Non-return valves

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4.1 Non-return valves and the system

Non-return valves, or nrvs as they are known, prevent fluid from travelling the wrong way in systems. A popular application is to prevent circulation in rotodynamic compressors and pumps, described in Chapter 3, Section 3.1.

P&IDs (Process/Piping &Instrumentation Diagrams), show the engineer how process equipment and instrumentation are connected. Different types of compressors and pumps are indicated by different symbols allowing system designers to decide what piping components are required. P&IDs do not show the orientation of pipework. Many items of equipment can have connections in a variety of orientations to suit the local installation. The physical orientation of the pipe run must be known before the final decision can be made regarding nrv style.

Rotodynamic machines are not always fitted with nrvs. A nrv is not required in a system with a single rotodynamic machine when all the pressure generated by the machine is dissipated as pipe friction losses. There is no opportunity for reverse flow. This situation rarely occurs in practice, because most pipe systems include changes in pipe elevation, which require the rotodynamic machine to impart some static head to the fluid which pressurises the system. When the machine stops the static head decays as a result of the fluid returning to the lowest points in the system. A non-return valve can prevent the fluid from returning to the suction source.

In some installations the fluid returning to the suction source does not cause a system problem. However the reverse flow can cause serious machine problems. Many compression machine types can run very successfully as an expansion machine, i.e. a turbine. Uncontrolled reverse flow can cause a compression machine to overspeed and damage itself. Some machines will not run successfully in reverse at all. Lube oil pumps driven from the machine spindle may not supply any lube oil when running backwards. Running at any speed in reverse can cause costly damage to bearings and gearing.

In complex systems, where good reliability and continuity of production must be assured, multiple rotodynamic machines are installed. Some machines will run continuously while others will be on stand-by in case a fault develops. In some processes the stand-by machines must take over almost instantaneously. There is no time for an operator to manually open isolating valves or even wait for power-actuated valves to open. The stand-by machine must be ready to run as soon as an operator presses the start button or the process control system initiates the start sequence. A non-return valve provides a good solution.

The running machines discharge into the system. The higher pressure fluid is prevented from returning to the suction source through stationary machines by nrvs. When a stand-by machine starts it must initially generate a slightly higher pressure than normal to open the nrv; but then the machine follows its HQ characteristic to find the point of equilibrium with the system curve. The failed running machine can then be isolated and inspected or repaired while production continues.

Some positive displacement machines need to be fitted with nrvs in a similar way to rotodynamic machines. The following machine types should be fitted with non-return valves when used in a stand-by situation:

- gear
- lobe
- screw
- rotary piston
- progressing cavity
- vane

Peristaltic machine installations should be reviewed with the manufacturer. Positive displacement machines which use internal valves do not require a nrv for simple stand-by functions.

Positive displacement machines with internal valves may be fitted with a non-return valve to prevent reverse flow in a particular situation. These positive displacement machines often require a substantial torque for starting on-line; that is starting at full discharge pressure. The starting torque can be as high as 150% of the normal running torque. This high value is only required for a very short time, normally less than a second, but it must be applied to start the machine. Only direct-on-line DOL starting, of ac squirrel cage fixed speed motors can supply this level of torque. Some motor designs do not develop a starting torque of this magnitude, even with DOL. Be warned!

With larger motor sizes, star-delta starting, S-D, is preferred to reduce the voltage drop in the electrical system. Star-delta starting produces very little starting torque, so a method of reducing the driven machine torque requirements is necessary. If started with a discharge pressure very close to suction pressure the starting torque can be reduced to 10 or 20% of normal running torque. A by-pass, returning discharge fluid to the suction system, can accomplish the required pressure reduction. If the by-pass is opened on a running system the high pressure fluid will be short-circuited to suction. A nrv is fitted to prevent this happening.

Mounting the nrv remote from the compression machine can create additional problems. Seawater pumps for offshore platforms are submerged, but the control equipment and non-return valves are on the platform. For some reason, foot valves are not used in the suction pipework. A discharge nrv is fitted at platform level. The discharge pipe from the pump to the nrv is empty at start-up. Beyond the nrv the discharge pipework is full of seawater. When the new seawater hits the nrv, tremendous pressure spikes are created. A back pressure regulator can be used to automatically bleed air out of the system and control the seawater pressure. The regulator sizing is critical.

Offshore operating staff have experienced many problems including over pressurised riser tubes, stretched flange bolts, damaged pump bearings, corrosion, erosion, broken bursting discs in downstream systems and other damage generally attributed to pressure and flow transients. According to D Fitzgerald, simulation of many of these problems is possible, using powerful computers.

The manner in which the fluid starts and stops to flow, under normal operating conditions, can be important for the long term durability of the nrv. Small rotodynamic machines, started DOL, will “run up” very quickly causing a rapid fluid velocity increase. The same machines will stop quickly when the power is switched off. These operating conditions can lead to the moving valve components bouncing off stops and seats. Larger rotodynamic machines will be started with closed discharge valves so the increase in fluid velocity can be controlled by the valve speed. Small positive displacement machines will react in a similar manner to small rotodynamic machines. Large positive displacement machines will probably be started on a by-pass, so the increase in fluid velocity can be controlled by the by-pass valve operation. The non-return valve required for a specific installation may require resilient “bump” stops and a resilient seat insert, or damping, or end-of-travel cushioning, to prevent shock loading.

Special versions of double non-return valves can be fitted in domestic drinking water systems to prevent contamination of the system. These valves are often called “backflow preventers”. When reverse flow tries to enter the system the downstream nrv opens a branch port and allows the suspect liquid to be dumped.

Non-return valves impose a friction loss on the system. A straight swing disc nrv, wide open, is generally assumed to be
similar to a square elbow in the pipe. If the nrn is not wide open the losses will be higher. Swing disc nrvs are manufactured in an oblique style, see Section 3.3.1 in Chapter 3.

