

Appendix 1.A1 Hydronic system design

1.A1.1 Introduction

Hydronics is the use of water as the heat transfer medium in heating and cooling systems. In building services applications heating and cooling is commonly delivered by means of water circulated from central plant to terminal units via a re-circulating pipework system.

This guide is intended to give an overview of the main issues that need to be considered during the design of hydronic systems. The guide covers both design aspects and the practical issues that need to be considered. The scope includes:

- pipe material and jointing method selection
- pipe and pump sizing
- heat transfer to and from pipes
- thermal expansion
- system pressurisation
- flow temperature control
- variable flow design considerations
- dirt and air removal
- commissioning considerations.

The guidance is applicable to medium and large scale re-circulating systems for non-domestic applications up to operating pressures of 10 bar including low, medium and high temperature heating systems, and chilled water or condenser cooling water systems.

Where necessary, reference is made to other publications for more detailed guidance.

1.A1.2 Pipe materials and jointing methods

1.A1.2.1 Pipe materials

Pipes are fabricated in a variety of materials. The most common alternatives that are applicable to heating or cooling water applications are as follows:

Steel to BS EN 10255 (BSI, 2004)

Steel is commonly selected for pipe sizes larger than 25 mm in diameter due to its strength and cheapness. The main drawback of steel pipe is that it will corrode rapidly in the presence of water and oxygen. Hence, external surfaces should be painted with an anti-corrosion paint whilst internal surfaces should be protected by corrosion inhibitor chemicals.

Thin-walled steel

Alternative steel products are available which offer some advantages over the more traditional steel pipes. Commonly referred to as 'thin-walled steel', the pipes are manufactured such that they are seamless rather than longitudinally welded. This means that the pipe is inherently stronger and can be manufactured with thinner walls. Because they are thinner, they are therefore lighter and easier to handle than normal steel pipes. The internal surfaces also tend to be machined to a much smoother finish thereby reducing the surface roughness. However, bare walled thin steel tubes will corrode in water and, due to the thinness of the walls, will fail more quickly than steel pipes with thicker walls. It is therefore essential that an effective water treatment regime is in place to protect the pipes as soon as they are filled. The pipes should not be used in damp locations where external corrosion could be a problem.

Copper to BS EN 1057 (BSI, 2006)

Copper is commonly selected for smaller pipes, 15–25 mm in size. In larger systems copper is often used as an alternative to steel for final run outs to terminal units. Although more expensive than steel, it has the advantage of being quicker to install. It is also smoother than steel and is less likely to corrode.

Stainless steel

Stainless steel is commonly used where water quality and hygiene is a priority including food, pharmaceutical and healthcare environments. Pipes are available in sizes up to 800 mm. Pipes are smooth bore and extremely resistant to corrosion.

Multilayer pipe

Multilayer pipe is an aluminium pipe that is coated internally and externally with either cross linked polyethylene or high density polyethylene. The aluminium core gives the pipe the strength of a metal pipe whilst the plastic coating makes the pipe corrosion resistant. The aluminium layer also makes the pipe impervious to oxygen ingress (a problem with some pure plastic pipes). Multilayer pipe is commonly selected as an alternative to copper for smaller pipe run-outs to terminal units. In small sizes 15–25 mm diameter, the pipe is flexible and can be bent by hand making it quick to install.

Plastic pipes

A variety of pure plastic pipes are available for heating and chilled water applications. These include:

- chlorinated polyvinyl chloride (PVC-C)
- unplasticised polyvinyl chloride (UPVC)

- medium and high density polyethylene (MPDE, HDPE)
- acrylonitrile butadiene styrene (ABS)
- polybutylene (PB)
- polypropylene (PP)
- cross linked polyethylene (PE-X).

The pressure and temperature ratings of most pure plastic pipes are lower than those for metal pipes and their expansion rates are considerably higher. However, the pipes are clean, corrosion resistant and, if flexible, may be faster to install.

Table 1.A1.1 provides a summary of the properties of common pipe materials.

1.A1.2.2 Factors influencing choice of pipe material

The following factors should be taken into account when deciding on the appropriate pipe material for a given applications.

Pipe strength

The pipe material selected and its jointing system must be able to withstand the maximum operating pressure in the system without leaking. Advice on calculating the maximum system operating pressure is given in section 1.A1.6.

Temperature

Metal pipes have temperature ratings that are well above the normal range of heating and chilled water operating temperatures. Plastic pipes may not have such a wide range and need to be checked. It is sometimes the case that a plastic pipe can withstand high temperatures for temporary periods, but the continued operation of the system at that temperature may reduce the overall life expectancy of the pipe.

Flexibility

Some plastic pipes are flexible thereby avoiding the need for multiple elbow fittings. This can make the pipes quick to install. Some pipes such as multilayer pipe are flexible but also hold their shape and support their own weight once bent. Some pure plastic pipes, such as polybutylene, do not hold their shape and will sag under their own weight. These types of pipe may need special supporting arrangements.

Oxygen diffusion

Oxygen diffusion is a problem for many pure plastic pipes. Over a period of time, oxygen is able to diffuse through the plastic and become dissolved in the water. This can then cause accelerated corrosion in steel components such as pipes and radiators. Some plastic pipes have oxygen diffusion barriers in them that provide some degree of protection. Multilayer pipes incorporate a layer of aluminium which does make it impervious to oxygen ingress.

Thermal expansion

Thermal expansion must be allowed for during system design. Expansion that is not properly catered for may lead to misalignment and failure at joints. Section 5 of this

chapter explains the main options. Plastic pipes tend to expand far more than equivalent metal pipes. Flexible plastic pipes such as polybutylene accommodate the expansion by bending or warping between supports. Rigid plastic pipes such as polypropylene need to be installed such that expansion is accommodated horizontally along the length of the pipe, as for steel or copper pipes. For all plastic pipes, careful attention should be given to the manufacturer's fixing and jointing instructions.

Life expectancy

The life expectancy of some plastic pipes can vary significantly depending on the pressure and temperature conditions under which it is used. Assurances should be obtained from the manufacturer to ensure that the life expectancy of the pipe is suitable for the application.

Plastic pipes are increasingly considered as alternative to metal pipes. Table 1.A1.2 provides a summary of the advantages and disadvantages of plastic pipes.

1.A1.2.3 Pipe jointing methods

The main jointing methods for pipes are described below.

Threaded

Threaded or screwed joints are commonly used for small sized steel pipes, i.e. 50 mm diameter or less. Pipe threads are cut by dies and the resultant threads are rough and imperfect. A pipe jointing compound or thread sealant must therefore be used to prevent leakage from around the threads. The jointing compound also acts as a lubricant when tightening the joint.

Flanged

Bolted flange joints are used for 50 mm diameter and larger steel and plastic pipes. They are common where pipe, piping components, or equipment must be disassembled for maintenance purposes. Opposing flange faces are tightened against a rubber, fibre, composite or metal gasket. To ensure an effective seal the gasket and flange faces must be clean and free from dirt or other obstructions. The flange bolts must be tightened to the correct torque and in the correct sequence following the manufacturer's instructions.

Butt welding

Butt welded joints are commonly used for 65 mm diameter and larger steel pipes. Butt welding is thermal welding in which the ends of the pipe and/or fitting are welded. The most popular method for welding pipe is the shielded metal-arc process. Butt welding creates a weld bead, both internally and externally. These are often left in place, but can be removed using special tooling if necessary. In general, welded pipe joints offer less resistance to flow than mechanical connections such as threaded or grooved end joints, and the overall installation costs are less.

Socket welding

Socket welded joints are formed by inserting socket connections into the ends of each of the pipes to be joined. These joints are almost exclusively used in joining small bore piping. An advantage with this type of joint is that the

Table 1.A1.1: Properties of common pipe materials

	Steel	Stainless steel	Copper	PVC-C	PVC-U	ABS	MDPE and HDPE	PE-X	PB	PP	Multi-layer	
Rigid/semi-flexible/flexible	Rigid	Rigid	Rigid	Rigid	Rigid	Rigid	Semi-flexible	Flexible	Flexible	Rigid	Semi-rigid	
Sizes available (nominal diameter, mm)	6-150 (BS EN 10255)	10-600	6-159 (BS EN 1057)	16-160	8-315	16-315	20-1200	10-400	10-28	12-400	12-125	
Lengths or coils	Lengths	Lengths	Both	Lengths	Lengths	Lengths	Both	Both	Both	Both	Both	
Expansion rate (relative to steel)	1	1.5	1.5	6	6	8	10	15	11.5	12	2.2	
Expansion from 0 °C to 80 °C (mm/m)	0.9	1.4	1.4	5.6	5.6	7.5	9	13.6	10.4	10.8	2	
Maximum operating temperature (°C)	260	260	200	100	60°C	70	HDPE100: 80	90	95	100 max	100 max	
Maximum operating pressure at 20 °C (bar)				16 bar	16 bar	10 bar	PE80: 12 bar PE100: 16 bar	12 bar	12 bar	10 bar	20 bar	
Density kg/m ³ (approximately)	7860	8060	8940	1540	1400	1100	PE100: 938-970	936-955	910-930	903-907	903-907	
Joining (see also manufacturer's information)	Threaded Weld Flanges Grooved Press-fit	Compression Flanges Press-fit Push-fit	Compression Capillary Soldered Flanges Press-fit Push-fit	Solvent Flanges Threaded	Solvent Push-fit Flanges Threaded	Solvent Flanges Threaded	Compression Push-fit Electrofusion Butt fusion Flanges Threaded	Compression Flanges	Compression Flanges Weld Push-fit Electrofusion	Compression Flanges Weld Push-fit Electrofusion	Socket fusion Butt fusion Electrofusion Compression Press Fit	Socket fusion Butt fusion Electrofusion Compression Press Fit

Table 1.A1.2 Advantages and disadvantages of plastic pipes

Advantages	Disadvantages
Plastic pipes usually supplied in coils, therefore individual pipe runs can be cut to length on site to minimize joints	Plastic pipe can be subject to oxygen diffusion, where oxygen molecules can penetrate through the tubing wall and if there are ferrous materials in the system (e.g. radiators) general corrosion will occur. Therefore all pipes used must have an oxygen diffusion barrier either integral or applied as a coating externally.
No painting of pipes required	Maximum temperature will vary with plastic type but limited to 80–90 °C. To achieve a life expectancy of over 25–30 years the temperature should generally be limited to 70 °C and 6 bar gauge.
Heat free jointing, therefore no requirements for hot working permits and lower skill level may be required	Materials cost higher than steel or copper pipe.
System is intrinsically clean after installation, and internal surfaces will not corrode – therefore no or minimum requirements for flushing to remove debris	Additional supports may be required for plastic pipes that sag under their own weight.
Reduced installation time	Additional allowance required for thermal expansion as coefficient of linear expansion of plastic is much higher than copper or steel.
Lightweight, making handling and off site prefabrication easier.	Less robust than steel, therefore probably not suitable for plant rooms and risers in some systems.

filler metal cannot enter the main pipe bore resulting in a smooth internal surface.

Grooved end

Grooved end joints are used for jointing all sizes of steel and ductile iron pipes. Grooves are cut into the ends of the two pipes to be jointed. A mechanical coupling is then fitted around the ends of the two pipes locking into the grooves creating a secure fixing. The coupling is tightening by fixing bolts onto a rubber gasket that fits over the ends of the two pipes creating a watertight seal.

Compression

A compression nut is tightened onto a circular ‘olive’ fitted to the end of the pipe being jointed. This causes the olive to compress into the compression fitting causing it to squeeze the pipe, simultaneously gripping it and creating a water tight seal. Compression fittings of this type are used for connecting copper pipes and fittings. Although easy to form, joints may not be as robust as soldered or brazed joints. Multilayer pipes may also use compression fittings. For these pipes an internal support sleeve is required, incorporating rubber o-rings which create a watertight seal. The compression of the olive then serves to achieve a strong grip of the pipe. The use of a lubricant may be required to avoid damage to the pipes and fittings through the use of excessive mechanical force during assembly. The choice and application of lubricants should be in accordance with the manufacturer’s recommendations for the particular material and application.

