



Introduction to Check Valves: History, Types, Operation, and Applications

An Online Continuing Education Course for Engineers

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Introduction to Check Valves: History, Types, Operation, and Applications

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History of Check Valves

Check valves have a long history of use in varied fluid conveyance systems and are key tools involved in the prolific evolution of human innovation and production. The earliest known origins of one-way non-return valves date all the way back to ancient Roman and Greek civilizations. In addition to the well-known aqueduct and home plumbing systems developed at the time, primitive check valves were particularly useful in the invention of the world's first known portable fire pump. Known as the *Ctesibius Fire Pump*, the hand-operated device utilized a pair of non-return valves and basic pneumatic principles to propel water in a relatively constant stream towards nearby fires.

Since that time, continuous advancements in manufacturing precision, operating concepts, and durable materials have led to major civilizational advancements that have reshaped the developed world. As illustrated in Figure 1, major milestones made possible by check valves include the complex steam engine, the array of advancements in the *Industrial Revolution*, the late 20th-century mastery of oil, gas, and water conveyance systems, and modern era advanced water treatment and chemical processing systems.

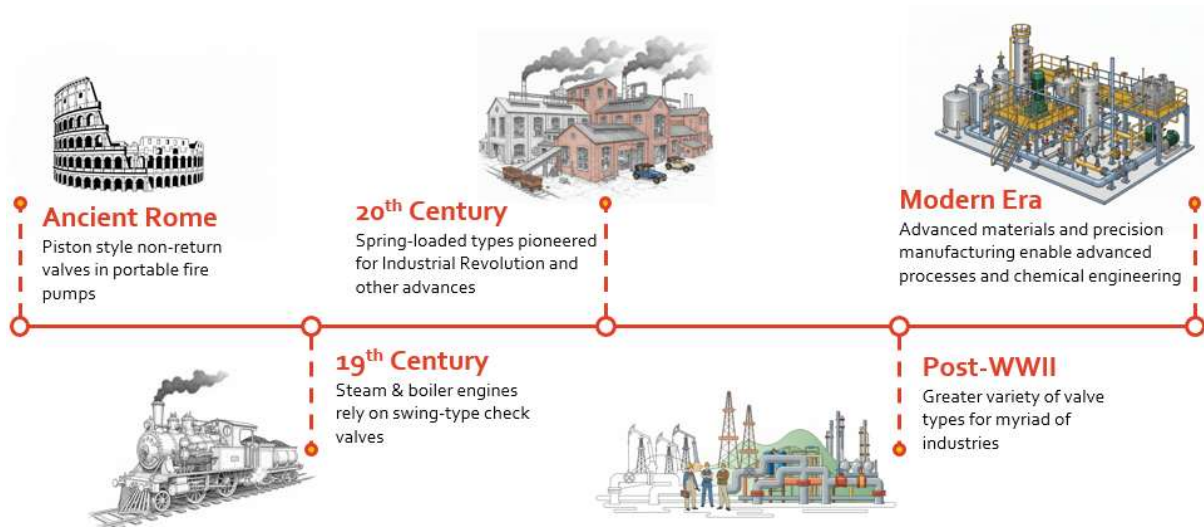


Figure 1. Timeline of Check Valve Development and Uses

Uses and Benefits

Check valves are essential components in fluid (liquids, gases, and slurries) conveyance systems because they ensure flow occurs in only one desired direction without risk of measurable flow reversal. Without check valves, many piping and process systems would face significant risks of damage, inefficiency, contamination, and reduced safety. Their passive and automatic operation - no external power or manual intervention required - makes them reliable promoters of system integrity and overall function. Key uses and benefits of today's variety of check valve types include, but are not limited to: preventing reverse flow, protecting mechanical equipment, minimizing pressure transients and water hammer, eliminating contamination of protected fluid systems, and ensuring efficient fluid conveyance.

The most fundamental reason we need check valves is to prevent reverse flow in fluid conveyance systems. When a centrifugal pump stops (or pressure in a piping system drops), gravity, residual pressure, and/or other forces can cause fluid to flow backward. This backward flow can drain pipes, tanks, or suction lines, leading to loss of prime in pumps or negative outcomes in connected systems. For example, in water supply or irrigation systems, a foot check valve at the pump inlet keeps the line filled, ensuring the pump restarts without dry-running and accelerated wear or damage. In sump pumps or (waste)water applications, check valves stop discharged water from returning to the basin, preventing excessive cycling and promoting overall energy efficiency. Similarly, in compressors, reverse gas flows can cause overheating or explosions within the equipment volute.