These valves will have slightly lower friction losses, everything else being equal. Piston nrvs generally have higher losses. Special streamlined versions of straight piston valves are manufactured to reduce losses to a minimum. Friction losses by piping and pipe fittings are a constant drain on energy. Whether or not overall efficiency is important from a corporate viewpoint, it is always important from a global perspective to reduce energy consumption, depending upon the source and cost of the energy. Compression machines frequently have small discharge connections. The first item a piping designer fits in the pipework is a reducer, to increase the pipe bore and reduce the flow velocity to an acceptable level. The velocity through the nrn should also be considered to ensure proper valve selection.

NOTE: A fitting to change the pipe size is always called a “reducer”. Even if it is fitted backwards to increase the pipe size it is still a “reducer”.

The type and size of the non-return valve which must be fitted in a system can be greatly influenced by the necessity of cleaning or inspecting the pipework with a “pig”. If “pigging” is a prerequisite then the non-return valve must be able to present a completely clear bore of approximately the same diameter as the pipe. A slightly larger bore would be acceptable, but not a smaller one.

Finally, it may be necessary to fit protection for the non-return valve or instrumentation to indicate correct function or valve status. Clean fluid systems are only clean after flushing and some time of normal operation. Systems which operate with a degree of solids content frequently have unexpected solids in the worst possible locations. Crude oil, specified to contain sand, sometimes contains pebbles. Equipment selected to pass sand up to 2mm may be damaged or disabled by 10mm pebbles.

Nrvs fitted to stand-by machines can be a considerably drain on energy if the valve is permanently “cracked-open” by sand on the seat. Permanent instrumentation may not be necessary if maintenance staff perform routine inspections with modern equipment. The high frequency acoustic signal created by a high velocity fluid passing through a small aperture should be easily detected.

4.2 Non-return valve design

The non-return valve is an automatic, self-powered valve which tries to ensure fluid only moves in one direction. The moving element normally rests on the seat to form a seal. A small pressure must be applied to the moving element to open the valve initially. Once open, fluid-dynamic forces are generated which hold the valve open or increase the opening. Fluid flow must usually stop before the valve will close. The fluid-dynamic forces created by any fluid flowing across the seat will generally prevent all valves closing. Springs may, or may not, be used to control opening and assist closing. Some valves rely solely on gravity to provide the closing forces. Valves which rely on gravity must be installed according to the manufacturers’ instructions. If level pipe is specified then the local pipe fall must be modified for a short distance.

Swing disc valves are gravity-powered. As the valve opens, the force required to hold the valve open increases. If the balance between disc mass and fluid-dynamic forces is incorrect the valve will not open completely. Increased fluid velocities may result in unexpected corrosion or erosion damage. Gravity-powered valves must be matched to the fluid and operating conditions.

When valves open fully, the disc or piston travel must be limited by a stop. Valves which open fully, but are not stop limited, are liable to “flutter”. Flutter can cause rapid wear of hinge pins or piston guides. Valves which use springs can suffer from early spring failure due to fatigue. Flutter can be caused by the shedding of eddies, or turbulence. Damping can be used to restrict the flutter movement. Fluid damping, using squish, can be effective when the fluid has some viscosity. Valves using springs can have variable rate springs fitted. If the full travel stop incorporates squish, to prevent rebound after rapid opening, this can be an effective flutter damper.

Squish can be incorporated into the seat and disc/piston design to prevent the valve slamming shut. Extra material is added around the seat contact area to create two squish zones. Trying to squeeze the fluid out of these zones during rapid closure slows the valve down. But there is a penalty to be paid. The increased area of limited clearance is an ideal site for trapping small solids. Squish protection for damped closure can lead to more problems caused by trapped solids, unless there is adequate clearance for the squish action to eject the solids. Valves with narrow seats can crush friable solids, such as coal. The squish zones tend to broaden the effective seat width and reduce the valve’s capability to crush solids. This effect must be considered, taking into account the nature of any pertinent solids. Ball valves usually have very narrow seats and can clear most solids enabling the seating to be effective. (See Chapter 3, Section 3.3.3.)

The problem of flutter may be restricted to small valves. As valves become larger the inertia of the moving parts becomes much greater. The increased inertia can effectively dampen flutter and lead to delayed closure, after reverse flow has commenced. Damping at the seat therefore becomes very important.

As with all valves, the flow areas must be checked and velocities calculated for design operating conditions. Areas around discs and pistons are as important as the main port areas. Flow areas which are smaller than others will be the zones where erosive, and possibly cavitation wear, will occur.

Non-return valve bodies can incorporate extra connections for special functions such as venting and draining. Valves for hot applications can sometimes be fitted with an external by-pass to allow system preheating at low flows.

4.3 Non-return valve types

Selecting the correct type of non-return valve is essential for process reliability. Frequent unscheduled interruptions can be very costly and also result in product delivery delays. The following descriptions should assist in informed valve selection.

Swing disc non-return valve

The swing disc non-return valve, also commonly known as the “swing check”, is the standard basic nrn usually supplied by a manufacturer unless a specific type is requested. Figure 4.1 shows a typical arrangement of a valve with a one-piece cast body.

All access to the internals is through the top cover. The valve has a replaceable seat. The hinge pin is located so that gravity

Figure 4.1 A typical on-piece body cast swing disc non-return valve
holds the disc against the seat. Some of these valves are suitable for vertical operation. The hinge pin is fitted through a boss in the body wall and retained by a screwed plug. This hole and the top cover are the only leak paths for process fluid. For hazardous applications the nature of the plug seal must be reviewed. A seal which isolates the plug threads is preferable.

Hinge pins are generally of 11/13Cr. The end-of-travel stop is cast into the body allowing plenty of scope for squish design. Cast valves of this style can usually be “pigged” without problems. Valves of this type are widely available, as shown by Table 4.1.