Soldered or brazed

Soldering is the process of joining metals by using a low melting point filler metal (usually an alloy of tin) to adhere the surfaces to be soldered together. Soldering is more like gluing with molten metal, unlike welding where the base metals are actually melted and combined. The main difference between soldered joints and brazed joints is that brazing uses stronger filler metals with higher melting

temperatures. The joints are therefore stronger and more resistant to vibration or movement. Copper pipes are often jointed using soldered joints. Socket type fittings are provided which overlap the ends of the tubes. A space is formed between the tube and fitting referred to as the ‘capillary space’. The solder (or filler metal) is melted into the capillary space and adheres to the surfaces. The solder may be applied externally or may be internally located and supplied as part of the fitting. Heat must be applied to melt the solder. A flux is required to encourage the solder to flow into the capillary space. If used for potable water it is a requirement that solders containing lead are avoided.

Solvent welded

Solvent welding is used for jointing of plastic pipes. Solvent cement is applied over the ends socket type joints which are then pressed together by hand. Properly applied, solvent cements can create a stronger joint than mechanical joints. Curing times for solvent welded joint on large diameter pipes can be up to 24 hours.

Socket fusion welding

Socket fusion welding is used for jointing plastic pipes. The technique employs a similar technique to that of butt welding in heating the surfaces to be joined, in this case involving the application of heat to the inside surface of the socket and the outside of the pipe. A special welding tool is provided by the pipe manufacturer for this purpose. Due to the size of the welding tool, welds are usually made on a workbench.

Electrofusion

Electrofusion joints are effectively welded joints for plastic pipes in which the heat is generated by small electrical heating circuits embedded within the fittings themselves. A purpose made electrofusion control unit is provided by the manufacturer to provide the correct power for the correct time. This type of fitting enables joints to be made in situ.

Table 1.A1.3: Advantages and disadvantages of push-fit and press-fit copper/steel joints

Advantages	Disadvantages
Heat free jointing, therefore no requirements for hot working permits	Potential that electrical continuity is not maintained once the joints are made; depending on system used earth continuity straps may be required. Checks must be made with the manufacturers.
Advantage can be made of relatively unskilled labour	A quality assurance system is required on site to ensure all joints are made in accordance with the manufacturers recommendations, to ensure 'O' rings are not damaged, pipes ends are prepared correctly, pipes are inserted into fittings correctly, pipes are supported correctly and press-fit joints are made correctly.
System is intrinsically clean after installation, therefore minimum requirements for flushing to remove flux residue	Poorly made joints can sometimes pass a pressure test, with no leakage observed during the test, but then fail weeks or months later.
Significantly reduced installation time	Pressure and temperature of push fit systems generally limited to 90 °C and 6 bar gauge. Press fit systems limited to 110 °C and 16 bar gauge. The systems use o-rings which will have a limited life expectancy depending on operating temperature/pressure.
An overall cost saving can usually be demonstrated	The system manufacturer's proprietary tools must be used for 'pres-fit' joints. Special care must be taken in the design and installation of pipe supports and facilities for thermal expansion to ensure joints are not misaligned which could cause failure of o-rings.

Table 1.A1.4: Recommended range of maximum water velocities.

Pipe diameter (mm)	Recommended maximum velocity limits (m/s)	
	Copper	Steel
15-50	1.0	1.5
Over 50	1.5	3

Push-fit

Push-fit joints enable a joint to be made simply by pushing the pipe into the fitting. Push-fit fittings are available for both copper and plastic pipes. Generally, when a length of tube is pushed into the joint it passes through a release collar and then through a stainless steel grip ring. This has a series of teeth that open out and grip the tube, securing it so that it can only be released using some form of disconnecting tool. Pushing the tube further into the joint ensures that it passes through a support sleeve, which helps to align the tube before passing through a pre-lubricated EPDM rubber o-ring. Only when the tube has passed through the o-ring and reached the tube stop is a secure joint created.

Press-fit

Press-fit joints are made by compressing the walls of the fitting onto the tube being connected using a special press-fit tool provided by the joint manufacturer. Care should be taken to ensure that due space allowance is made for use of the tool head. Consideration should also be given to the weight of such tools when working overhead.

Push-fit and press-fit joints are modern alternatives to the other more traditional jointing methods for metal pipes. Table 1.A1.3 provides a summary of the advantages and disadvantages of these jointing methods.

Specific guidance on the installation of pipework for different types of pipework system is provided in HVCA publication TR20: *Installation and Testing of Pipework Systems* (HVCA, 2003). This guide is structured as a set of

10 stand-alone specifications dealing with low, medium and high temperature hot water heating, hot, cold and chilled water service, condenser and cooling water, steam and condensate, natural gas and oil.

1.A1.3 Pipe and pump sizing

1.A1.3.1 Pipe sizing

The following considerations should be taken into account when selecting the appropriate pipe size for a given design flow rate:

Pipework noise

Pipes must be sized such that the velocity of the water running through them will not be high enough to cause either vibration induced noise or erosion of the pipe material. Erosion of relatively soft metals such as copper can occur at elbows if the water velocity is excessive. Table 1.A1.4 indicates recommended maximum water velocities.

Air and dirt settlement

Small air bubbles or particles of debris carried by the flowing fluid may settle out in the pipe at low velocities. Ideally, full load design velocities should be maintained at a value greater than 0.5 m/s. Where full load design velocities may fall below this value additional dirt or air removal devices should be considered. BSRIA Guide BG 29/2011 (Brown, Parsloe, 2004) provides recommendations on the maintenance of system cleanliness.

Pump energy

Pipes must be sized such that the energy consumed by the pump is not excessive. Smaller pipes will have a greater resistance to flow and will therefore incur a greater pump energy consumption compared to larger pipes. Pump energy consumption will be roughly proportional to the average pressure loss per metre (expressed as Pascals per

metre, Pa/m) of the straight pipe lengths in the system. As a general rule, to minimize the life cycle energy consumption of a pipework system (i.e. the embodied energy of its pipes plus the pump life cycle energy consumption), pipes should be sized based on a criterion of not exceeding 200 Pa/m.

Pipework cost

Pipes must be sized such that the cost of pipework is maintained within acceptable limits. Pipework noise and pump energy can both be reduced by increasing installed pipe sizes, however, this is likely to incur an increase in the cost of the installed system.

Practicality of installation

Pipes must be sized such that the physical sizes of pipes are maintained within acceptable limits. Pipework noise and pump energy can both be reduced by increasing installed pipe sizes. However, this is likely to require an increase in the services void areas required to accommodate the pipes.

Detailed advice on optimal pipe sizing is provided in BSRIA publication BG 12/2011 *Energy Efficient Pumping Systems – a design guide* (Parsloe, 2011).

Having decided the parameters governing pipe size selection, actual pipe sizes can be determined using the data provided in CIBSE Guide C, chapter 4 'Flow of fluids in pipes and ducts' (CIBSE, 2001). This guide incorporates a spreadsheet which enables pipe sizing tables to be generated for any pipe material, size and fluid type. Using these tables, pipes can be selected based on their required design flow rates that comply with the pre-determined selection parameters (whether this is velocity limit or pressure loss limit).

The same tables enable the pressure losses through all straight pipe lengths to be calculated, this being the pressure loss per metre times the pipe length. However, to determine the overall pressure loss around a complete pipe system, the losses due to fittings such as bends, tees, contractions and enlargements, and components such as valves, strainers and terminal units must also be determined and added to the straight pipe losses. Fittings losses can represent a significant proportion of the total. In particular, actuated control valves and differential pressure control valves can incur significant pressure losses. CIBSE Guide C, chapter 4 contains resistance factors for fittings and valves from which their pressure losses can be calculated. Valve manufacturers also publish pressure loss data for their products.

For the purpose of sizing a pump, the maximum pressure loss for the system, when operating at its design flow rate value, must be calculated by summing the pipe and fitting losses around the pipework branch or circuit with the highest resistance. This is commonly referred to as the 'index circuit'. The index circuit is usually (but not always) the circuit from the pump to the most remote terminal unit, and all other pipe branches are irrelevant in terms of pump sizing. The reason why the circuit serving the most remote terminal unit has the highest pressure loss is simply because this is the circuit with the longest length of pipework, and hence the highest pipe pressure losses. Only where a terminal unit with a particularly high resistance is located on a branch closer to the pump, might the index be somewhere other than that serving the most remote unit.

1.A1.3.2 Pump selection

1.A1.3.2.1 Pump types

A pump used to force water around a closed pipework circuit is sometimes referred to as a 'circulator'. The vast majority of circulating pumps consist of a single or three phase electric motor that drives an impeller forcing water around the pipework system.

For most building services applications the pump is a centrifugal type, i.e. the impeller rotates in a scroll or volute shaped casing. As the impeller rotates, water is thrown from the blade tips centrifugally into the casing and out through the discharge opening. At the same time more water is drawn into the 'eye' of the impeller through a central inlet opening in the side of the casing.

Centrifugal pumps may be 'in-line' or 'end suction'.

For in-line pumps, the inlet pipe connection is in line with the outlet pipe connection. In-line pumps can therefore be connected in line with the pipe, and if small enough, the weight of the pump can be supported by the pipework.

For end suction pumps, the water is sucked into the pump centre horizontally and comes out from the casing at 90 degrees to the inlet. The pump and its motor are usually mounted on a concrete base.

Pumps may also be 'glanded' or 'glandless'.

The uniform feature of glanded pumps is the separation between the pumped fluid and the electric drive motor. The connection between the impeller and the motor is made by either a common shaft or by coupled shaft parts. Mechanical seals maintain water tightness between the two components. These may be prone to damage and must be checked or re-fitted at regular intervals.

In a glandless pump, the pump and drive motor are encapsulated in a single casing. As a result the pumps are quieter and more compact. Canned rotor pumps are examples of glandless pumps. Because the motor and pump are housed in a single casing, any heat generated by the motor is transferred to the water. Hence, glandless pumps are not usually considered suitable for chilled water systems.

For pumps operating in medium or high pressure systems, the construction and choice of materials may differ from that in low pressure applications. Pump manufacturers can advise on appropriate pump construction and selection for different temperature and pressure conditions.

1.A1.3.2.2 Pump sizing

Pump manufacturers tend to express the performance of their pumps by means of 'pump curves'. A pump curve indicates the relationship between the pressure differential generated by the pump and the resulting flow rate achieved. The aim during pump sizing is to select a pump that can deliver sufficient flow and pressure to match the requirements of the pipework system into which it will be installed. Figure 1.A1.1 shows a typical pump curve (black line).

Having calculated the required system flow rate and maximum pressure loss during the pipe sizing exercise, (referred to as the ‘design flow rate’ and ‘design pressure loss’ values), these can be used to plot a point relative to the pump curve. This point is the intended ‘design operating point’ or ‘duty’ of the pump when connected to the system.

Based on the design operating point, a ‘system curve’ can be established which enables the prediction of flow rate and pressure differential under any operating condition. The system curve can be established by applying the approximate square law relationship between flow rate and pressure loss. For example, if you double the flow rate through a system, the pressure loss quadruples and if you halve the flow, the pressure loss reduces to one quarter of its previous value. Hence, from a single operating point, it is possible to estimate the system pressure loss at any flow rate. The point at which the system curve crosses the pump curve will be the actual operating point i.e. the selected pump, when connected to the system will operate at this point generating differential pressure and flow rates that can be read off from the pump curve. A typical system curve (grey line) and operating point are shown in Figure 1.A1.1.

Since pumps are available in a range of sizes and capacities, it is very unlikely that the calculated design operating point for a particular system will lie exactly on a manufacturer’s published pump curve. The pump should therefore be selected with a curve which lies above, but as close as possible to, the design operating point. This will ensure that the pump is capable of generating sufficient pressure differential to achieve the required flow rate.

If necessary, the performance of the selected pump can be modified so that its curve better matches the anticipated design operating point of the system. One method of achieving this is to ‘trim’ the pump impeller, i.e. reduce its diameter. This can be undertaken by the manufacturer before the pump is delivered and installed.