Protecting equipment, especially pumps, is another critical need. Backward flow can cause impellers in centrifugal pumps and blowers to spin in reverse, leading to accelerated mechanical wear, seal failure, or complete breakdown. Positive displacement pumps benefit particularly, as check valves help maintain proper operation by holding pressure and preventing unintended reverse movement.

Preventing pressure transients and water hammer (also called hydraulic shock) is vital in liquid systems. When flow suddenly stops or reverses, it creates shock waves that can rupture pipes, damage joints and supports, and interfere with instruments. Additionally, these shock waves may cause check valves to slam shut, resulting in excessive system vibrations and loud banging noises. Traditional swing check valves may contribute to slam if they close too slowly (allowance too much reverse flow), but properly selected types (like spring-loaded or non-slam designs) close quickly before full reversal, mitigating these surges and extending system life.

Another critical aspect is preventing contamination. In potable water systems, check valves (often called backflow preventers) are mandated by the Environmental Protection Agency (EPA) and ensure that contaminated water doesn't enter clean supply or distribution lines. In chemical plants, they prevent mixing of incompatible substances, avoiding reactions that could release toxic gases, cause corrosion, or result in unwanted combustion.

Additional benefits include flood prevention in drainage or stormwater systems (stopping water from backing up into low areas), energy efficiency (pumps don't fight unnecessary back pressure or refill drained lines), reduced downtime, and lower maintenance costs. In oil & gas, HVAC, pharmaceuticals,

and power generation systems, check valves provide passive isolation of defined systems, prevent rogue emissions, and support overall safe operations.

Check valves are crucial for directional flow control, equipment protection, surge mitigation, pressure retention, contamination avoidance, and overall system reliability. Their simple yet effective design prevents minor issues from escalating into costly failures, making them a cornerstone of safe and efficient fluid transport across residential, commercial, and industrial applications.

Fundamentals of Operation

Check valves (also known as non-return or one-way valves) are automatic mechanical systems designed to allow flow in a single direction while simultaneously preventing flow reversal (backward flow) in dynamic conveyance systems. Different types are available to suit a variety of operating conditions and fluid types; all have the same basic principles.

Forward Flow

- Fluid pressure from the inlet/upstream side of the valve exceeds the combined weight of a closure device (a disc, ball, or piston) and any system backpressures.
- The closure device is lifted upwards, allowing flow passage through the body of the valve.
- Pressure differential before and after the valve keeps the valve open, as system conditions change.

Flow Reversal (Backward flow) Prevention

- When forward flow is stopped (either by turning off a pump or closing an upstream isolation valve), the closure device returns to its closed position via gravity, spring pressure, and/or system backpressures.
- The watertight seal between the closure device and valve seat prevents any flow reversal or seepage upstream of the valve.

Figure 2 identifies major components of a typical check valve.

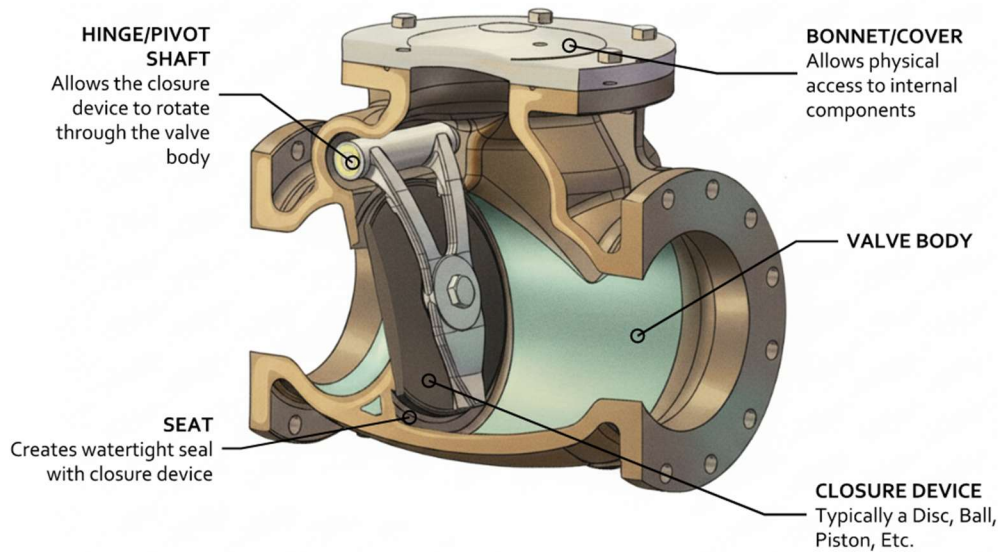


Figure 2. Major Components of a Typical Check Valve

Codes and Standards

Various well-recognized Standards Development Organizations (SDOs) provide guidance and standards for the design, construction, and use of check valves. The American Petroleum Institute (API), the American Society of Mechanical Engineers (ASME), and the American Water Works Association all provide codes that are meant to ensure quality and consistency across the industry. Some notable sections include the following;