<table>
<thead>
<tr>
<th>Body material</th>
<th>Seat material</th>
<th>Disc material</th>
<th>Pressure rating</th>
<th>Sizes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cast carbon steel</td>
<td>Hard faced carbon steel</td>
<td>11/13 Cr</td>
<td>ANSI 150lb</td>
<td>2” to 4”</td>
</tr>
<tr>
<td>11/13 Cr</td>
<td>11/13 Cr on carbon steel</td>
<td>6” to 12”</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hard faced carbon steel</td>
<td>11/13 Cr</td>
<td>ANSI 300lb</td>
<td>2” to 4”</td>
<td></td>
</tr>
<tr>
<td>11/13 Cr on carbon steel</td>
<td>6” to 12”</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hard faced carbon steel</td>
<td>11/13 Cr</td>
<td>ANSI 600lb</td>
<td>2” to 4”</td>
<td></td>
</tr>
<tr>
<td>11/13 Cr on carbon steel</td>
<td>6”</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11/13 Cr on carbon steel</td>
<td>8” to 20”</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11/13 Cr</td>
<td>11/13 Cr</td>
<td>ANSI 900lb</td>
<td>3” &amp; 4”</td>
<td></td>
</tr>
<tr>
<td>11/13 Cr on carbon steel</td>
<td>6”</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11/13 Cr on carbon steel</td>
<td>8” to 20”</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11/13 Cr</td>
<td>11/13 Cr</td>
<td>ANSI 1 500lb</td>
<td>2” &amp; 4”</td>
<td></td>
</tr>
<tr>
<td>11/13 Cr on carbon steel</td>
<td>6”</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11/13 Cr on carbon steel</td>
<td>8” to 12”</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 4.1 One-piece body, swing disc non-return valve materials and ratings

Butt weld connections are available as an option instead of flanges. Valves for pressure ratings over 300lb may have corrugated soft metal gaskets or ring-type joints for the body cover. Elastomer inserts in either seat or disc is possible. Valves of this type are available for pressures up to ANSI 2500 lb in sizes up to 48”. Alternative body materials include:

- cast iron, (for 16 barg)
- low temperature carbon steel
- 1¼% Cr ½% Mo steel
- 5% Cr ½% Mo steel
- 18% Cr 10% Ni 2% Mo stainless steel

The design can be modified slightly by increasing the angle of the seat; this is claimed to reduce water hammer effects. Cast valves can be of the oblique style. Both modifications may prevent “pigging”.

The seat is normally screwed in to the body; therefore check how it is locked. The hinge pin should be locked in the body and the disc rotates about the pin. This construction ensures the body is not a wearing part. When the seat and hinge pin are of different materials to the body, selective corrosion or galvanic corrosion may be a problem; it is advisable to seek the manufacturers’ advice. For austenitic stainless steel valves, a hardenable stainless steel should be used for the hinge pin. 17-4PH could be a good choice.

Closed die forged bodies are produced as standard for valves of ANSI 900lb and 1 500lb. Sizes include DN6 to DN50. Connection options include screwed, socket weld, butt weld and flanged. The flanged versions may have the flanges butt-welded to a forged body and so it is important to check the weld quality. Some small high pressure valves may not be full bore; and so check the seat size if this is important. Forged body valves with hammer lug connections are specifically manufactured for oilfield applications.

The style of construction shown in Figure 4.1 can be used for special materials if the complete body is machined from the solid. The hinge pin can be fitted from the top, through the cover, and clamped in position. The facing for the cover seating is made by machining a flat on the circular body. The integrity of the valve is improved by removing the hinge pin retaining plug. Valves are available up to DN200 in the following materials:

- aluminium, Alloy 20, bronze, duplex stainless steel
- Hastelloy™, Inconel™, Monel™, nickel, Nitronic™
- tantalum, titanium, zirconium

The design of the swing disc valve can be modified slightly by moving the position of the hinge relative to the disc centre-line. The disc can be pivoted from a point within the disc diameter, called a “tilting disc valve”. Moving the centre of rotation closer to the disc reduces the mass and the inertia, although it makes the seat and seal design more complicated.

Figure 4.2 shows an oblique style valve for steam. Valves of this style are available up to DN1000 for pressures up to 60 barg. Valves for liquid can be up to DN350 with pressure capabilities to 500 barg. Oblique style valves can be fitted with pneumatic actuation to override the fluid dynamic forces. These valves are not full bore.

The swing disc can be made in two other styles:

- two-piece body
- wafer

![Figure 4.2 An oblique style swing disc non-return valve](Courtesy of Dresser-Masonelan)

![Figure 4.3 A two-piece body swing disc non-return valve](Courtesy of YPS Valves Ltd)
The two-piece body version is similar to that shown in Figure 4.1. The body is split vertically next to the seat location. The body flange is used to hold the seat and the hinge pin in position, see Figure 4.3. One possible leak path is removed, increasing the valve integrity. Valves of this style are cast in exotic alloys, as listed above, for sizes from DN15 to DN150 in pressure ratings up to PN50.

The wafer version is useful for locations where space is restricted. Wafer valves are built in sizes from DN50 to DN900 in pressure ratings up to ANSI 2500 lb. Carbon steel is standard with a stainless steel option. Some wafer valves have an "O" ring seat insert as standard.

Full bore wafer non-return valves, from DN15 to DN100, are suitable for 100 barg at temperatures up to 200°C. Reduced-bore stainless steel or gunmetal valves, for 40 barg maximum, with Viton™ seat seals are available from DN50 to DN400. The bore of the DN50 valve is 31 mm; DN400 is 305 mm. Maximum operating temperature is 105°C.

A derivative of the simple flat swing non-return valve is the curved plate non-return valve. The flat disc is replaced by a curved plate which seals the bore. The valve body has a bore diameter slightly larger than the pipe bore and is fitted with a replaceable insert profiled to a shaped metal seating. The curved plate is designed to lift into the horizontal position and rest in the top of the valve bore. The flow path is completely unhindered and results in very low pressure drops and allows the valve/pipeline to be cleaned or inspected by a "pig".