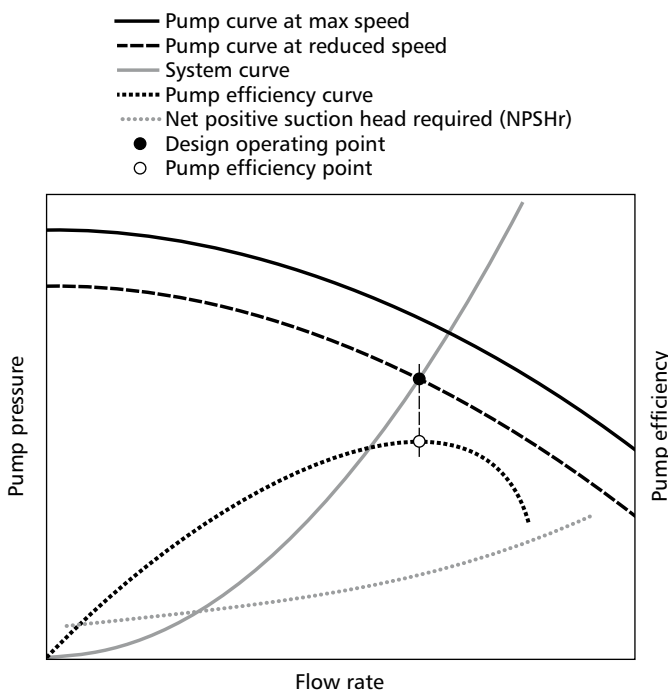


Figure 1.A1.1: Pump, pump efficiency and system curves

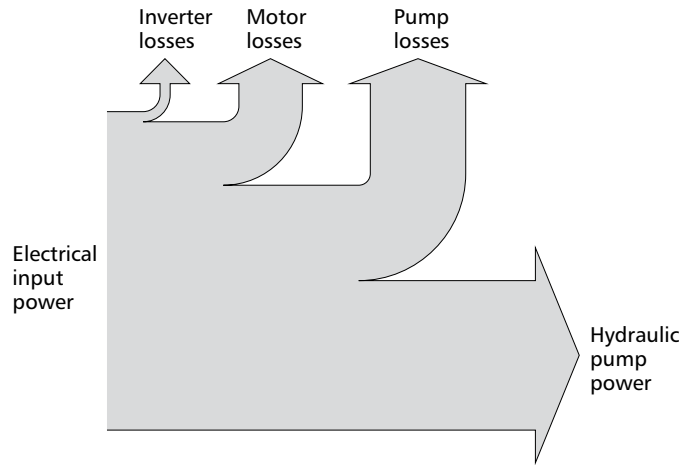


Figure 1.A1.2: Energy losses from pump and motor combinations

However, for the final setting of pump flow rate during commissioning, the pump speed should ideally be adjusted using an inverter drive supplied with the pump motor (this is more energy efficient than throttling a regulating valve to achieve the required flow rate). By either trimming the impeller, or reducing a pump’s speed, the pump curve effectively moves to a position that is parallel to, but below the manufacturer’s ‘nominal’ maximum speed pump curve. This effect is illustrated in Figure 1.A1.1.

1.A1.3.2.3 Efficiency and operating energy

As previously stated, pump sizing inevitably involves selecting a pump with a curve that lies above, but as close as possible to the calculated design operating point. There may be several alternative pumps that can achieve the required operating point, but future energy consumption can be minimized by selecting the pump, motor and inverter drive combination that operate with the highest possible combined efficiency at the design operating point.

The combined efficiency of a pump, motor and inverter combination can be defined as the hydraulic pump power (i.e. the power available to propel water around the system), divided by the electrical input power (i.e. the power delivered to the electric motor and inverter drive). This relationship is shown in Figure 1.A1.2. A low overall efficiency is an indication that energy is wastefully transferring to noise or heat rather than fluid motion.

Pump efficiency, motor efficiency and inverter efficiency can be separated for any given combination. Hence, the energy consumed by a pump per second (i.e. overall pump input power) is given by the equation:

$$P = \frac{\Delta p Q}{\eta} \tag{1.A1.1}$$

where P is the pump (electrical) input power (W); Δp is the pump pressure (Pa), Q is the flow rate (m^3/s) and η is the efficiency.

Efficiency can be sub-divided as:

$$\eta = \eta_{pump} \times \eta_{motor} \times \eta_{drive} \tag{1.A1.2}$$

where η_{pump} is the pump efficiency, η_{motor} is the motor efficiency and η_{drive} is the drive efficiency.

Pump efficiency, η_{pump} varies depending on the resistance of the system to which the pump is connected. Pump efficiency tends to be highest in the central region of a pump's stated operating range and reduces when the pump is connected to a system for which the resulting operating point is near either the top or bottom of the published pump curve. The typical variation in pump efficiency is illustrated in Figure 1.A1.1 (black dotted line). For a particular pump, the manufacturers' data can be used to establish the pump efficiency at the design operating point.

Minimum requirements for electrical motor efficiencies η_{motor} are explained in BS EN 60034-30-1:2014 *Rotating electrical machines. Efficiency classes of line operated AC motors (IE code)* (BSI, 2014). This standard separates motor efficiencies into four bands IE1, IE2, IE3 and IE4 where IE1 is the least efficient, and IE4 is the most efficient. The relevant banding will be indicated on the name plate of any product that complies with this standard. (Note that these bandings replace the manufacturer's labeling scheme which defined EFF1, EFF2 and EFF3 efficiency bands.)

Ongoing directives from the European Parliament have, since 2015 made it a requirement that minimum efficiency IE3 must be maintained for power ratings from 7.5 kW to 375 kW or an IE2 motor plus frequency inverter. In 2017 the threshold value will reduce to 0.75 kW.

Hence, for building services applications requiring regular or frequent operation of the pumps, the minimum band for motor efficiency should be IE2. Where the pumps are to be in continuous operation, IE3 should be proposed.

Variable speed drive efficiencies, η_{drive} are available from inverter drive manufacturers. Efficiencies of 96–98% are commonly stated.

It can be seen that the best way to minimise pump energy consumption is to take every opportunity to reduce system design flow rates pressure losses whilst maximising pump, motor and inverter drive efficiencies under all anticipated operating conditions. By enabling variable flow during normal system operation, additional significant savings can be achieved as described in section 1.A1.3.2.5.

1.A1.3.2.4 Net positive suction head

Net positive suction head is the term used to describe the absolute pressure of the fluid at the inlet to the pump, minus the vapour pressure of the fluid (i.e. it is a measure of how far the pressure of the water is above its vaporization pressure). Vapour pressure values for different water temperatures can be obtained from CIBSE Guide C, chapter 2, Properties of water and steam.

For a particular pipework system, the net positive suction head is referred to as the net positive suction head available (NPSHA) and, for a re-circulating pipework system, it can be calculated as the absolute pressure (i.e. gauge pressure plus 1 bar) at the cold fill connection to the system, minus the vapour pressure of the fluid, and minus any pipeline pressure losses between the cold fill connection point and the pump inlet.

Pump manufacturers use a similar terminology to describe the amount of pressure required at the pump inlet to prevent air or vapour bubbles from forming inside their pumps. This is known as the net positive suction head

required (NPSHR). If allowed to form, air or vapour bubbles can implode violently inside the pump causing significant damage. This effect is known as *cavitation*. The NPSHR value is a feature of each particular pump and varies with speed, impeller diameter, inlet type and flow rate. NPSHR is established by the manufacturer and is often included on the pump performance curves.

Hence, if the NPSHA is greater than NPSHR cavitation should not occur. However, if NPSHA is lower than NPSHR cavitation is possible.

Options for increasing the NPSHA in a re-circulating system include:

- reducing the resistance, and hence pressure losses, of pipes between the cold fill point and pump inlet
- for open systems, raising the height of the feed tank
- for closed systems, increasing the cold fill pressure generated by the pressurisation unit.

NPSHR values are often plotted by pump manufacturers relative to their operating curves, as illustrated in Figure 1.A1.1 (grey dotted line).

1.A1.3.2.5 Variable speed pumps

The ease with which modern inverters allow pumps to vary their speed introduces significant energy saving possibilities. This is because the design operating points calculated for heating and cooling systems are usually based on flow rates and pressure losses that will only be required when systems are performing at full load, i.e. when delivering their maximum anticipated amounts of heating or cooling. This is only likely to coincide with the hottest summer days or the coldest winter days. For all other times there is scope to reduce system output and therefore pump less water.

One method of achieving variable flow is to install multiple pumps in parallel and controlling them such that they switch on and off depending on system demand. However, this method of achieving variable flow is not as energy efficient as a single variable speed pump sized to achieve the same duty. This is because pumps operating in parallel do not increase the flow by a fixed amount per additional pump, i.e. two identical pumps installed in parallel do not achieve double the flow of the individual pumps on their own. A single variable speed pump is therefore preferable in most situations.

The potential energy savings achievable from variable speed pumping can be assessed using the pump affinity laws. For any fixed geometry pump operating against a constant resistance at two speeds N_1 and N_2 , the resulting changes in flow rate, pump pressure and pump power will be as predicted by the following equations.

$$Q_2 = Q_1 (N_2/N_1) \quad (1.A1.3)$$

$$p_2 = p_1 (N_2/N_1)^2 \quad (1.A1.4)$$

$$P_2 = P_1 (N_2/N_1)^3 \quad (1.A1.5)$$

where Q is the flow rate (m^3/s), p is the pump pressure (Pa), P is the pump power (W) and N is the pump speed (rev/s).

If system resistance remains constant, then the affinity laws predict that if the pump speed is halved, then:

- flow rate is halved
- pump pressure reduces to one quarter (i.e. a half squared)
- power consumption reduces to one eighth (i.e. a half cubed).

This indicates the prospect of a significant energy saving if the pump speed can be reduced during periods of low load. For most heating and cooling systems, this represents the majority of the time the system is in operation.

However, savings of this magnitude are only achievable if the system is designed in such a way that pump pressure can be allowed to reduce significantly under part load conditions.

There are four common methods of controlling pump speed:

- *Constant pressure control*: pump speed is controlled such that the pressure differential across the pump is maintained at a constant value equivalent to the pressure loss around the system at the maximum flow rate.
- *Proportional control*: pump speed is controlled such that the pressure differential across the pump reduces in proportion to flow rate towards a pre-selected value, typically equal to approximately 50 per cent of the pressure loss around the system at the maximum flow rate.
- *Quadratic pressure control*: pump speed is controlled such that the pressure differential across the pump reduces based on a quadratic curve relationship to flow rate towards a pre-selected value.
- *Remote sensor control*: pump speed is controlled such that the pressure differential across the pump reduces towards the design pressure differential across the most remote DPCV controlled sub-branches. Differential pressure sensors, wired back to the BMS, are required across the selected sub-branches.

Constant, proportional and quadratic pressure control rely on integral sensors and software supplied with the pump. Because there is no requirement for external sensors in the pipe work system, these options are sometimes referred to as 'sensorless' solutions.

Out of these four methods, the most energy efficient solutions are remote sensor control and quadratic pressure control followed by proportional control. Constant pressure control is poor in comparison with the other methods because the full cube law reduction in pump power cannot be achieved since pump pressure is held at a constant value. Furthermore, pumps that are controlled in this way often exhibit very poor efficiencies under part load conditions as the pump attempts to maintain a constant pressure differential against a system which, due to valve closures, has a high resistance.

As a general rule, proportional or quadratic pressure control is the best solution in systems where there is a fairly uniform load pattern i.e. it can be predicted that all heating or cooling terminal unit control valves will open or close roughly at the same times. In more complex systems serving multiple branches or risers with distinctly varying load

patterns, remote differential pressure sensor control is required to ensure that sufficient pressure and hence flow is available at system extremities under all operating conditions.

More detailed explanation of the relative energy saving benefits of alternative methods of pump speed control is provided in BSRIA guide BG 12/2011 *Energy Efficient Pumping – a design guide* (Parsloe, 2011).

1.A1.4 Heat transfer to and from pipes

Pipes carrying heated or chilled liquids will inevitably emit or absorb heat to or from the surrounding air. These emissions need to be taken into consideration during the sizing of central heating or cooling sources, and the selection of system operating temperatures.

National building regulations increasingly place limits on the amount of heat that is permitted to be lost or gained from pipework. In the UK, the *Non-domestic building services compliance guide* (DCLG, 2013) provides recommended maximum heat loss or heat gain values for Part L compliance (in Watts per metre pipe length). These values apply to different pipe sizes in low, medium and high temperature heating systems and cooling water systems. To achieve these recommended maximum values, appropriate insulation thicknesses can be calculated according to BS EN ISO 12241 (BSI, 2008). Typical thicknesses for alternative operating temperatures and insulation material is provided in the *TIMSA HVAC Guide for achieving compliance with Part L of the building regulations* (TIMSA, 2008).

