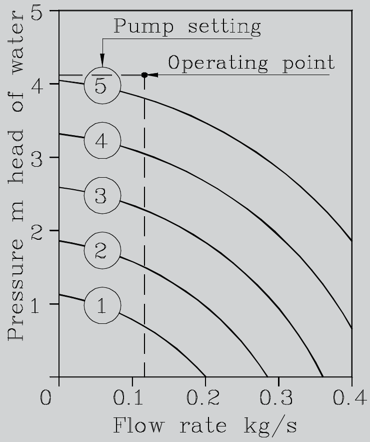

Figure 2

Pipe Sizing: Tabulation Method

Tabulation Method

In the first part of this article, we looked at the basic principles of pipe sizing for heating systems. To apply the principles of heating pipe sizing, we need to consider the installation of a small domestic heating system. The proposed system comprises a low water content boiler, (with a flow resistance of 0.275 m head), 5 convector radiators and an indirect 'quick-recovery' hot water storage cylinder. These are fed by a two-pipe fully pumped system of flow and return mains with a three-port diverter valve. System controls will give priority to the hot water cylinder. First, draft a schematic diagram of the proposed layout, adding estimates of actual pipe lengths. A typical sectional schematic is illustrated in Figure 3, (alternatively the data could be noted on a plan of the layout).

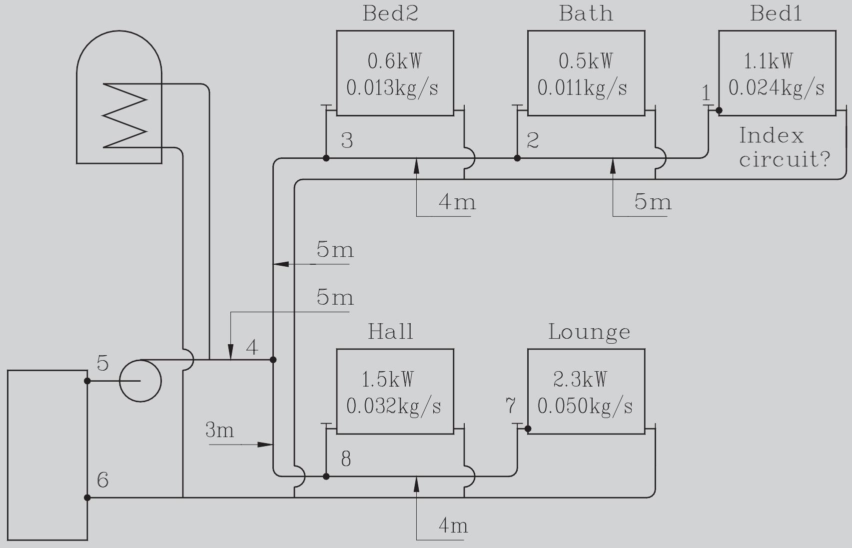

Figure 3

Note: for simplicity on this example a diverter valve controls the heating / hot water and so either the heating, or the hot water, (but not both) will circulate. Where a-mid position valve that allows simultaneous heat-up of both hot water and heating is used the flow circuit to the hot water cylinder would also have to be considered.

Heat emitter schedule

1	2	3
Room	Heat output required (kW)	Mass flow rate (kg/s) Column 2÷46
Lounge	2.3	0.050
Hall	1.5	0.032
Bedroom 1	1.1	0.024
Bedroom 2	0.6	0.013
Bathroom	0.5	0.011
Total	6.0	0.130

Next, a heat emitter schedule can be created. This should be based on the room heat loss requirements, listing the room types with their associated heat emitter outputs in watts. These figures can all be divided by 46, (assuming an 11°C temperature drop) to obtain the mass flow rates required for each emitter. It will also help if the mass flow rates are then added to the schematic layout drawing, see figure 3 again.

Reference numbers

Number each section of piping on the drawing, starting with the most remote heat emitter, working back towards the boiler and number each tee, (along what will probably be the index circuit). These piping references, 1-2, 2-3, 3-4 etc. should then be transferred to column 1 on the tabulation chart, (see later).