Flat plates are inefficient for supporting evenly distributed loads and need to be disproportionately thick. End caps for pipework are therefore elliptical. The curved plate is much stronger than a flat disc and can be made much thinner and consequently lighter. The reduced weight of the curved plate allows the valve to open fully at lower fluid velocities and accept lower density fluids. This valve style is ideal for gases. In fact, the design was originally developed for use in the pulverised coal-feed lines on large boilers. The valves were fitted to eliminate the danger of explosions in the feed lines due to blow-backs from the boiler.

As the curved plate is virtually invisible to the flow when the valve is wide open, these valves are very suitable for solids handling and abrasive applications.

**Swing disc non-return valve with external loading**

The swing disc non-return valve, with external loading is a logical development from the previous valve design. The disc is attached to the hinge pin which now rotates in bearings in the valve body. A shaft seal is required where the hinge pin is extended through the body wall. Externally the hinge pin is fitted with a radial arm and adjustable weight. The external weight can be used to increase the effective weight of the valve disc and reduce opening, or reduce the effective weight and increase opening. In both cases it must be remembered that the inertia of the valve moving parts has been increased and the valve response to similar forces will be slower. The hinge pin seal can provide a degree of damping.

When a standard swing disc nrv is mounted horizontally, the force required to hold the valve open increases as the valve opens. If it is mounted vertically the force reduces. An external weight on a radial arm can be used to counterbalance or partially counterbalance the disc weight effect. Alternatively, the arm can be oriented so that the external weight complements the disc weight. The arm can be set at any angle and the weight adjusted until the desired valve performance is achieved.

An external dashpot can be fitted to limit the disc angular velocity and angular acceleration. Also a quadrant can be attached to the valve body to allow the valve to be locked open or closed or to limit the opening. The external lever can be held in the open position permanently by a wire and fusible link. This arrangement enables the valve to prevent reverse flow in the event of an external fire.

Because the external loading is a fairly simple modification of this valve type, the availability is similar to those shown in Table 4.1. The external lever can be replaced by a pulley or sprocket which allows a constant external torque to be applied to the hinge pin.

**Twin disc non-return valve**

The problem of valve inertia has just been mentioned above. The twin disc non-return valve, significantly reduces the problem. The single disc described previously is divided in two and supported across the centre-line of the valve bore. The twin disc nrv has two nominally semi-circular discs. The inertia of each disc is less than half that of the normal swing disc because the axis of rotation has been moved and the "half" disc can be thinner. The linear movement required to achieve full opening is much shorter. The two discs are pivoted from a single central hinge pin or a central column.

Because this valve has an obstruction in the centre it cannot be cleaned or inspected by a "pig". This shortcoming must be considered but the basic design concept is eminently suitable for large valves. A well-designed twin disc non-return valve will have a flow coefficient as high as, or higher than, a conventional swing disc design. Some manufacturers do not offer valves for applications with pulsating flow. Installations with reciprocating machines, and some other positive displacement machines, should therefore be reviewed with the valve manufacturer. Some rotodynamic machines can be prone to surge when operated with certain system characteristics. The possibility of surge should be evaluated in these circumstances.

The valves are installed with the hinge pin vertical. On opening, the discs rotate towards each other and move to a position pointing downstream. Physical stops should be provided to prevent over travel.

These non-return valves are most popular as a wafer pattern, see Figure 4.4, in all pressure ratings. The wafer construction permits considerable space saving and is much lighter than that of flanged valves. Higher pressure versions can be similar to the lug style, with the body od the same as the flange od. Clearance holes allow the use of one set of studbolts. With this design the bolting is around the outside of the valve, still however maintaining the "wafer" face-to-face dimension (API 594 standard). The lug (also known as a wafer lug sometimes) and double flanged types are equally as popular, if not more so, in the
hydrocarbons industry. This type of valve is also sometimes referred to as a double plate check valve (API 594 standard).

Twin disc nrvs are available in three designs:

- conventional
- retainerless
- cartridge

The conventional approach is to fit the hinge pin through the valve body and provide the pressure containment by a screwed plug or flange. The retainerless design fits all the internals axially from one end of the body. Internal stops secure the hinge pin without piercing the body pressure containment. The cartridge valves have all the internal components, including the seats, mounted in a sleeve which is locked axially in the valve body. Again, the valve body is not pierced with potential leak paths. Spare cartridges can be stocked to allow rapid repair in emergency situations. The cartridge can be serviced and inspected on a bench rather than on site. All designs should include a fixed spring stop to allow each disc to be independently sprung and balanced for synchronised operation.

Popular valves have bodies and cartridges of cast steel with 11/13 Cr discs. Seats can be integral and hard-faced or have resilient inserts. Valves from DN50 to DN600 can have pressure ratings from ANSI 150lb to 1500lb; valves up to DN300 have ratings of 2500lb. Valves up to DN2100 and valves with pressure ratings up to ANSI 4500lb are also available. Some metal wafer non-return valves have a lining. Stainless steel valves with PFA lining are mass-produced in sizes from DN15 to DN100. Maximum pressure is 100barg at temperatures up to 200°C. Cast iron wafer valves, with aluminium bronze discs, are available from DN50 to DN600 for 16 barg. Bodies can be painted with epoxy for corrosion protection.

Because these valves have two sealing elements, the elements can respond individually to variations in flow velocity. If the valve is subject to uneven flow distribution across the bore the discs will open to different positions. Wear may be localised in one half. If the discs are sprung against each other, rather than a fixed stop, travel stop damage and early spring failure may result. The detailed design of the valve should be fully investigated if uneven flow distribution, possibly caused by close proximity of bends to the inlet, is likely.