For heating pipes, the Non-domestic building services compliance guide requires that pipes are insulated in all areas outside of the heated building envelope. In addition pipes should be insulated in all voids within the building envelope and in spaces which will normally be heated if those spaces might be maintained at temperatures different from those maintained in other zones. Heat losses from uninsulated pipes should only be permitted where the heat can be demonstrated as always useful. It is normal that the final connections to radiators are uninsulated.

For cooling pipes, the guide requires that pipes are normally insulated along their full length. Heat gains to uninsulated pipe should only be permitted where the proportion of the cooling load relating to distribution pipework is proven to be less than 1 per cent of the total load.

Provision may also be necessary for the control of condensation on pipe surfaces. Advice on insulating to prevent condensation is provided in the *TIMSA HVAC Guide for achieving compliance with Part L of the building regulations*.

For large heating or cooling systems it may be necessary to compensate for excessive non-useful heat losses or gains. The amount of heat lost or gained from the pipework should be calculated and an allowance made when sizing the central boiler or chiller plant.

In such systems there may also be a reduction in the outputs of heating or cooling emitters due to the change in temperature of the circulating liquid that takes place

between the central plant and the emitter. For example, in a large district heating system, due to the heat emissions from buried pipes, the temperature of the water reaching the heat emitters may be significantly less than the temperature at which it left the heat source.

Using the following equations (sourced from CIBSE Guide C, section 3.3), the temperature change in the fluid passing through a pipe can be calculated as:

$$\Delta\theta_m = \frac{U(\theta_u - \theta_a)d_{op}}{1330M} \quad (1.A1.6)$$

where $\Delta\theta_m$ is the change in temperature per unit length ($^{\circ}\text{C}$), U is the overall thermal transmittance to/from insulated pipe ($\text{W}\cdot\text{m}^{-2}\cdot\text{K}^{-1}$), θ_u is the temperature at upstream section of pipe ($^{\circ}\text{C}$), θ_a is the air temperature ($^{\circ}\text{C}$), d_{op} is the outside diameter of pipe (m) and M is the mass flow rate ($\text{kg}\cdot\text{s}^{-1}$).

The overall thermal transmittance to/from an insulated pipe is given by:

$$U = \frac{1}{R_n + \frac{d_{op}}{h_{so}d_{on}}} \quad (1.A1.7)$$

where R_n is the thermal resistance of insulation, h_{so} is the outside heat transfer coefficient (or film coefficient) ($\text{W}\cdot\text{m}^{-2}\cdot\text{K}^{-1}$), d_{on} is the outside diameter of insulation (m) and where the thermal resistance of the insulation R_n is given by:

$$R_n = \frac{d_{op}}{2k_n} \ln\left(\frac{d_{on}}{d_{op}}\right) \quad (1.A1.8)$$

where k_n is the thermal conductivity of insulation ($\text{W}\cdot\text{m}^{-1}\cdot\text{K}^{-1}$).

Using these equations the overall change in temperature between central plant and terminal units can be determined.

Increasing circuit flow rate is wasteful of pump energy whilst increasing the emitter size adds unnecessary cost. The best method to compensate for the change in temperature is therefore to increase the set-point temperature of the central plant.

Hence, if a heating system is designed based on a temperature differential of 30°C (i.e. 70°C flow and 40°C return) but the temperature drop between the boiler and the most remote heat emitter is estimated (from the above equations) to be 3°C then it would be appropriate to set the boiler flow temperature at 73°C to ensure that the water reaching the emitters is at least equal to the design value of 70°C .

1.A1.5 Pipework movement

Provision must be allowed in pipework systems for thermal expansion or contraction. When pipes are restricted from moving freely, large forces and moments may be imposed on pipe supports, anchors, and connections to equipment leading to failure. Furthermore, pipes that grow in length between two securely fixed points may fail due to buckling or bowing.

In addition to pipework thermal expansion, the movement of pipework may also be caused by:

- *Building settlement movement:* whenever pipes are routed across structural movement joints in buildings, they may be subjected to differential displacement.
- *Vessel settlement:* pipes may be installed with rigid connections to vessels used for storage of fluids. If installed whilst the vessel is empty, settlement or compression of spring mountings may occur when the vessel is filled.
- *Plant vibration during start-up:* equipment that is installed on anti-vibration mountings may experience excessive vibration as the motor starts-up or runs-down, and passes through the resonant frequency of the vibration isolation system.
- *Water hammer:* water hammer is caused by shock waves created due to fast closure times of automated valves.
- *Flow induced movement and vibration:* high velocity flow of liquids in pipes can cause pipe displacements at bends or sharp contractions.

Provisions for pipework movement should be allowed in each of these cases.

1.A1.5.1 Pipework expansion

Relative expansion rates for pipes of different materials are indicated in Table 1.A1.1. It can be seen from Table 1.A1.1 that plastic pipes exhibit expansion levels that are up to 13.6 mm per metre. For such materials it is recommended that the pipe manufacturer's specific guidance relating to expansion is followed.

For metal pipes, the expansion rates are significantly less at around 1.4 mm per metre. However, significant forces are generated which must be allowed for in the design of the system and the structural planning of the building.

In general, there are two ways in which linear pipe expansion may be controlled.

- the use of natural flexibility
- the use of expansion joints.

1.A1.5.1.1 Natural flexibility solution

Each change in direction requiring a bend or elbow introduces some 'natural' flexibility into the pipe system. The ability of a pipe to bend is a function of pipe material, its nominal size, wall thickness, and the length.

The result of the pipe being able to bend is to reduce the forces acting within the system and to reduce the pipe stresses.

Figure 1.A1.3 shows how offsets, or purpose made expansion loops can be used to accommodate pipework expansion. Anchor points are created against which expansion forces push. The anchor points are rigid, fixed points in the pipework system and are usually created by welding the pipe to a bearer which is bolted to a structural element.

It can be seen that in absorbing the expansion, pipes between anchors may move laterally. Therefore, the pipe supports or guides between anchor points must allow for this lateral movement.

With reference to Figure 1.A1.3, the required length of an offset can be calculated using the following equation. For an expansion loop, the expansion is effectively absorbed over two offsets; hence the length of each offset can be halved.

For steel pipes:

$$l_o = 0.1 (dx)^{0.5} \tag{1.A1.9}$$

For copper pipes:

$$l_o = 0.06 (dx)^{0.5} \tag{1.A1.10}$$

where l_o is the length of offset (m), x is the deflection caused by linear pipe expansion (m) and d is the nominal diameter of pipe (m).

The stresses caused by pipework expansion can be minimized by anticipating the amount of expansion in each pipe, and then cutting the pipes so that their lengths, when cold, are equal to the required length minus 50% of the anticipated expansion length. The pipework is then assembled cold with spacer pieces of length equal to half the expansion, sandwiched between the connecting flanges. When the pipework is fully installed and anchored at both ends, the spacers are removed and the flange bolts are tightened. When warmed through half of the total temperature rise, the piping is at a neutral point i.e. unstressed. At the working temperature, having fully expanded, the piping is stressed in the opposite direction. The effect is that instead of being stressed from 0 to F units of force, the piping is stressed from $-0.5F$ to $+0.5F$ units of force. This method of installation is known as ‘cold draw’ or ‘cold pull’.

1.A1.5.1.2 Expansion joint solution

If natural flexibility is insufficient, or the forces created by expansion are excessive, then expansion joints must be provided. There are several different models and it must be decided which is the best for the pipe system being designed. Different types of expansion joint will impose different forces on pipes and anchor points.

Expansion joints can be divided into two main groups. These are ‘unrestrained’ and ‘restrained’ as described below.

Unrestrained expansion joints are essentially axial expansion joints, this being the only model that falls into the unrestrained group. Generally, they are designed to accommodate movements of between 25 and 50 mm. They

are limited to axial travel only and must be suitably anchored and guided. Pipe guides are pipe support fixings (such as roller supports) which enable the pipe to move axially but not laterally. These are required in order to avoid unwanted lateral movement between anchor locations.

The forces experienced on anchor points tend to be greater in pipe sections with unrestrained expansion joints than in sections with restrained expansion joints. This is because the pressure inside the pipework contributes to the force exerted at the anchors. Restrained expansion joints include restraining rods which prevent the internal pressure from exerting a force at anchors.

Figure 1.A1.4 shows a typical arrangement of axial expansion joints (bellows) relative to anchor points and pipe guides.

Restrained expansion joints include a variety of expansion joint models including lateral, hinged and gimbal expansion joints. With all of these models, anchor forces are generally lower than with unrestrained expansion joints, and fewer pipe guides are required.

Lateral expansion joints are usually limited to lateral travel only, although ‘fully articulated’ models can allow lateral movement in any direction from their main axis. Figure 1.A1.5 shows a typical use of a lateral expansion joint used to accommodate the movement in a short offset between two parallel pipe runs.

Hinged (or angled) expansion joints are limited to angular travel only, but effectively create articulating sections of pipe when used with in groups of 2 or 3 units. Figure 1.A1.6 shows a typical use of hinged expansion joints to accommodate the movement in an offset between two parallel pipe runs.

Gimbal expansion joints are similar in principle to the hinged model, but they are able to angulate in any direction from their main axis. This makes them suitable to accommodate thermal expansion in complex multi-directional pipe arrangements. Figure 1.A1.7 shows a typical use of a gimbal expansion joints to accommodate the movement in an offset between two pipes travelling in different directions.