Heating system tabulation chart

1	2	3	4	5	6	7	8	9
Pipe reference	Mass flow rate (kg/s) From schedule	Assumed tube dia. (mm)	Measured length (m)	Fitting lengths (m) from Table 1	Equivalent length (m) Columns 4+5	Resistance to flow (m/m run) from Table 2	Total resistance (m head) Columns 6x7	Final tube dia (mm)
1-2	0.024	10	5	1.71	6.71	0.032	0.215	10
2-3	0.035	12	4	2.29	6.29	0.020	0.126	12
3-4	0.048	12	5	2.57	7.57	0.039	0.295	12
4-5	0.130	15	5	1.00	6.00	0.007	0.042	15
6-1	Upper floor return - calculated as sum of runs 1-5 as above						0.678	As above *
						Circuit Total	1.356	
7-8	0.050	12	4	1.71	5.71	0.039	0.223	12
8-4	0.082	12	3	2.57	5.57	0.110	0.613	12
6-7	Lower floor return - calculated as sum of runs 7-8 and 8-4 as above						0.836	As above *
						Circuit Total	1.672	
5-6	0.130	Boiler - resistance obtained from manufacturer's data					0.275	-
						Index Circuit Total	1.947	

* Note: flow and return tube diameters will normally be the same for each section of the circuit.

Mass flow rates

Next we have to determine the mass flow rate through each section of piping. Section 1-2 supplies bedroom 1 heat emitter only, so the mass flow rate to enter into column 2 on the tabulation chart for this section is 0.024 kg/s. Section 2-3 however supplies both bedroom 1 and the bathroom heat emitter, so its mass flow rate will therefore be the sum of the flow rates for these two heat emitters: 0.024 + 0.011 = 0.035 kg/s. This is the figure that should be entered in column 2 for pipe section 2-3. Moving further along the pipe run, section 3-4 supplies all three upper-floor heat emitters, a total of 0.024 + 0.011 + 0.013 = 0.048 kg/s, and again this mass flow rate figure should be entered into column 2 for pipe section 3-4.

Piping section 4-5 serves all the heat emitters on both the upper and lower floors, so its mass flow rate will be 0.13 kg/s, this figure should again be entered in column 2. Furthermore, because the control system uses a diverter valve, this figure will also be the mass flow rate for the boiler, represented by section 5-6 on the tabulation chart. The return piping, section 6-1 can then complete the upper floor circuit, and for most simple two-pipe domestic system layouts we can use the same resistance figures for the flow for this section, see again the tabulation chart.

Moving on to the lower floor circuit, the lounge heat emitter is supplied by piping section 7-8, and its mass flow rate of 0.050 kg/s can be entered into the appropriate row of column 2. Section 8-4 feeds both lounge and hall emitters, its mass flow rate will be 0.050 + 0.032 = 0.082 kg/s and again

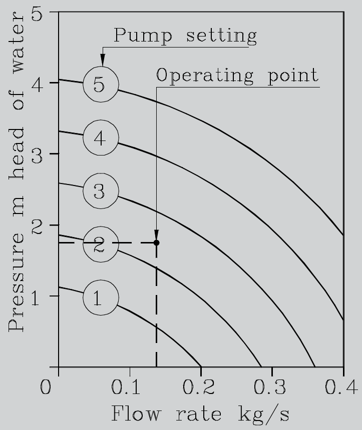

Figure 4

Heating system tabulation chart

1	2	3	4	5	6	7	8	9
Pipe reference	Mass flow rate (kg/s) From schedule	Assumed tube dia. (mm)	Measured length (m)	Fitting lengths (m) from Table 1	Equivalent length (m) Columns 4+5	Resistance to flow (m/m run) from Table 2	Total resistance (m head) Columns 6x7	Final tube dia (mm)

this figure can be entered into column 2. As with the upper floor circuit, the return section 6-7 is simply a repeat of the flow piping resistance figures.

Assumed tube diameter

We now have to assume suitable tube diameters for the various sections of piping as this will enable us to estimate the equivalent lengths for fittings. We can use table 2 to do this. Using the first column, locate a figure that is equal to, or slightly above, the mass flow rate required for that section of piping. For pipe section 1-2 this would be 0.025 kg/s. The table indicates that we could choose any diameter from 6 to 22 mm for this section, however, the smaller the tube diameter chosen the higher the resistance to flow will be. If 6 mm diameter were proposed then the resistance to flow would be high at 0.566m head per metre run. At the other extreme, if 22 mm tube were proposed, the resistance to flow would be only 0.001m head/m run. For this pipe section we will choose 10 mm tube, we can note this diameter in column 3, and its resistance figure of 0.032m head per m run, can also be entered into column 7 of the tabulation chart. Using the same technique, we can estimate that 12 mm tube would be suitable for pipe section 2-3; it would have a resistance of 0.020 m head/m run, and these figures can be entered on the chart.