**Piston non-return valve**

The piston non-return valve, belongs to a general group of nrvs called “lift nrvs” or “lift checks”. These are linear motion valves similar in concept to globe valves. The ball non-return valve, described in the next Section, belongs to the same group but has different properties. The piston non-return valve can be used for the most arduous clean applications, such as dosing and metering. Spring-loaded valves can be cycled up to 1000 times per minute. Figure 4.5 shows the construction of a typical high pressure non-return valve for sizes up to DN80.

The valve shown has butt weld connections and a bolted, spigotted cover. Small valves of this type may have a screwed cover. The valve has a replaceable seat and a top-guided piston. Guiding can be bottom, crow-foot or wing-guided, or top, or both. The valve relies on gravity alone to close. Spring-loading is also popular. When springs are fitted it is important that the springs do not become coil bound. For valves which cycle regularly, the springs must be stressed to avoid fatigue. The valve performance can be optimised by adjusting the spring design, spring rate and initial compression.

The flow passages in small valves can be tortuous when machined from the solid. The velocity in the passages should be checked as well as through the seat. The tortuous flow path makes these valves unsuitable for solids handling applications. Forged body valves are mass-produced in carbon steel and austenitic stainless steel. Typical pressure ratings include PN20, PN50, PN100, PN150 and PN250. Specialist manufacturers produce valves for ANSI2500lb and 4500lb. Some flanged valves are made by welding on flanges, so the weld quality should always be checked. Some small valves have an angle pattern but are not produced in such large quantities.

Flow passage problems are eliminated in larger valves by casting the whole body. All valves are not full bore, so check seat areas when evaluating the pressure drop. Figure 4.6 shows the typical seat area as a function of pipe area for common pipe schedules.

Some designs are very similar to cage-trim globe control valves, see Chapter 6, Section 6.3.1. Figure 4.7 shows a cage-trim piston non-return valve. Notice the flanges are not integral but mounted and retained by shear rings. The valve seat
is retained by the cage. All components are assembled through the top cover. The valve can be maintained in situ without special tools. Squish can be built into the valve design to soften end-of-travel and closing. End-of-travel squish can be accomplished by the machining of the back of the piston and the stop. Closing squish is adjusted by the positioning of the ports through the cage relative to the full diameter of the piston.

Valves of this style and angle pattern, with various end connections, are produced in a range of sizes and pressure ratings, see Table 4.2.

![Diagram](image)

**Table 4.2 Sizes and ratings of cage-trim non-return valves**

<table>
<thead>
<tr>
<th>Body material</th>
<th>Pressure rating</th>
<th>End connections</th>
<th>Sizes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cast carbon steel</td>
<td>ANSI 150lb</td>
<td>Screwed</td>
<td>DN50</td>
</tr>
<tr>
<td>Cast low temperature steel</td>
<td>ANSI 300lb</td>
<td>Flanged</td>
<td></td>
</tr>
<tr>
<td>Cast stainless steel</td>
<td>ANSI 600lb</td>
<td>Socket weld</td>
<td></td>
</tr>
<tr>
<td></td>
<td>ANSI 1500lb</td>
<td>Butt weld</td>
<td></td>
</tr>
<tr>
<td></td>
<td>ANSI 2500lb</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cast carbon steel</td>
<td>ANSI 150lb</td>
<td>Flanged</td>
<td>DN80</td>
</tr>
<tr>
<td>Cast low temperature steel</td>
<td>ANSI 300lb</td>
<td></td>
<td>to</td>
</tr>
<tr>
<td>Cast stainless steel</td>
<td>ANSI 600lb</td>
<td></td>
<td>DN150</td>
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<tr>
<td></td>
<td>ANSI 1500lb</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>ANSI 2500lb</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Special high pressure versions, to ANSI 4500lb, machined from solid forgings are available in suitable materials. Pistons and seats would normally be made from austenitic stainless steel. The piston cage can be carbon steel or stainless steel, both with the bore surface treated to eliminate friction and galling. The valve body can be cast in more exotic materials, such as those used in swing disc non-return valves.

The tortuous flow passage problems can be largely eliminated by constructing an in-line valve, see Figure 4.12. General purpose cast iron valves, rated at PN10, are produced in sizes from DN50 to DN400 and incorporate a flat Buna "N" seal ring on the piston. These valves are very popular as foot valves for pumps; matching strainers are available.

Wafer pattern valves, in carbon steel or stainless steel, suitable for 48 barg and 150°C, are available in sizes from DN15 to DN150. Soft seats, of neoprene or Viton™, are also an option.

Small non-return valves can be fitted with compression fittings or screwed ends. Because of the small seat sizes involved, the fluid pressure forces are small, and the piston or disc can be made quite thin and therefore light. Valve discs can have bonded soft seals to act against integral metal seats. Valves up to ¼" or for 12mm od tube may be assembled by internal screw threads, see Figure 4.8. These valves are capable of operating up to 414barg at temperatures up to 204°C. Slightly larger valves, for ⅜" and 1" tube and pipe, may only be rated for 139barg. Any internal threads, not protected by seals, would render the valve unsuitable for NACE applications.

Valves for cold water system applications with brass bodies and screwed or single ferrule compression fittings will be suitable for 10barg and temperatures up to 95° or 105°C. Sizes will generally be suitable for use with copper pipe of 8mm to 54mm od.

The backflow preventers used in drinking water systems follow a similar type of construction as the valve shown in Figure 4.8 but incorporate three separate valves, two nrvs and an automatic dump valve. Figure 4.9 shows a diagrammatic arrangement. Under normal operating conditions, both nrvs are open and the dump valve is closed, and flow travels from the supply to the consumer. If the pressure differential reverses and water attempts to flow into the supply, both nrvs close. The downstream non-return valve has a moveable seat which slides back and opens the dump valve. Water, which could contaminate the supply system, is diverted to the dump connection which can be piped to a drain. When the normal differential pressure conditions are restored, the dump valve is closed and both nrvs open.