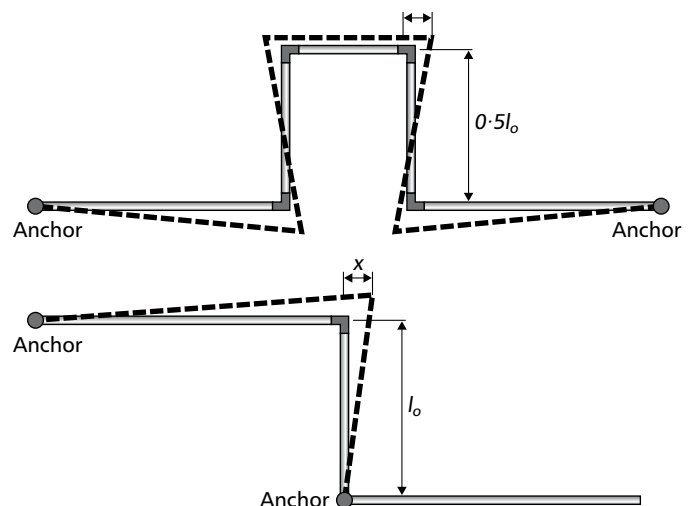


Figure 1.A1.3: Use of natural changes in direction to accommodate expansion

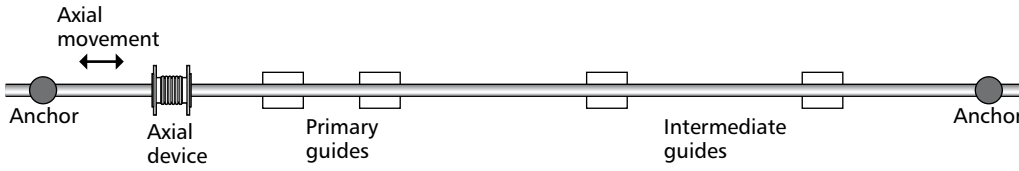


Figure 1.A1.4 Use of axial expansion devices

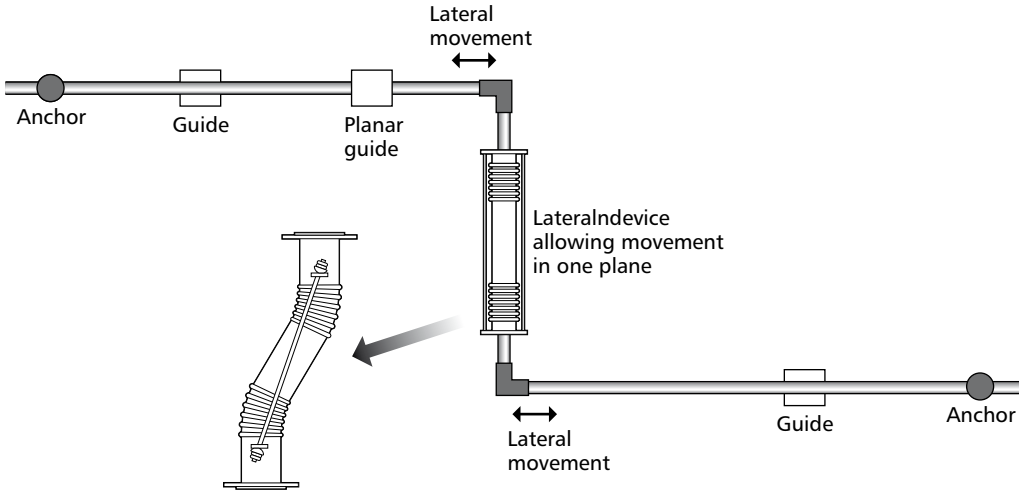


Figure 1.A1.5 Use of lateral expansion devices

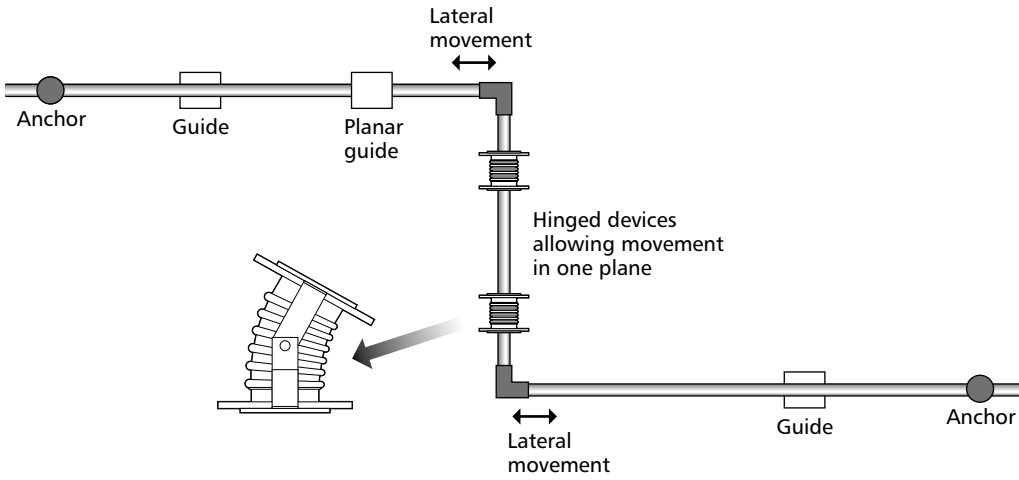


Figure 1.A1.6: Use of hinged or angular pipe expansion devices

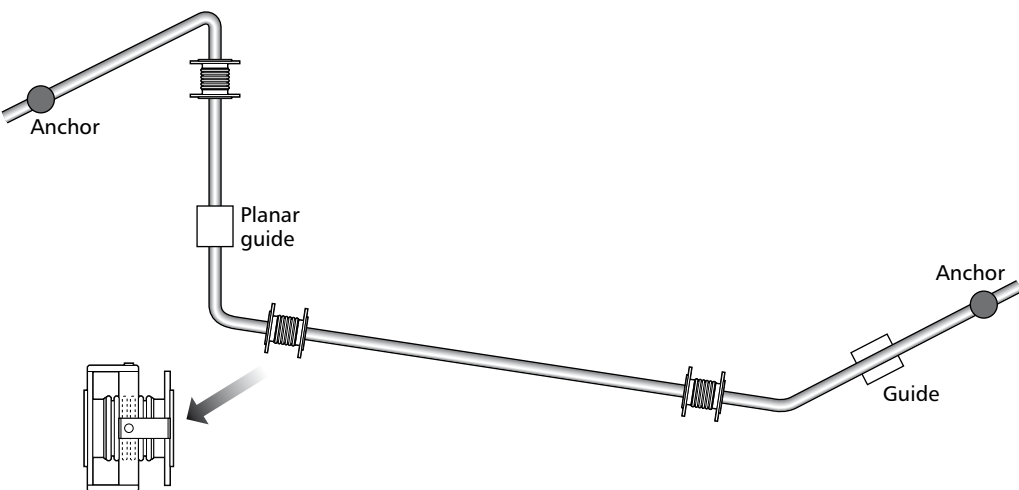


Figure 1.A1.7 Use of gimbal pipe expansion devices

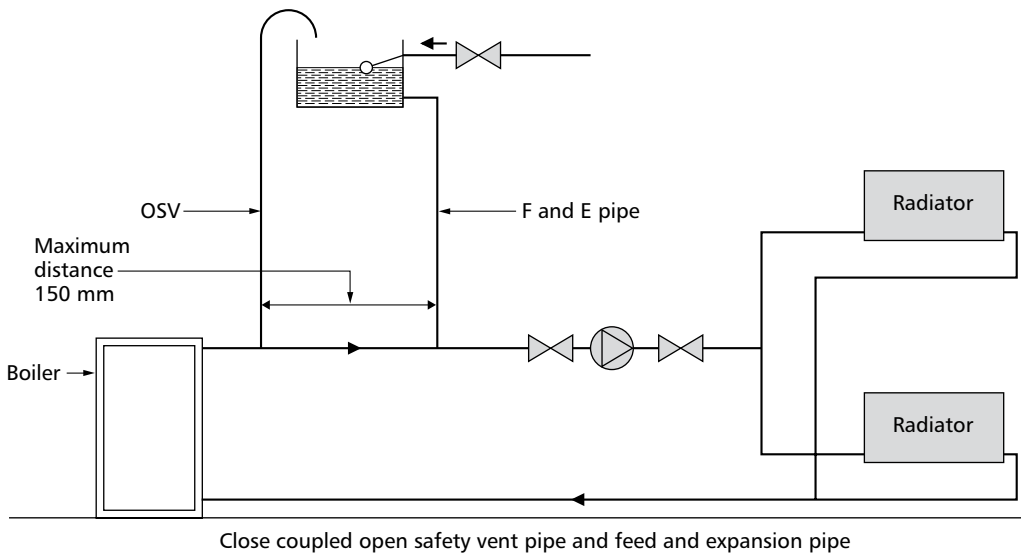


Figure 1.A1.8: Simple open feed system

It can be seen that most expansion devices use a flexible bellows which distorts in a controlled manner to accommodate pipework movement. It is important that the bellows is capable of withstanding the system operating pressure in order to prevent the bellows material from expanding and flexing outwards. Some devices may incorporate limit rods, to prevent over-compression or over-extension of the bellows. In the event of anchor failure, they act to contain the system pressure thereby preventing damage to the bellows and pipework.

There is invariably more than one way to accommodate the movement of pipework due to expansion and it is essential that, for whatever solution is adopted, the forces exerted on the anchor points are calculated and notified to the structural engineer. It is recommended that specialist advice is sought from the expansion device manufacturer regarding their selection and application.

1.A1.6 System pressurisation and expansion

Pipework systems must be provided with a means for filling the system and an allowance for expansion. Water expands and contracts when heated or cooled. For chilled water systems expansion is caused when the water heats from its chilled condition to ambient. In heating systems expansion is caused when the water is heated from ambient to its design flow temperature. The resulting change in volume must be catered for within the design of the system otherwise excessive pressures may be generated leading to system failure.

Table 1.A1.5: Operating temperatures ranges for heating systems

System	Temperature / °C	Minimum pressure / bar
Low temperature	<90	1
Medium temperature	90–120	3
High temperature	>120	5

1.A1.6.1 Open systems

In an open system, expansion and contraction of the fluid is catered for by the inclusion of an open tank located above the highest point in the system. Commonly referred to as a ‘feed and expansion tank’ the tank provides a water source from which the system can be filled, and also accommodates expansion of the water as it is heated. These systems must also have an open safety vent pipe to provide an unrestricted path from the boiler for the relief of pressure if the boiler controls should fail. The safety vent pipe should be located as close as possible to the boiler and with no means of isolation between the boiler and the safety vent pipe outlet connection. The safety vent pipe should rise to a height above the tank sufficient to prevent any discharge occurring under normal operation. The formula to find out the height of the vent pipe above the water level in the tank is:

$$(\text{Height (m)} \times 40 \text{ mm}) + 150 \text{ mm} \quad (1.A1.11)$$

where height is the distance from the water level in the tank to the lowest point in the heating system.

Figure 1.A1.8 shows a typical open system arrangement.

Open systems are usually only found on smaller or older systems. On larger systems they are less popular because they provide a ready path for the ingress of dissolved oxygen which can increase the corrosion rate of steel components.

1.A1.6.2 Sealed systems

Larger, commercial heating and cooling pipework systems are likely to be sealed systems where expansion and contraction of the water is catered for by the inclusion of an expansion vessel and associated pressurisation pumps.

Alternative methods of pressurisation are applicable to chilled water systems and low, medium or high pressure hot water heating systems (LTHW, MTHW or HTHW systems), where the operating temperatures of these systems are as indicated in Table 1.A1.5.

It can be inferred from Table 1.A1.5 that for medium and high temperature systems, the pressure in the system must be maintained at all times at a value which is sufficient to prevent the water from boiling and ‘flashing’ into steam.

