

The Science Behind the Flow

Pump Physics Made Simple

Pump operation relies on the fundamental principles of Physics to move a fluid efficiently and reliably to overcome system resistance and deliver flow to the intended application. Concepts of Physics such as Newton's Laws of Motion explain how forces move fluid, while Bernoulli's Principle describes the relationship between fluid velocity and pressure within the system. The Laws of Conservation of Energy and Mass govern how pumps convert mechanical energy into flow and explain how flow rates are maintained throughout the system. These laws guide the design and operation of pumps, and their understanding helps to make the pump design efficient and reliable for any system and application.

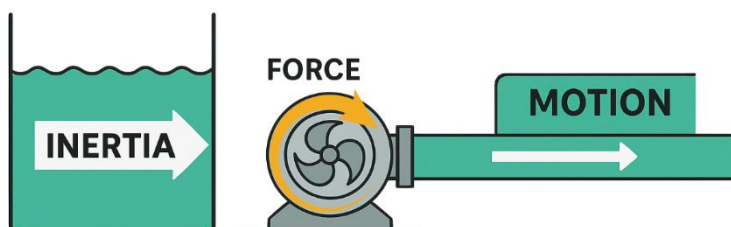
Newton's First Law of Motion (Law of Inertia): Getting Fluid to Move

Newton's First Law of Motion, or the Law of Inertia, explains how fluid flow is established. It states a fluid mass will stay still or keep moving unless an external force acts on it. In pump systems, water or any other fluid in a stationary pipe will not be able to move on its own. The stationary fluid will not flow until the pump pushes it, and when in motion it will keep moving until pipe friction and other system resistance like pressure loss over bends, valves, etc. slows it down and eventually stops the movement altogether. This law helps engineers design pump systems that move fluids efficiently and smoothly.

A body at rest stays at rest, and a body in motion stays in motion unless acted on by an external force.

Think of a pump as the "push" that convinces a stationary fluid to move and keeps it moving. Without the physics explained by Newton's First Law of Motion, fluid would never start flowing on its own. Newton's First Law explains why external force and hence energy input is necessary to initiate flow.

The pump provides the external force through the rotation of the impeller to overcome the fluid's state of inertia and initiate flow. Once the fluid is moving, it tends to keep moving naturally due to inertia. When designing a system and selecting a pump, one must account for friction and other losses from pipes, fittings, valves, and any other resistance within the system that gradually slows the fluid. Pumps are sized to supply enough force to start fluid flow and maintain the desired velocity throughout the system.



Newton's First Law of Motion
The Pump is the
"Starter" for stationary fluid and
the "Keeper" for moving fluid

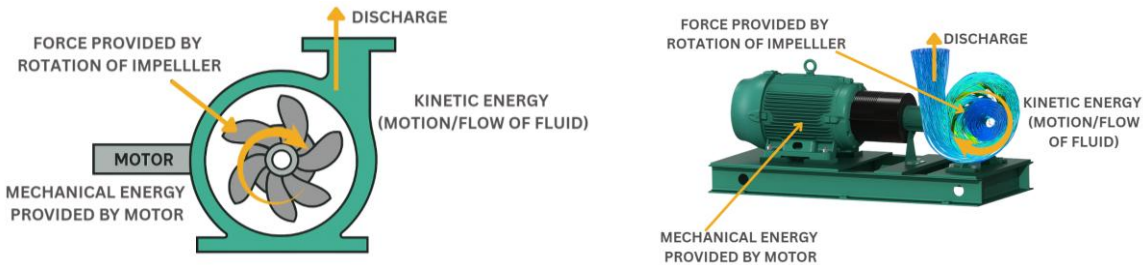
Once the pump starts the fluid moving, the next question is: how much force is needed, and how does that force control how fast the fluid moves? This is explained by Newton’s Second Law of Motion (Law of Acceleration).

Newton’s Second Law of Motion (Law of Acceleration): Force Created Flow

Newton’s Second Law of Motion governs pump performance. It explains how force causes acceleration, the foundation of how pumps move fluids through a system.

The acceleration of an object is directly proportional to the net force acting on it and inversely proportional to its mass.

Pumps follow the physics concept in Newton’s Second Law of Motion by converting mechanical energy into fluid acceleration. The motor drives the impeller, which applies force to the liquid and accelerates it. This acceleration converts the mechanical energy of the motor into kinetic energy, generating fluid motion and total pressure.



According to the Law of Acceleration ($F_{(force)} = m_{(mass)} \times a_{(acceleration)}$), the greater the force (generated by impeller rotational speed), the greater the acceleration, and therefore the higher the flow rate and pressure. In **centrifugal pumps**, the impeller imparts this acceleration to the fluid; as motor torque and impeller speed increases, so does fluid acceleration and total pressure.

This direct relationship links the mechanical input from the motor to the hydraulic output generated by the impeller, showing that the force applied by the impeller blades determines how much the fluid accelerates and influences how much total pressure the pump develops.