Backflow preventers of this type should be fitted in the consumer’s local pipework and not in the distribution system. Valves are small, DN15 and DN20, suitable for pressures up to 10barg and temperatures up to 65°C. Bodies in bronze can have screwed connections or be fitted with single ferrule compression fittings for standard copper pipe. The sliding seat which actuates the dump valve may be fitted with a rubber bellows or membrane. Valves of this type must be approved by the appropriate authority before fitting to the system.

A special derivative of the piston non-return valve, a type of plate valve, is used exclusively on gas applications. Special plate valves have been developed for reciprocating gas compressors. A non-return valve is required at the inlet and outlet of each cylinder to ensure the gas only travels downstream. These valves generally have the plate and spring combined in a single component. The plate flexes to allow the valve to open. Figure 4.10 shows an exploded view of a typical valve. The bottom component is the valve seat. The od of the seat is stepped to allow clamping in the compressor cylinder.

Many valves are retained by a cage in a similar manner to cage-trim control valves and the piston nrv shown in Figure 4.7. The flow passages are shaped curved slots. The valve plate consists of concentric rings connected by slender spokes to a central boss. The flow passages are generally narrow to allow the plate to be very thin. A thin, light plate has very low inertia and can respond quickly to changes in gas velocity. Compressors frequently operate faster than 1000rpm and valve inertia would create serious problems. The complete valve assembly is held together by a central stud. Additional small helical compression springs may be fitted near the periphery of the valve plate to supply additional spring load. Simple versions of this style of valves, with a single port, are sometimes called “reed valves” and are used in small air and refrigeration compressors.

The compressor valves described can be used for process applications with gas. The valve can be mounted in a body or as-

![Diagram](image)
4 Non-return valves

Ball non-return valve

The ball non-return valve is suitable for the most arduous, dirty or clean applications. The nature of the ball shape produces smooth fluid streamlines which reduce the tendency for erosive wear considerably. Great attention must be paid to the detail design if the ball nrv is to achieve its real potential. Failure to deal with these detail design problems will result in high fluid losses and rapid wear.

The main problem to be understood and resolved is the weight and inertia of the ball. The volume of the ball is much greater than the equivalent piston and when made of the same material is much heavier. The increased inertia means the ball is much slower to respond to fluid and spring forces. The fluid forces generated are smaller than those of a piston due to the balls lower drag coefficient.

Selecting the right material can assist in reducing impact damage. If good lift is not achieved damping is unlikely to be a problem.

Ball non-return valves are generally small and are similar in style to piston nrvs, see Figures 4.5 and 4.8. The ball may, or may not, be spring-loaded. The spring must not rest on the ball directly as this will inevitably prevent the ball from rotating. A light follower must be used. The most popular commercial ball is a standard ball bearing. These are manufactured in SAE52100 carbon steel. Balls are also routinely made in AISI440C, tool steel, tungsten carbide and bronze.

Metal ball non-return valves are generally restricted to sizes between DN8 and DN50 with pressure ratings from ANSI150lb to 2500lb.

A special version, the double ball non-return valve, is produced in the smaller sizes. Two nrvs are built into one body. These valves follow the in-line, straight construction shown in Figure 4.8. Valves can have screwed or compression fittings. The valves are used for high pressure lubrication in conjunction with single-shot lubricators. A very small quantity of oil is injected at regular intervals into machine elements such as:

- compressors cylinders
- engine cylinders
- compressor stuffing boxes
- pump stuffing boxes

The double ball is a safety feature to ensure combustion products or process products do not escape in the event of lube oil line fracture. These valves are used routinely to 414barg; higher pressures are possible.

Diaphragm non-return valve

Diaphragm non-return valves, are made in two distinctly different designs:

- "duck-billed"
- flat disc

The flat disc diaphragm valve uses the flexibility of an elastomer disc against a multi-port plate to produce the valve action. Flow in the correct direction bends the elastomer disc away from the ported plate to allow the fluid to flow. If the fluid tries to change direction the elastomer disc straightens out and seals off the ports. This style of valve is recommended for clean fluids. Valve bodies are of cast iron or cast iron coated with PTFE. The steel ported plate can be Rislan™ coated or PTFE coated. Various elastomers can be used to suit the fluid. Sizes range from DN10 to DN200 for PN16, valves up to DN150 can be PN25. Maximum operating temperature is 100°C.

The “duck-billed” nrv relies on a moulded diaphragm to seal against itself. A tube is moulded and one end is formed and flattened to seal the bore. The slightest increase in internal pressure opens the flattened portion and allows flow. If the internal pressure falls below the surrounding pressure the flattened portion closes and seals. The length of the flattened portion is significant and the valve can seal around solids. The tube seal is very effective and the valve can be used for critical applications. The flow path is unobstructed when open and large solids should pass freely.
can be passed. The basic tube is available in a range of materials:

- natural rubber, chlorobutyl rubber, Neoprene™, Buna N,
- polyurethane, Hypalon™, Viton™, EPDM.

The valve can be used by attaching the moulded tube to the end of a pipe. Tubes for this purpose are made in sizes to suit pipes from $\frac{3}{8}$" to 120"nb. Alternatively the moulded tube can be built into a cast iron or fabricated steel body to form a flanged valve assembly. This style of valve is made in sizes from 3" to 48" nb. Standard small valves can withstand back pressures of 10 barg and large standard valves can withstand 2 barg. Special high pressure tubes can be moulded to special order.

Non-return foot valve

Foot valves are a special type of non-return valve, intended for the suction pipes of pumps. Most pumps require priming before starting. Priming involves filling the pump casing with liquid and expelling any trapped air. Some pumps are self-priming and these pumps will be specifically described as such. Even these pumps need some liquid in the pump casing to be able to work properly.

The foot valve is designed to maintain the suction pipework and the pump casing full of liquid. Foot valves are used on pump installations where the pump lifts liquid from a source below the pump.