Heat emitter schedule

1	2	3
Room	Heat output required (kW)	Mass flow rate (kg/s) Column 2÷46
Total		

This process can be repeated for each section of piping with figures entered into columns 3 and 7 as appropriate, see tabulation chart for assumed tube diameters.

Measured lengths

Column 4 is used to record the actual lengths of tube required for the various piping sections. Studying Figure 3 shows us that section 1-2 is 5m long, the figure to enter into column 4 of the tabulation chart. This process can then be repeated for each numbered section of piping, referring again figure 3 and the tabulation chart.

Equivalent lengths of fittings

Piping section 1-2 has an assumed diameter of 10 mm, and the fittings required are 1 angle valve and 1 capillary elbow. Studying Table 1 shows that the length for the angle valve is 1.5 m whilst the length for the elbow is 0.21 m, a total of: 1.5 + 0.21 = 1.71 m. This total can be noted in column 5 of the tabulation chart and added to the measured length figure in column 4. In this case 5 + 1.71 = 6.71 m is the total equivalent length figure for the section of piping and its fittings and this figure should be noted in column 6. Section 2-3's diameter is 12 mm and its fittings comprise 1 angle valve and 1 tee, the equivalent lengths totalling 1.8 + 0.49 = 2.29 m. Again this can then be added to the figure from column 4 to give the total equivalent length for piping section 2-3, in this case 4 + 2.29 = 6.29m. This process should be repeated for the remaining sections of piping, (3-4 and 4-5) for this circuit.

Total resistance

Column 8 of the tabulation chart is used to determine the total resistance for each section of piping; this is achieved by using the figures from columns 6 and 7. For piping section 1-2 the figures to be multiplied are 6.71 x 0.032 = 0.215 m head. This calculation can now be repeated for piping sections 2-3, 3-4 and 4-5 with the results noted in column 8.

The figures in column 8 for piping sections 1-5 can now be totalled: 0.215 + 0.126 + 0.295 + 0.042 = 0.678 m head, this gives the flow resistance for the upper floor circuit return piping, which is section 6-1, and this figure should also be noted in column 8. The total resistance for this circuit is the sum of these resistances: 0.215 + 0.126 + 0.295 + 0.042 + 0.678 = 1.356m head, see again tabulation chart.

This process can be repeated for the remaining piping sections of the lower floor circuit.

Boiler resistance

As the proposed boiler has a relatively high flow resistance, the manufacturer's data sheet can be consulted to find out the actual flow resistance through its heat exchanger. In this case the figure is 0.275 m head, and this too should be noted in column 8.

Index circuit

We can now compare the total resistances for each of the circuits: the upper floor resistance is 1.356 m head; the lower floor circuit is 1.672 m head, (not including the resistance of piping section 4-5 which is shared between the two circuits). This means that the index for this example is the lower floor circuit. This is because the lounge and hall heat emitters have higher mass flow rates, and using 12 mm diameter tube for this circuit will result in a higher resistance to flow. This is not a problem provided that the pump pressure required is not too large. If it is, then the tube diameters chosen are too small and should be increased and the resistances recalculated.

Pump setting point

The boiler resistance figure has to be added to the Index Circuit resistance: 1.672 + 0.275 = 1.947 m head, to give us the pump pressure required to circulate the water around our system, and it, together with the figure for the total mass flow rate, 0.13 kg/s, will enable us to find the pump setting point. In this case the lines representing pump pressure and flow rate intersect in the area between setting points 2 and 3, see Figure 4. When commissioning the system, the pump should therefore be set to position 3.

Brian Curry, April 2001

Copper Development Association

COPPER
the professional choice
for plumbing
and heating systems

UK Copper Board
5 Grovelands Business Centre, Boundary Way, Hemel Hempstead, Herts. HP2 7TE
e-mail: copperboard@copperdev.co.uk
www.ukcopperboard.co.uk