How Newton’s Second Law of Motion Applies to Pump Operation

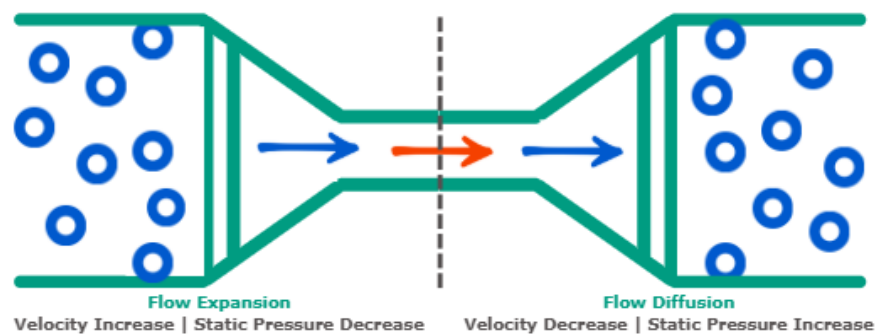
Concept	Pump Application
Force Application	The impeller exerts force on the fluid particles as it rotates, pushing them outward due to centrifugal acceleration.
Acceleration of Fluid	The impeller blades change the velocity of the fluid. As velocity increases, so does the kinetic energy of the fluid.
Total Pressure Generation	The accelerated fluid develops total pressure moving from the impeller eye to the periphery; and when it moves through the volute, part of its velocity head is converted into pressure head.
Flow Rate Relation	Increasing impeller rotational speed increases fluid mass acceleration, leading to higher flow and pressure, demonstrating that this output is proportional to the applied force.

Bernoulli's Principle: Energy in Motion

Once the fluid begins to move, its energy state continuously changes form between velocity, pressure, and height as it moves through the pump. Bernoulli's Principle is a fundamental concept in fluid dynamics that describes this relationship and forms the basis for understanding how pumps transform energy within a system. By converting mechanical energy from the motor into kinetic (velocity) and potential (pressure and height) energy states, pumps maintain efficient, steady flow. Proper design, installation, and operation ensure that these energy conversions happen smoothly, maximizing performance while minimizing energy losses throughout the system.

In a streamline flow of an incompressible fluid (such as water), when **the fluid's velocity increases, it's pressure decreases, and vice versa**, assuming no energy is added or lost.

In simple terms: when fluid moves through a narrow section of a pipe, it accelerates, and the static pressure drops in the narrower section of pipe; this process is called flow expansion. As it flows back into a wider section, it decelerates, and the static pressure builds back up; this process is called flow diffusion. It is worth noting that throughout this process, the total pressure of the fluid has remained unchanged (assuming no addition or loss of energy).



For example, think of a regular garden hose flowing steadily with water. When you kink or partially squeeze the exit opening, the water jets out at higher velocity. When the exit opening is restored, the water flow slows down again. Bernoulli's Principle helps explain how energy behaves in any moving fluid, including those in pump systems.



Velocity increases



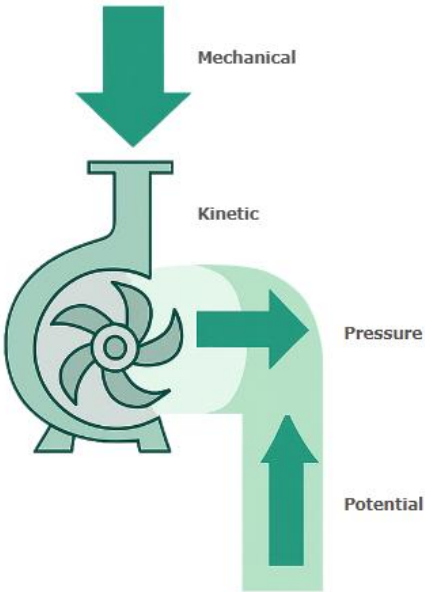
Velocity decreases

Bernoulli's Principle helps explain how the pump transforms the energy states of the flowing fluid. Once the energy received from the motor has been converted into kinetic energy of the fluid by acceleration, the pump transforms part of it into potential energy within the stationary volute, due to conversion of velocity head to pressure head as a result of carefully slowing the fluid down. As the fluid flows through the system, the energy state can continuously shift between velocity head, pressure head, and elevation, depending on the design of the system and piping. Of course, energy losses can and do occur in the system in reality, due to pressure drop across bends, valves, fixtures, etc. and due to friction losses in piping, not to forget any pressure demands from the primary application itself. The efficiency of the pump depends on how effectively it converts mechanical input energy into hydraulic output for a given application, maintaining the perfect balance between flow rate, pressure, and lift.

How a Pump Adds Energy to Fluid:

Imagine a pump moving water through a pipe that rises to a higher floor in a building. A centrifugal pump adds mechanical energy to the fluid, which allows it to overcome gravity and friction within the system. This added energy changes the constant in Bernoulli's equation because the pump is actively doing work on the fluid. When the fluid passes through the impeller, the following happens:

- **At the eye (inlet):**
 - The fluid enters with relatively low velocity and pressure.
 - As it moves toward the smaller impeller eye, velocity increases slightly, causing a small pressure drop, making proper suction conditions essential.
- **Through the impeller blades:**
 - The spinning impeller accelerates the fluid, adding kinetic energy.
 - Bernoulli's principle relates velocity to energy, but here the pump actively supplies the energy to increase both velocity and flow rate.
- **In the volute (pump casing):**
 - The flow area widens, causing velocity to decrease and pressure to rise.
 - This is a direct application of Bernoulli's principle: kinetic energy is converted into pressure energy, enabling the fluid to move efficiently through the system.