The pump casing and the suction pipe can be filled manually by pouring liquid into the pump. Alternatively the liquid can be induced into the pipework and casing by applying a vacuum to the casing. In both cases the foot valve prevents the liquid running straight out and emptying the casing. It must be remembered that a foot valve is a resistance in the suction system and results in a loss of suction pressure and NPSHₐ/NPIₚₐ for the pump. The resistance must be considered when designing the pipework and selecting a valve, see Chapter 8, Section 8.2.

There are many types of non-return foot valve to suit many applications:

- plate
- poppet
- ball
- flat diaphragm
- tube diaphragm

All valve types may be fitted with a suction strainer; the design of the strainer being dependent upon the pump application. Contractors’ pumps, i.e. those pumps used on building sites to drain ditches and pits, may be suitable for handling solids up to 100mm. The strainer must limit the solid intake to the pump’s capacity. A heavy duty wire cage is necessary. Process pumps generally operate with clean liquids. A perforated metal tube or woven wire mesh, of adequate flow area, is adequate.

The plate versions are very similar in style to the small valve shown in Figure 4.8 with different body constructions. Small valves can have three-piece bodies similar to the ball valves in Section 3.3.3, Chapter 3. Small and large valves can have one-piece bodies with all the internals fitted through the downstream end of the body. The spring retainer holds all parts in position. Plate versions are available in cast iron, brass and bronze. Sizes range from DN15 to DN200 with pressure ratings from PN6 to PN40. Valves with elastomer sealing inserts may be limited to 110°C but all metal valves can be suitable for 350°C. Plate foot valves are recommended for clean liquids. A derivative of the plate version uses a crown-foot guided valve. This design is available from DN175 to DN 800 for pressures up to 10barg.

The poppet style valves are very similar to the controlled closure nrv shown in Figure 4.13. The body is a one-piece casting and all components are fitted through the downstream end. The spring retainer holds all parts in place. These valves are made in cast iron, bronze and austenitic stainless steel. Sizes range from DN50 to DN400 with pressure ratings from PN10 to PN40. Elastomer seals are used to prevent leakage and temperature limits will be 80°/110°/150°C depending upon the compound used. These foot valves are not recommended for liquids carrying solids.

The ball style foot valve is not like the ball non-return valve described earlier. The non-return foot valve version is designed for vertical or horizontal mounting and the ball is not spring-loaded. The ball is lifted by hydrodynamic forces and is pushed into a pocket alongside the liquid flow path. When the valve is wide open most of the ball is retracted, almost providing a full-bore passage. The ball version of the foot valve is intended for liquids carrying solids. These valves are made with cast iron bodies and balls can be of cast iron or non-metallic. Nylon and polyacetal balls have proved useful. Valve sizes range from DN50 to DN350 for pressures up to PN10. Working temperatures cover -10° to 80°C.

The flat diaphragm valve uses the flexibility of an elastomer disc against a multi-port plate to produce the valve action. When the pump creates a suction depression the elastomer disc is bent away from the ported plate to allow the liquid to flow. This style of valve is recommended for clean liquids. Valve bodies are cast iron or cast iron coated with PTFE. The steel ported plate can be Rislan™ coated or PTFE coated. Sizes range from DN10 to DN200 for PN16, valves up to DN150 can be PN25. Maximum operating temperature is 100°C.

The tube diaphragm foot valve is a logical development of the flat diaphragm version. The tubular diaphragm lies inside the perforated plate strainer. When the pump creates a suction depression, the tube collapses away from the strainer and opens the flow path. If the depression is removed the tube expands to regain its normal shape and form a seal against the strainer. This style of valve is only effective with clean liquids. Tube diaphragm foot valves are available in sizes from DN40 to DN300 with a maximum operating pressure of 6barg. Standard body material is cast iron with a natural rubber diaphragm.

Controlled closure non-return valve

The problem of water hammer generation due to rapid valve closure has already been emphasised. Peak pressures experienced through water hammer can cause considerable damage with consequential loss of production. Some non-return valve designs can be modified to regulate the velocity of the moving element(s). The modifications are an improvement on squish which can only function close to the end-of-travel. A form of damping is included to limit valve element velocity. These valve types are also called “non-slam valves”.

The swing disc non-return valve can be modified to include external loading, and was described earlier. Damping, in the form of a dashpot, can be attached to the external arm. Depending upon the forces to be restrained, damping can be achieved using atmospheric air or oil. Atmospheric air is best when possible since there are no consumables, no shortage of supply, and no maintenance refills. Oil is used when air becomes impractical. Needle valves should be fitted to allow adjustment at site to suit actual operating conditions. If orifices are used, a good selection of taper pin reamers will be required for final adjustment. Dashpots with fixed orifices may require seasonal oil changes to cope with viscosity variations.

The cage-trim version of the piston nrvs described earlier can be modified to include damping, see Figure 4.11. The two valves are basically the same. The piston in the controlled closure version is modified to include viscous damping by the product. The volume of fluid above the piston is trapped and only allowed to enter or exit via controlled ports. To open, the fluid above the piston must flow through the spring-loaded ball...
check valve. To close, fluid must flow from below the piston to above, via the removable orifice. Both flow paths are adjustable to optimise performance. Squish is still used to cushion the extremes of travel. These valves are available in a range of sizes and ratings and angle pattern, see Table 4.3. Special high pressure versions, to ANSI4500lb, machined from solid forgings are available in suitable materials. The comments regarding seat areas and Figure 4.7 apply to these valves also.

The valve shown in Figure 4.11 is constructed with a standard globe valve style body. Other designs straighten the flow path to avoid corners. Figures 4.12 and 4.13 show two different styles:

- annular plate
- poppet valve

The annular plate style is used extensively in high pressure hydraulic systems where the liquid is very clean. The poppet valve style is very popular for oilfield applications where the fluid may contain solids such as sand. Figure 4.14 shows a detail of the poppet/seat arrangement. Care is taken with both designs to maintain smooth streamlines. The shape of the moving element, plus squish built into the seat design, can control the valve closure. Damping can be incorporated when necessary.