- American Petroleum Institute:
 - 6D - Pipeline Valves
 - 594 - Wafer and Lug Check Valves
 - 598 - Valve Inspection and Testing
 - 602 - Small Forged Valves
- American Society for Testing and Materials International (ASME):
 - B16.10 - Face-to-Face Dimensions
 - B16.34 - Valves—Flanged, Threaded, and Welding End
- American Water Works Association (AWWA):
 - C508 - Swing-Check Valves for Waterworks Service
 - C510 - Double Check Valve Backflow Prevention Assembly
 - C518 - Double-Disc Swing-Check Valves for Waterworks Service

Additionally, the National Sanitation Foundation (NSF) 61 code is often referenced and enforced for valves and equipment to ensure safety and reliability in potable water systems.

Selection and Performance

Consideration of key system variables is critical to selecting the correct check valve type for a given system, leading to reliable, safe, and long-lasting performance. Key variables not only include application-specific details such as fluid type and system pressures, but also can include valve-specific details such as stroke time (opening/closing time) and crack pressure (minimum pressure differential on valve for detectable passage of flow).

When selecting a check valve for a particular application, design engineers most often make their choice by referencing accepted industry standards or manufacturer recommendations. While this approach may be sufficient for small or conventional systems, larger and more complex systems with a greater range of operating variables require careful study and consideration to properly select and size the correct check valves for the application.

For simple, or conventional, applications, key factors to consider include;

- Fluid Type
- System Pressures & Temperature
- Control or Operating Strategy
- Flow Rates
- Orientation or Configuration

Larger and more complex systems often require greater study and analysis for determining the correct type and size of check valve. Performing transient analysis of key operating scenarios is essential for predicting common issues such as water hammer, excessive surge pressures, and valve slam, which may damage the system. Modern analyses are typically completed with specialized software such as *AFT Pipeline*, *OpenFlows HAMMER*, or *Synergi Pipeline Simulator*, and are often performed by specialty consultants, especially in high-value or high-criticality projects. This software can incorporate application-specific variables such as valve opening/closing times, cracking pressure (the force/flow needed to mechanically open a check valve closure device to allow passage of flow), and overall equipment material types and weights.

Check Valve Slam

Check valve slam occurs when a valve closure device (disk, ball, plate, etc) closes abruptly and forcefully against the seat, usually generating a loud bang, vibration, or severe water hammer that rattles pipes and risks damaging equipment. The most frequent occurrence of check valve slam happens when centrifugal pumps are quickly shutdown – either due to primitive controls/programming or power outages. When the pump stops pushing fluid forward, the flow decelerates, comes to a stop, and then starts reversing due to gravity, elevation differences, or backpressure from the downstream side. If the check valve hasn't fully closed by the time meaningful reverse flow develops, that backward-moving fluid slams the disc the rest of the way shut. The slam, while loud and abusive to nearby personnel, can

also result in significant shock waves that travel the length of the piping system, creating additional noise and potential damage to system components.

The disconnect, or lag, in closure is inherent to the passive design check valves and their reliance on gravity or reverse flow to seal shut, slam is elevated and unsustainable when;

- Initial forward flow deceleration (negative acceleration) is high, exceeding several ft/s²
- Reverse velocity at time of closure exceeds 1 ft/s
- The system has a high static head or long upward sloping pipe runs
- Minimal or no surge protection devices used (e.g. surge tanks, etc.)

Flow Coefficient

A valve's flow coefficient is defined as the volume of fluid (in gallons per minute, gpm) that will flow through a valve with a Cv value of 1.0 at a pressure drop (head loss) across the valve of 1 psi. The Cv is a function of the internal parts and construction of the valve.

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When selecting a check valve, the following steps should be followed:

1. Consult the manufacturer's literature for the operating range of the system and the type of check valve type.
2. Calculate the pressure drop across the valve.
3. Confirm the existing flow rate is within the operating range of the system.

$$\Delta P = (Q^2 \times SG) / Cv^2 \quad \text{Eq. 1}$$

Where;

- ΔP = pressure drop across the valve (psi)
- Q = flow rate (gpm)
- SG = specific gravity of fluid (dimensionless, water = 1.0)
- Cv = valve flow coefficient