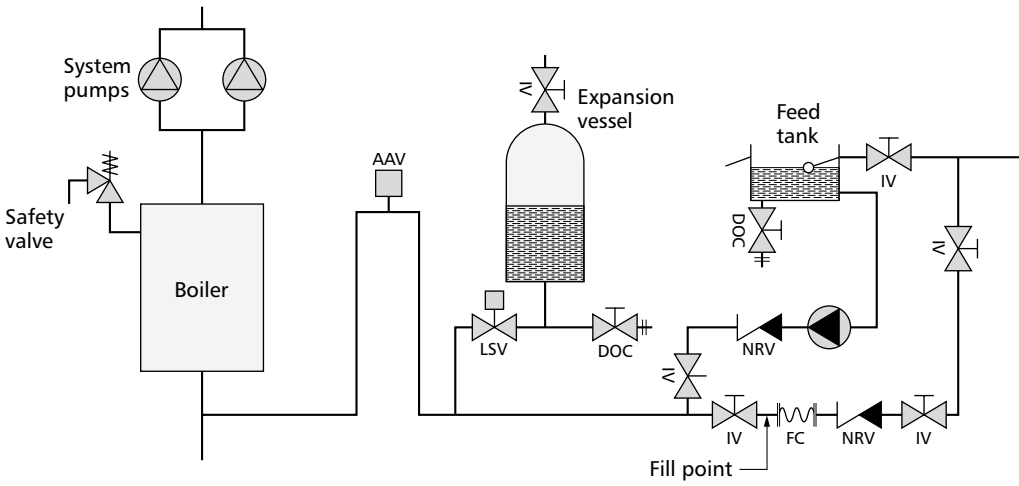


Figure 1.A1.9 Pressurisation by expansion

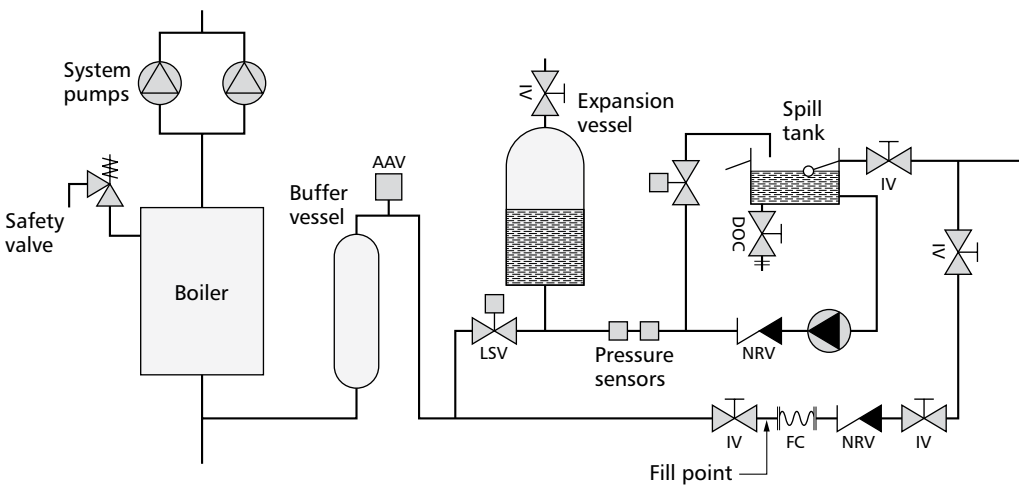


Figure 1.A1.10: Pressurisation by pump

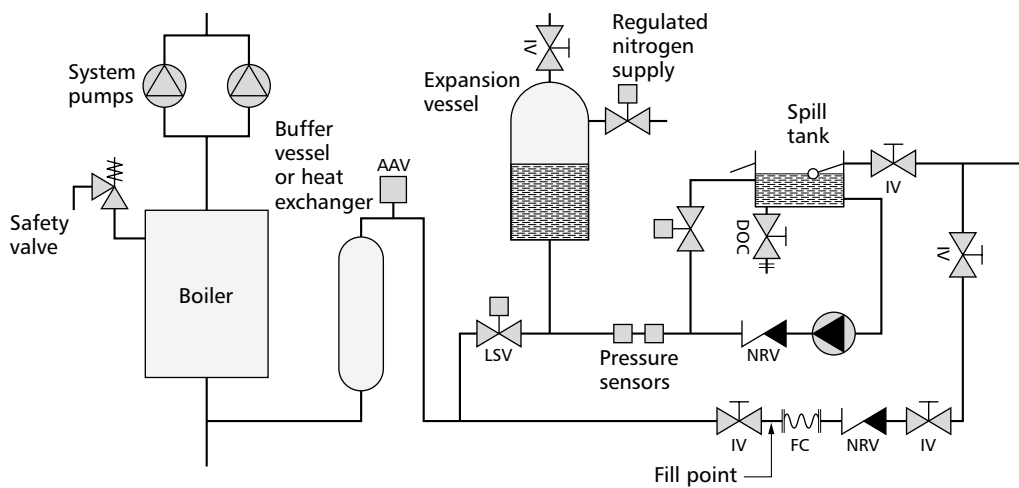


Figure 1.A1.11 Pressurisation by gas

The amount of pressure required to keep water from boiling is known as the saturation vapour pressure and varies with temperature. Vapour pressure values for different water temperatures can be obtained from CIBSE Guide C, chapter 2, *Properties of water and steam* (CIBSE, 2001).

For example, if water at 120 °C is to be maintained as water, then the corresponding vapour pressure is 198.53 kPa absolute or 98.53 kPa gauge pressure, as indicated in CIBSE Guide C, chapter 2. However, to ensure that boiling will definitely not occur, a margin should be added to this pressure. BS 7074: *Application, selection and installation of expansion vessels and ancillary equipment for sealed water systems, Part 2* (BSI, 1989) recommends that an anti-flash margin equivalent to 11 °C in temperature is allowed. Hence, the minimum pressure required in the system would be the vapour pressure of water at 131 °C which from Guide C, chapter 2, is indicated is approximately 278 kPa absolute or 178 kPa gauge pressure.

There are three common methods of pressurisation for sealed systems which are roughly applicable to chilled and low temperature heating, medium temperature heating and high temperature heating applications. These alternatives are explained in the following sections.

1.A1.6.2.1 Pressurisation by expansion

Pressurisation by expansion is suitable for LTHW systems and chilled water systems. This involves the addition of an unvented expansion vessel to a heating system which is charged with gas and sealed. The function of the vessel is to take up the increased volume of water as it is heated, and by so doing, apply additional pressure in the system. In practice, expansion vessels are used which incorporate a flexible rubber diaphragm which separates the water on one side from a factory applied charge of nitrogen on the other. Nitrogen is used as it is less soluble than air in water and is less likely to enter the water causing corrosion problems. An anti-gravity pipework loop is incorporated for heating applications to prevent heated water from the system rising due to its natural buoyancy into the expansion vessel. This feature is not required for chilled water systems. For larger systems operating at low temperature, the principles of operation remain the same. The expansion vessel will increase in size and may even be duplicated.

1.A1.6.2.2 Pressurisation by pump (spill systems)

Pressurisation by pump is an alternative approach which is suitable for MTHW systems or LTHW systems requiring large expansion volumes. This system relies on the operation of a pump to generate pressure in the system, in conjunction with an expansion vessel to accommodate system expansion and a spill valve that discharges water into a spill tank to maintain constant pressure. The spill valve allows water of expansion to escape into the spill tank once a pre-set pressure is reached. Hence, the expansion vessel does not have to be sized to accommodate all of the expansion water, and the accumulation of water in the expansion vessel does not add additional pressure to the system. While the system remains at the design working temperature, and at constant pressure, the spill valve remains closed and the pump is idle. When the system temperature and pressure fall, the pump will start and the pre-set pressure will be restored. A buffer vessel is commonly installed between the pump and the expansion vessel to reduce surging of water from the

pumps into the heating system and to minimize the risk of heated water entering the expansion vessel and spill tank.

1.A1.6.2.3 Pressurisation by gas

Pressurisation by gas is applicable to HTHW systems and utilizes an initial charge of gas to generate a high pressure in the system. A pressure cylinder is connected to the heating system filled partly by water and partly by air or an inert gas (such as nitrogen). The initial supply of gas is from a small air compressor or gas bottle. An initial pressure can therefore be applied to the system at a level well above the boiling point of the system water. The water of expansion is discharged from the system by a spill valve to a spill tank which is open to atmosphere and, as the system cools and contracts, a pressure pump draws water from the spill tank and returns it to the system. The pressure controller regulates the admission of water from the pump or its expulsion through the spill valve. In most units two pumps are used to run in parallel to meet unusual demands, and the water of expansion passes through a heat exchanger to lower the temperature and, if possible, prevent it flashing to steam when discharged.

1.A1.6.2.4 Pressurisation units

Pre-packaged 'pressurisation units' based on each of these aforementioned solutions are available from manufacturers. Such units usually incorporate a 'quick-fill' connection which allows temporary connection from the mains water supply via a back-flow prevention device (usually a reduced pressure zone valve). This connection enables the system to be filled quickly without the need to run the pressurisation unit pump. It should be disconnected after use. Fill water connections should be sized such that they enable the system to be filled within a reasonable time period. Recommended fill connection sizes are indicated in Table 1.A1.6, corresponding to a fill pressure sufficient to generate 1.3 bar at the top of the system.

In addition to the pressurisation unit, other features are necessary for the safe operation of heating systems including a safety valve fitted to the boiler that is set to open if the pressure in the boiler exceeds a set value. A high pressure switch may also be incorporated to stop firing of the boiler in the event of over pressure, before the excess pressure triggers safety valve operation.

1.A1.6.2.5 Pressurisation unit sizing

For most LTHW systems utilizing pressurisation by expansion, the sizing of the expansion vessel is critical in determining the final pressures in the system. The pressure generated due to the expansion of water into a sealed vessel must be calculated in order to ensure that the maximum operating pressures of system components are not exceeded.

Table 1.A1.6: Recommended fill connection sizes

System volume / litres	Minimum fill pipe size /mm
<2,000	25
2,000-10,000	40
>10,000	50

The maximum allowable pressure at the pressurisation unit cold fill point will depend on the system component with the lowest recommended operating pressure, and its location in the system.

For example, if the boiler and cold fill point are located at the lowest part of the system, then it is likely that the boiler's pressure rating will dictate the maximum working pressure. In this case the maximum working pressure would be the boiler operating pressure minus the safety valve lift margin (typically 0.5 bar) minus a margin of 0.7 bar.

However, if the boiler and cold fill point are located at the highest part of the system, then it may be that terminal units located the lowest part of the system will dictate the cold fill pressure. In this case, the maximum acceptable cold fill pressure might be calculated based on the recommended operating pressure of the terminal units, minus the system static pressure (i.e. the pressure due to the height of the system).

Having determined the maximum fill pressure to the system, an expansion vessel can be sized to accommodate the volume of system expansion without exceeding the maximum fill pressure.

Example sizing calculations for expansion vessels in heating systems are provided in CIBSE AM14: *Non-domestic hot water heating systems* (CIBSE, 2010), and in BSEN 12828: 2003 *Heating systems in buildings – design for water based heating systems* (BSI, 2003). It should be noted that BSEN 12828: 2003 replaces BS7074 Part 2, and differs in that it introduces a requirement to size the expansion vessel with some water reserved in the vessel at the cold fill state. Example calculations for expansion vessels in cooling water systems are provided in BS 7074-3: *Application, selection and installation of expansion vessels and ancillary equipment for sealed water systems Part 3, Code of Practice for Chilled and Condenser Systems* (BSI, 1989).

1.A1.6.2.6 Pressurisation unit connection point

The pressurisation unit connection point is the only point in the system where an external pressure is applied and is termed the 'neutral point' because the pressure at this point remains constant whilst pressures elsewhere in the system will vary due to height, pump pressures and system pressure losses. The fill point and consequent neutral point should normally be connected at the inlet side of boilers or chillers so that these items always operate at a pressure that is less than the fill pressure. Furthermore, pumps should normally be located on the flow side from boilers or chillers so that pump pressure is not added to fill pressure thereby increasing the pressure inside the boilers or chillers. By locating the neutral point at the pump inlet ensures that the pump pressure is additive meaning that the entire system is always above atmospheric pressure and the required net positive suction head (NPSHR) of the pump can be maintained under all operating conditions.

1.A1.7 Valve types

All hydronic systems are dependent for their successful operation on the inclusion of properly designed and selected valves. Pipeline valves may perform a variety of functions including:

- isolation
- flow regulation
- differential pressure control
- flow control
- a combination of the above.

The main valve types and associated pipeline components are described in the following sections.

Double regulating valves

A double regulating valve is a regulating valve that can perform the double function of flow isolation and regulation. This double function is achieved by incorporating a locking mechanism in the handle of the regulating valve. This allows the valve to be regulated until the required flow rate is achieved and then locked in place. If the valve is subsequently closed for isolation purposes, on re-opening, the valve handle will only open as far as its locked position. Some double regulating valves have pressure tappings across the opening making it possible to measure flow. These are commonly referred to as 'variable orifice double regulating valves'.

Fixed orifice flow measurement devices

A fixed orifice flow measurement device uses the pressure differential across an orifice plate as an indicator of flow rate. An orifice plate is a plate with a circular opening at its centre of a diameter that is less than the internal bore of the adjoining pipe. Pressure tappings are fitted upstream and downstream of the orifice plate and are used to measure the pressure differential signal across the orifice.

Fixed orifice double regulating valves

Fixed orifice double regulating valves are so called because they comprise a fixed orifice flow measurement device, close coupled to a double regulating valve enabling flow rate to be measured and regulated from a single location. This combination is commonly referred to as a 'commissioning set'. The two components can be cast into a single body or screwed together. For larger sizes, they may be linked by a short section of pipe (spool piece). The flow measurement device must be located upstream of the double regulating valve to avoid any flow disturbance at the inlet to the orifice plate.

Control valves

Control valves are installed on terminal unit branches as a means of automatically controlling the flow of water through the terminal units, and hence, the amount of heating or cooling they deliver. In constant flow systems, the control valves are typically 3-port or 4-port valves, both of which reduce the flows through terminal units by diverting them through by-passes; overall flow rate remains constant. In variable flow systems, the control valve is typically a 2-port valve which simply throttles the flow. Control valves may be operated by temperature sensitive actuators located in the occupied space, as in the case of thermostatic radiator valves, or by motorized actuators linked at a remote sensor and building management system. Advice on the selection of control valves is provided in CIBSE Guide H: *Building control systems* (CIBSE, 1989) and KS7: *Variable flow pipework systems* (CIBSE, 2006).

Differential pressure control valves (DPCVs)

DPCVs are installed in systems to prevent two port control valves from having to close against excessive pressures. Without this type of protection, some 2-port control valves may generate noise or lose their authority resulting in poor modulating control of heating or cooling outputs.

DPCVs are self-acting valves that act in response to changes in pressure differential across the control valves (or circuits containing control valves) that they protect. This pressure differential is transmitted to either side of a flexible diaphragm inside the valve via small capillary tubes. As the diaphragm flexes in response to the changing pressure differential, it causes the valve plug to move thereby varying the opening through the valve. The effect is to maintain a constant pressure differential between the inlet to the valve and the upstream point to which the capillary tube attaches. This pressure setting can be varied, but once set the action of the valve will hold the pressure differential constant regardless of changes in the resistance of the circuit and regardless of changes in the available pump pressure.