Both designs are capable of having full-bore seats, but in practice this is rarely achieved. Full-bore seats require plenty of space which makes the valve body large and long. To comply with standardised valve lengths the seat area is compromised. The seat flow area, and the areas around the moving element, should be checked and the velocities evaluated. Erosion corrosion can occur with clean fluids when the protective oxide layer is removed. More exotic materials of construction or surface treatment may be required to obtain satisfactory service life. Alternatively, the pipe size can be increased locally to permit a larger valve to be installed.

<table>
<thead>
<tr>
<th>Body material</th>
<th>Pressure rating</th>
<th>End connections</th>
<th>Sizes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cast carbon steel</td>
<td>ANSI 1500b</td>
<td>Screwed</td>
<td>up to DN50</td>
</tr>
<tr>
<td></td>
<td>ANSI 3000b</td>
<td>Flanged</td>
<td></td>
</tr>
<tr>
<td></td>
<td>ANSI 6000b</td>
<td>Socket weld</td>
<td></td>
</tr>
<tr>
<td></td>
<td>ANSI 1500b</td>
<td>Butt weld</td>
<td></td>
</tr>
<tr>
<td></td>
<td>ANSI 2500b</td>
<td>Proprietary clamp</td>
<td></td>
</tr>
<tr>
<td>Cast low temperature steel</td>
<td>ANSI 1500b</td>
<td>Flanged</td>
<td>DN80 to DN300</td>
</tr>
<tr>
<td></td>
<td>ANSI 3000b</td>
<td>Butt weld</td>
<td></td>
</tr>
<tr>
<td></td>
<td>ANSI 6000b</td>
<td>Proprietary clamp</td>
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<td></td>
<td>ANSI 1500b</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>ANSI 2500b</td>
<td></td>
<td></td>
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<tr>
<td>Cast stainless steel</td>
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<td>Flanged</td>
<td>DN350 to DN900</td>
</tr>
<tr>
<td></td>
<td>Butt weld</td>
<td>Proprietary clamp</td>
<td></td>
</tr>
</tbody>
</table>

Table 4.3 Sizes and ratings of controlled closure piston non-return valves

Valves of these styles are manufactured in large sizes. Up to DN1800 are already installed and DN2500 are advertised. Valves smaller than DN150 are rare. Pressure ratings up to ANSI2500lb are standard. The poppet style valve is also manufactured to API pressure ratings: 2000, 5000 and 10 000.

The gas compressor plate valve shown in Figure 4.10 can be considered as a controlled closure valve. The very light plate design and very low inertia, enables the valve to respond rapidly to changes in velocity. The background history of the use of these compressor valves means that small valves must be able
to operate at frequencies in excess of 17Hz. Pulsating flow and repeated changes in gas direction are not problems.

**Special Note: Pump valves**

Reciprocating pumps, like reciprocating compressors, require inlet and outlet valves to ensure the liquid always travels from inlet to outlet. The valves are non-return valves, for a very dynamic application. Small pumps for clean liquids can operate at speeds up to 1500rpm which require valves to operate successfully at frequencies up to 25Hz. Reciprocating pumps are used for a wide variety of applications not just high pressure. A diversity of valve types is available to cope with extreme requirements. If a mass-produced nrv is not suitable for a particular application, a pump valve, used in a similar manner to the compressor plate valve shown in Figure 4.10, may be a viable solution. Figure 4.15 shows some pump valves in common use.

**Special Note: Valves for dry solids**

Non-return valves are generally unsuitable for dry solids applications. The ball valve without spring for vertical mounting or the duck-billed nrv, could be suitable depending upon the specific operating conditions. System design should remove the necessity for non-return valves. The use of power actuated isolating valves and an appropriate control system would provide the most reliable installation.

**Special Note: Non-metallic valves**

Reduced bore wafer swing-disc nrvs, in PVC or polypropylene are available in sizes from DN50 to DN350 for pressures up to 8 barg. Viton™ seat seals are standard. Operating temperature is limited to 90°C. Bore size may be considerably smaller than pipe bore; DN50 valve has 26mm bore; DN350 valve has 240mm bore. Full-port valves are available from DN15 to DN200. PVC valves, with cement socket bodies, in sizes from DN15 to DN100 are suitable for 5 barg. The hinge and disc seal are Buna “N”.

Piston non-return valves can be non-metallic. Valves from DN15 to DN100, in PVC or polypropylene are suitable for 10 barg up to 50°C. Non-metallic valves in polyacetal, limited to DN10 to DN25, can be suitable for 95°C. The piston can be fitted with EP or Viton™ seals. Valves are fitted with cement socket connections. Some polypropylene valves are available with female BSP connections. Small valves, DN6 to DN30, are manufactured in POM and polypropylene for 8 or 5 barg. Wafer pattern bodies, for valves in polypropylene and uPVC, are suitable for 10 barg for sizes from DN15 to DN300. A Viton™ soft-seat limits maximum temperature to 90°C. Similar designs are also available in PVDF.

Non-metallic ball nrvs, in PVC or ABS with union connectors, ⅜” to 4c, have EPDM seals and are suitable for a maximum working pressure of 10 barg.

**Special Note: Hygienic valves**

It is possible that the wafer versions of all-metal swing-disc non-return valves, may be suitable for hygienic installations. The crevice created by the hinge pin could be removed by the fitting of a suitable plastic bearing. Manufacturers should be contacted regarding third-party testing and certification.

In-line piston non-return valves, in stainless steel are popular for hygienic applications. The two-part valve body is clamped by an external nut. Valves from 1” to 3” are supplied with butt weld tails for direct fabrication in the pipework.

### 4.4 Useful references

- **Start-up dynamics of offshore water winning pumps**, D Fitzgerald, World Pumps no. 331, pp. 31-37, 1994 Elsevier Ltd.
- **ANSI/API 594 Check Valves: Wafer, Wafer-Lug, and Double Flanged Type.**