Pressure independent control valves (PICVs)

PICVs combine the 2-port valve and differential pressure control valve into a single body. Therefore the valve is self-protected against excess pressures. Because the integral DPCV holds the pressure differential constant across the integral 2-port control valve, the result is that whenever the control valve is fully open, the flow rate through the valve always returns, approximately, to its set value (since a constant pressure differential across a fixed resistance results in a constant flow rate).

The opening through the 2-port control valve can be varied manually, and can therefore be used to regulate the flow rate through the valve to the required design value. A flow setting dial on the valve spindle can be used for this purpose. Once set, the valve should perform the function of a constant flow regulator (or 'flow limiting valve') whenever the 2-port control valve is fully open. Only when the control valve begins to close might the flow rate change from its set value.

Constant flow regulators

A constant flow regulator is any self-acting device that operates to hold the flow rate through the branch in which it is installed constant regardless of pressure and flow rate changes in surrounding branches. When used in variable flow applications, these devices are often referred to as 'flow limiting valves' since they limit the maximum flow but allow the flow to drop to zero as control valves throttle.

The simplest type of constant flow regulator comprises a spring loaded stainless steel cartridge inside a brass casing. An interchangeable orifice plate forms the entry port of the cartridge which enables a variety of flow values to be specified. The outlets from the device are via specially profiled holes. The pressure exerted on the orifice plate causes the cartridge to compress against the spring thereby restricting the outlet holes. The result is that flow rate is held constant regardless of changes in pressure.

Constant flow regulators are seldom used for terminal branch control in variable flow systems, since their action might interfere with modulating flow control. However,

they can be used in system by-passes where a constant flow is required under all operating conditions.

1.A1.7.1 Valve authority

For automatic valves that have a control function, it is important that the valves are selected with the appropriate authority.

The authority of a valve is an indication of how accurately the valve will be able to modulate flow as it opens and closes. Valves designed for isolation purposes (e.g. ball or gate valves) often have very poor authority because as they close, there may be no significant change in flow until the valve reaches the last part of its travel when the flow suddenly drops to zero.

To achieve good authority, the pressure loss across the control valve relative to the pressure loss around the circuit in which it is located, needs to be as large as possible. This will ensure that small changes in the resistance of the valve will have a large influence on flow rate.

Acceptable authority in constant flow systems using 3- or 4-port valves to control the flows through terminal units is 0.5, i.e. the pressure loss across the control valve is approximately equal to the pressure loss across the terminal unit that it serves, and is therefore 50% of the total loss through the terminal unit and valve combined.

The minimum acceptable authority in variable flow system using 2-port control valves to control flows through terminal units is 0.2, i.e. the pressure loss across the control valve should be not less than 20% of the total pressure loss across the entire terminal unit sub-branch in which the valve is located. Although 0.2 is a minimum to suit terminals with low flow rates, where possible, valves should ideally be selected with authorities in the range 0.25 to 0.5.

The best achievable authority is 1, i.e. the only pressure loss in the circuit through which flow is to be controlled is the 2-port valve itself. In theory, this is the authority achievable by a PICV since the pressure differential across the 2-port control valve is controlled at a constant value by the integral DPCV.

Further guidance on control valve authorities and valve selection can be found in CIBSE Guide H and in CIBSE KS7.

1.A1.8 Design considerations**1.A1.8.1 Flow temperature control**

For heating systems in particular, control of temperatures in occupied spaces can sometimes be improved by varying the temperature of the circulating liquid.

For example, in a heating system serving radiators, if the water is supplied at a constant temperature of say 80 °C, then when the set-point room temperatures are achieved and thermostatic radiator valves begin to close, the radiators will continue to emit heat as the radiators cool. This can result in significant over-heating.

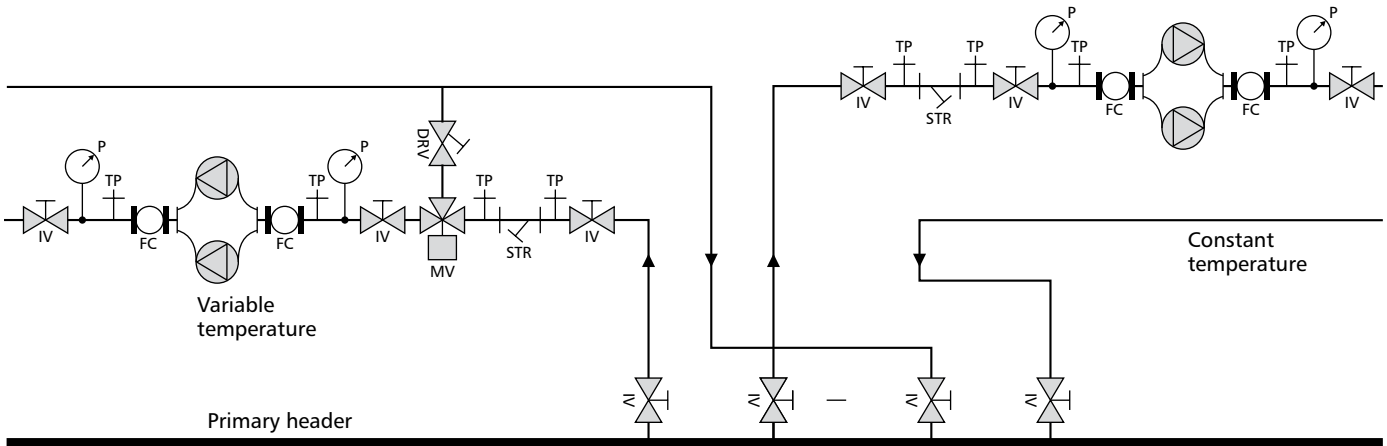


Figure 1.A1.12: Constant and variable temperature circuits

Hence, for this type of situation, better control of room temperatures is achieved if the temperature of the circulating water is varied depending on the external design conditions. One common solution for heating systems is the use of ‘weather compensated control’. This type of controller measures outdoor temperatures and varies the temperature of the water supplied to radiators accordingly. Such a system might only provide water at 80 °C on the coldest days in winter (coinciding with the design condition) and at all other times the water supplied will be at a reduced temperature, as determined by the controller.

This type of system is known as a ‘variable temperature’ system as opposed to a ‘constant temperature’ system. Variable temperature control can be achieved by some boilers which are able to modulate their supply water temperature. However, where there is a need to maintain water from the boiler at a constant high temperature (perhaps to serve hot water heaters) then a mixing circuit will be required in enable the supply temperature to be varied.

Figure 1.A1.12 shows a comparison between a constant temperature circuit and a variable temperature circuit.

It can be seen that a constant temperature circuit takes water from the heat source and supplies it direct to the terminal units at the same temperature. Variable temperature circuits incorporate a three port valve to enable mixing of the return water with water from the heat source thereby varying the flow temperature to terminals.

For the reasons explained, heating or cooling emitters with a slow thermal response tend to operate more effectively in variable temperature systems. However, emitters with a faster response operate more effectively in constant temperature circuits. This includes forced convection units i.e. coils for which air is blown by a fan across a heating or cooling coil. For these types of emitter, the volume of water inside the heat emitter is relatively small and the operation of the fan ensures that excess heating or cooling energy is quickly dissipated.

Variable temperature circuits can be used as a means of achieving low return temperatures in order to maximize the energy efficiency of low carbon heat sources such as condensing boilers, CHP or solar heating. This solution works best in situations where the means of varying the flow temperature is achieved by the control of the heat source itself e.g. variable temperature boilers. The use of a

variable temperature secondary circuit may be of little benefit if the low temperature returning water is being mixed with high temperature flow water in a primary circuit before returning to the heat source. Furthermore, the adoption of a variable temperature circuit will inevitably limit the potential for the pumps to reduce their speed under part load conditions, thereby missing out on potentially significant pump energy savings.

1.A1.8.2 Variable flow systems

In a variable flow system, the flow rate varies depending on the demand for heating or cooling from the system. Terminal units are typically fitted with two port control valves that throttle the flow when the zone served by the terminal unit reaches its set-point temperature value. As two port control valves throttle the flow in the system, the pump is made to reduce its speed thereby saving energy.

The main advantages of variable flow systems are as follows:

- *Pump energy savings*: due to the cube law relationship between pump speed and power (as predicted by the pump affinity laws) there is the potential for significant pump energy savings relative to constant flow systems.
- *Larger temperature differentials*: the efficiencies of low carbon emission heating and cooling sources are often improved when the temperature differentials between flow and return are maintained as high as possible. Since variable flow systems throttle the flow when the heating or cooling load is satisfied, their temperature differentials tend to increase under part load conditions, whereas in a constant flow system the temperature differential would decrease. Hence, variable flow systems are essential when it is important to maintain a high temperature differential.

Advice on the design of variable flow systems is provided in BSRIA guide BG 12/2011: *Energy Efficient Pumping Systems – a design guide* (Parsloe, 2011). The following sections describe the main issues relating to variable flow system design.

1.A1.8.2.1 System by-passes

By-passes are required in order to ensure a constant path for flow and to allow water treatment chemicals to circulate

to system extremities. To maintain the system temperature differential at as large a value as possible, the amount of water that is allowed to by-pass heating or cooling emitters should be kept to a minimum. The minimum acceptable by-pass flow is usually dictated by the pump. The amount of water that a pump can deliver before it runs the risk of overheating can be calculated for a given situation.

In the case of glandless pumps where the system water is cooling the motor, the minimum flow rate through the pump should not be allowed to fall below 10% of the nominal flow rate of the pump, unless otherwise indicated by the pump manufacturer.

In the case of glanded pumps, the minimum flow rate should be set at a value which does not cause an excessive heat gain to the circulating water. The maximum possible increase in temperature can be calculated from the equation:

$$\Delta T = P / (c_p \times q_m) \quad (1.A1.12)$$

where ΔT is the temperature increase of the water as it passes through the pump ($^{\circ}\text{C}$), P is the pump power (W), c_p is the specific heat capacity of water ($\text{J}/\text{kg}\cdot\text{K}$) and q_m is the mass flow rate of water (kg/s).

The pump power at zero (or near zero) flow can be determined from the pump manufacturer's published data.

Having decided the flow capacity of system by-passes, their locations and design can be decided. In general, it is beneficial to locate by-passes at system extremities to ensure that water treatment chemicals reach all parts of the system.

By-passes can be fitted with pressure relief valves that open when they see a rising pressure differential. However, this solution will not work in systems where pump pressure reduces under part load conditions, since by-passes will experience a reducing rather than increasing pressure differential.

By-passes can also be fitted with constant flow regulators to maintain a fixed minimum flow. For these systems the amount of water by-passing the system is constant and must be added to the pump flow duty when sizing the pump.

To avoid wasting pump energy by circulating water through constant flow by-passes, a more energy efficient solution is to install 3- or 4-port diverting control valves in terminal branches at system extremities (sized as if they were 2-port throttling control valves). This approach will ensure that the by-passed flow rate is included within the overall system design flow rate value.

1.A1.8.2.2 System layout

To maximize pump energy savings and operating temperature differentials, system design should aim to minimize pressure variations (and hence flow rate variations) across terminal unit branches. In general, this can best be achieved by locating some form of differential pressure control device as close as possible to each terminal unit.

BSRIA guide BG 12/2011: *Energy Efficient Pumping Systems* indicates comparative energy performances of alternative

system layouts. The following options are considered to achieve the best results.

- *PICV control*: the use of PICVs to modulate flows through terminal units is effective because the integral DPCVs within each PICV act to maintain flow rates through individual terminal units constant regardless of closures in adjacent circuits. By-passes can be created by fitting terminal unit branches at system extremities with 3 or 4-port diverting control valves and constant flow regulators.
- *DPCV valve modules*: the use of DPCVs as part of valve modules located locally to the terminal units they serve is effective because the action of the DPCVs to maintain pressure constant across each circuit will ensure that flows through individual terminal units remain constant regardless of closures in adjacent circuits. By-passes can be created by fitting terminal unit branches at system extremities with 3- or 4-port diverting control valves.
- *Branch DPCVs*: DPCVs can be located on pipework branches serving groups of terminal units although their locations should be close enough to the terminals they serve to prevent excessive pressures and hence flow rates through the terminal units. As a general rule, DPCVs serving heating or cooling coils with 2-port valves should be located such that they maintain a pressure differential of no more than 1.5 times the design pressure loss across the highest resistance terminal unit branch. Similarly, DPCVs located on branches serving groups of radiators should be limited to control at a pressure differential of no more than 10 kPa. These limits will ensure that the flow rate across any individual terminal unit will never exceed 160 per cent of its design value under part load conditions.

1.A1.8.2.3 Hot water provision

Traditional hot water storage cylinders are not always compatible with heating systems that operate with large temperature differentials. Large design temperature differentials result in prolonged heat-up periods, and inevitably, the return temperature of the heating water must exceed 60°C if temperature is used to control legionella bacteria.

To maximize the temperature differential across hot water heating circuits, the heat exchange rate should be maximized. This will enable water to be heated quickly whilst minimising storage where bacteria can multiply. One option is the use of plate heat exchangers for the instantaneous heating of hot water within so called 'heat interface units'.

This type of unit heats the incoming mains cold water by means of a plate heat exchanger. Heating water circulates on one side of the plate heat exchanger transferring heat to mains cold water passing through on the other side. The heated water then feeds straight to the hot water taps. To control the heating capacity of the unit, self-acting control valves regulate flow rates through each side of the plate heat exchanger.

The heat transfer across the heat exchanger is such that heating water entering at temperatures up to 80°C can be cooled to around $20\text{--}30^{\circ}\text{C}$ as it heats the incoming cold

water. Hence, whenever there is a draw-off of hot water, return water temperatures are maintained at low values. When there is no draw off of hot water, the self-acting control valve inside the unit throttles the heating flow to a minimum thereby causing the pump to reduce its speed and hence power consumption.

Because the heating demands for hot water are for shorter periods (relative to the periods required to heat cylinders), there is more scope to allow for diversity of usage in the sizing of heating system pumps and pipe sizes. This can be further assisted by the inclusion of a buffer tank in the heating system to deal with large simultaneous demands for hot water.

1.A1.8.3 Air and dirt removal

Excessive amounts of either air or dirt left in the system can lead to difficulties in obtaining repeatable flow measurements during the commissioning process. Furthermore, problems associated with corrosion or bacteria proliferation are more likely during the ongoing operation of the system.

These problems can be avoided by proper venting and de-gassing of the system to remove air, and flushing and chemical cleaning of the system to remove solids.

1.A1.8.3.1 Air removal

Air vents should be located at system high points to enable the removal of trapped pockets of air during the initial fill of the system. This will often need to be a manual process whereby the installer opens each of the vents in turn to release trapped air.

This type of manual venting may prove difficult in large or complex systems or in high rise buildings due to the sheer number of vent locations that must be visited. Furthermore, in large or tall systems, even if manual venting is carried out properly, additional air bubbles may be generated as dissolved gas within the system water comes out of solution due either to increased water temperature through boilers, or the gradual reduction in static pressure as the water travels up vertical risers.

For systems that may be difficult to vent by manual means, some form of de-aeration facility is advisable. A purpose designed de-aeration unit can be installed in order to remove air from the system before commissioning, with the option to leave it in place permanently.

De-aeration units can work by either temperature or pressure.

Temperature based de-aeration

These units are installed in-line in the hottest part of the system (e.g. the outlets from boilers or the inlets to chillers) and are able to catch air 'microbubbles' released due to the relatively high temperature of the circulating liquid at those points. Captured bubbles are collected by a mesh or packing material in a low velocity chamber (under laminar flow conditions) and rise naturally to a vent where they are automatically released. These types of unit are limited by the static pressure in the system and are not suited to medium to high rise installations. Units should only be

installed at low static pressure points as advised by the manufacturer.

Pressure based de-aeration

These units, sometimes referred to as 'vacuum degassers', can be installed at any point in the system, and are more effective than temperature based units in that they are able to remove dissolved gases from the water. This is achieved by generating a temporary vacuum around the liquid. Water is extracted from the system into a cylinder, degassed and then re-introduced to the system. The degassed water is then circulated around the system where it is able to dissolve any additional pockets of trapped air which can then also be removed. Although the volume of the cylinder is small relative to the size of the system, repetition of this process means that over a period of time, all of the water in the system is de-gassed.

1.A1.8.3.2 System cleaning

System flushing and chemical cleaning is an essential precursor to the commissioning of most large scale pipework systems. Furthermore, once the system is in operation, there will be an ongoing requirement to dose the system with chemicals to prevent corrosion or biofouling.

Existing and newly installed pipework will inevitably contain various types of debris and contaminants. These can be classified under the following headings.

Installation debris

Extraneous materials that commonly find their way into systems during installation include millscale, welding slag, metal swarf, cutting oil, soldering flux, jointing compounds and grease. Furthermore, in larger pipes there is the potential for larger objects such as tin cans or plastic bags to inadvertently enter the system.

Corrosion products

Corrosion in steel pipework may result in increased levels of suspended solids due to the formation of insoluble iron compounds. Furthermore the settlement of solids in low velocity areas of the system may give rise to localized 'under-deposit' corrosion or provide a hiding place for bacteria. Microbiological induced corrosion is usually caused by sulphate reducing bacteria. These bacteria metabolise naturally occurring sulphate in the water to produce sulphuric acid under clumps of bacteria resulting in localised pitting corrosion.

Biological fouling

All natural sources of water (including tap water) contain many different types of bacteria, some of which may multiply and lead to problems within a pipework system if they encounter suitable conditions for growth. Systems left filled and untreated or which are filled and subsequently drained, can quickly develop a biofilm layer on pipe surfaces. The biofilm (a mixture of live and dead bacteria and their excretions) helps the bacteria to resist the action of biocides and seeds bacteria back into the system water. It can also create the starting environment for the microbiological induced corrosion previously mentioned. Pseudomonas bacteria, in particular, have been linked with particularly severe cases of biological fouling.

Dynamic flushing and chemical cleaning procedures are described in BSRIA Application Guide BG29/2011: *Pre-commission cleaning of pipework systems* (Brown, Parsloe, 2011). All newly installed pipework systems should be flushed and cleaned in accordance with this guidance by a suitably experienced pre-commission cleaning specialist.

To enable an effective clean, in accordance with the BSRIA guidance, it is essential that appropriate facilities and features are incorporated in the installed pipework system. These should be identified and planned at the design stage. The main features recommended in the BSRIA guide are as follows.

Flushing by-passes across central plant

By-passes across central plant items should be provided to permit main pipework to be flushed and chemically cleaned without having to circulate the dirty water and chemicals through central plant, i.e. boilers or chillers.

Flushing drains on central plant connections

Suitably sized flushing drains should be provided on flow and return connections to central plant items – to enable these items to be flushed through.

Flushing by-passes across terminal units

By-passes across terminal unit connections should be provided to permit pipework to be flushed and chemically cleaned without having to circulate the dirty water and chemicals through terminal units, i.e. fan coil units, chilled beams or air handling units.

Flushing drains on terminal unit connections

Line size drains should be provided on flow and return connections to central plant items and terminal units to enable these items to be flushed through.

Strainers

Strainers should be provided in pipework connections to central plant items to provide ongoing protection. In addition, strainers should be provided in front of all pumps so that, if used for flushing purposes, there is no risk that debris particles could enter the pumps and cause damage. Strainers should also be provided on main branches (e.g. off riser connections) to trap debris that might enter the terminal unit connections.

1.A1.8.3.3 Maintenance of system cleanliness

It is essential that cleaned systems are properly maintained by regular dosing with water treatment chemicals. Corrosion inhibitors and biocide chemicals in particular must be maintained at appropriate levels to prevent deterioration of system water quality.

However, it is inevitable that over a period of time, and despite proper treatment with corrosion inhibitors, there will be some ongoing corrosion of steel components that will lead to an increase in the amount of solid material in the system. This material may in the form of fine particles that are carried in the fluid stream, possibly settling out at low velocity regions. Standard in-line system strainers

typically have mesh sizes of 0.8 mm upwards and are unlikely to collect this material.

Options to trap and remove fine corrosion debris include filtration or separation solutions such as:

- *Side stream filtration* whereby a proportion of the main flow is side streamed through a filter unit removing material before being circulated back into the system. Because the unit is installed in parallel with the main flow, usually with its own pump, it can achieve a high level of filtration without incurring an additional pressure loss across the system pumps.
- *In-line dirt separators* that combine low velocity conditions with a specially designed packing that encourages the settlement of fine dirt particles. Collected particles can then be released via a manually operated drain cock. Such units have relatively low resistance meaning that they can be installed in the main flow without adding significantly to system pressure losses.
- *Magnetic separators* that exert a magnetic attraction over particles of iron oxide i.e. magnetite. Magnetite is a black oxide which appears as small insoluble particles which, if left, can settle out in low velocity areas such as the bases of radiators forming a thick sludge. Magnetite is more likely to form in closed heating or cooling systems than rust which requires higher oxygen levels. As inferred by its name, magnetite is magnetic and can therefore be separated from the flow by exposure to a strong magnetic unit.

1.A1.8.3.4 Commissioning

Commissioning is defined as the advancement of an installation from the state of static completion to full working order to specified requirements. For hydronic systems, it includes the setting to work of system pumps and the regulation of flow rates. The regulation of flow rates is particularly important; if flow rates are not properly distributed throughout the system, the required amounts of heating or cooling may not be delivered and the building will not meet the comfort requirements of the occupants. Alternatively, excess energy consumption may be incurred due to excessive flow rates or inadequate control of flows.

All re-circulating pipework systems should be commissioned in accordance with the requirements of CIBSE Code W: *Water distribution systems* (CIBSE, 2003) and BSRIA Guide BG2/2010: *Commissioning water systems* (Parsloe, 2011).

The emphasis of both of these documents is on building heating and cooling systems although the recommendations may also be applied to other types of water distribution systems. The guidance is equally applicable to new-build and retrofit applications and is independent of the scale of the system.

Code W sets out the general requirements for balancing and commissioning water distribution systems to meet the requirements of the designer. BSRIA Guide BG2/2010: *Commissioning water systems* provides a more detailed description of the practical aspects of commissioning procedures in a step-by-step format.

It is a requirement of Code W that water distribution systems should be inherently commissionable, i.e. designed, installed and prepared to specified requirements in such a manner as to enable commissioning to be carried out. This is most likely to be achieved if the commissioning requirement is in the brief from the outset, and specialist commissioning input sought early in the design process.

The main commissioning activity for most hydronic systems will be the regulation of flow rates to achieve the designer's specified flow rate values. Depending on the layout of the system, and the valve types selected, flow regulation will involve an exercise of either proportional balancing or flow setting as described in the following sections.

Proportional balancing

Proportional balancing is the process of bringing the fluid flow rates throughout a distribution system into balance with one another, in their correct proportions and within tolerances specified by the designer.

The procedure is applicable to sub-branches fitted with manually operated regulating valves such as fixed orifice double regulating valves. In such systems, the adjustment of each regulating valve will cause a change in flow rates through all other branches, and therefore, the balancing process must follow a prescribed procedure. The balancing procedure must always start at system extremities and work its way back towards the pump. Furthermore, for each group of sub-branches to be balanced, the end (i.e. most remote) sub-branch must be made the least favoured at the outset by throttling its regulating valve if necessary.

For proportional balancing to be successful, regulating flow measurement devices must be fitted in each branch and sub-branch throughout the system.

Flow setting

Flow setting is a more appropriate term for achieving the correct balance of flow rates in systems fitted with self-acting valves such as constant flow regulators, differential pressure control valves and pressure independent control valves. For each of these valve types, flow rates can be set adjusting the valve whilst verifying flow rate at a separate flow measurement device. Because the valves are self-acting they will respond to any changes in pump or system pressure and automatically adjust themselves so that the set flow rate is maintained. Hence, there is no necessity for a prescribed balancing procedure such as that for manually operated valves.

Because the valves are self-acting, there is no need for multiple valves to be installed on all system branches and sub-branches. Suitably sized valves located at terminal unit sub-branches (or branches feeding to groups of terminals) are sufficient.

A detailed description of proportional balancing and flow setting is provided in CIBSE Code W *Water distribution systems* and BSRIA Guide BG2/2010: *Commissioning water systems*.

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