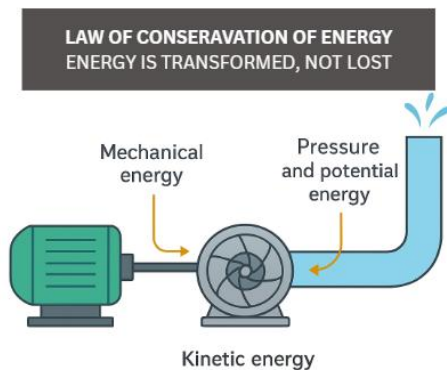
Energy Transformation Within a Pump

Pump Section	Energy Behavior	Bernoulli's Effect
Suction (Eye of Impeller)	Velocity ↑, Pressure ↓	Static pressure ↓ as velocity increases↑
Impeller	Adds mechanical energy	Pump does external work → total energy increases
Volute	Velocity ↓, pressure ↑	Conversion of kinetic energy to pressure energy

Forms of Energy in Pumping:

- **Mechanical energy:** The pump motor drives the impeller, giving fluid energy in the form of motion (kinetic) and the ability to rise to a higher elevation (potential).
- **Kinetic energy:** The impeller accelerates the fluid, increasing velocity. While local pressure may drop as velocity rises, the pump ensures overall pressure is sufficient to move the fluid.
- **Potential energy:** As the water rises, its potential energy increases [Potential Energy (PE) = $\rho_{\text{(fluid density)}} * g_{\text{(acceleration due to gravity)}} * h_{\text{(height)}}$], requiring the pump to supply enough energy to overcome gravity. The higher the fluid involved, the more energy is needed.
- **Pressure energy:** The pump also increases fluid pressure so it can flow through pipes, valves, and fittings efficiently, converting mechanical energy from the motor into energy usable by the fluid.

Law of Conservation of Energy: Energy Transformed, Not Lost

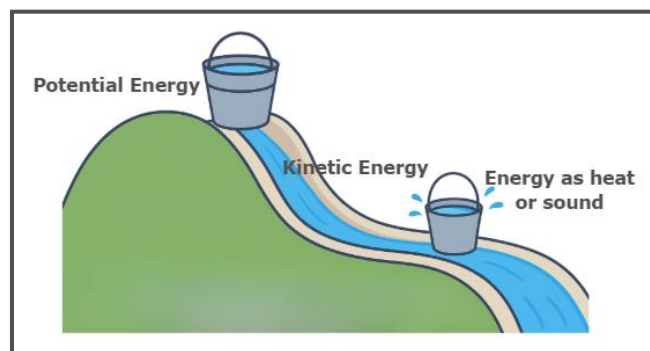


Bernoulli's Principle is a special case of the Law of Conservation of Energy. While Bernoulli's Principle describes how the pump transforms energy states within the fluid, showing how that energy is distributed as pressure and velocity within the fluid, the Law of Conservation of Energy explains the overall energy transformation throughout the system. It states that energy cannot be created or destroyed, only converted from one form to another. In pump systems, this principle governs how the mechanical energy supplied by the motor is transformed into kinetic energy (fluid motion), pressure energy, and potential energy (elevation), ensuring efficient and continuous operation.

Energy cannot be created or destroyed in a closed system.

Imagine you have a bucket of water at the top of a hill. If you pour the water down the slide:

- The potential energy of the water at the top (because of its height) is converted into kinetic energy as it flows down.
- When the water hits a lower bucket, some energy splashes into heat or sound, but the total energy is still the same, it has just changed forms.



Energy is never lost, it is transformed from mechanical input into the various forms that move, pressurize, and elevate fluid. Understanding energy transformation ensures pumps are designed and operated efficiently. It allows engineers to predict how energy supplied by the motor is distributed, prevent

excessive wear or cavitation, and optimize system performance. By applying the law of energy conservation, pump systems deliver reliable flow, pressure, and efficiency in any application.

This table compares Bernoulli’s Principle and the Law of Conservation of Energy in the context of pump operation. While both concepts describe energy in a fluid system, they operate at different levels. Bernoulli’s Principle focuses on the distribution of pressure, velocity, and elevation within the fluid along a streamline, assuming ideal flow with no energy gain or loss. In contrast, the Law of Conservation of Energy takes a broader view, accounting for all forms of energy—including mechanical, thermal, and frictional losses—showing how energy is transformed but never created or destroyed. Together, these principles help explain how pumps impart energy to fluids and how that energy behaves throughout the system.

Comparison of Bernoulli’s Principle and the Law of Conservation of Energy

Aspect	Bernoulli’s Principle	Law of Conservation of Energy
Definition	Along a streamline, the total energy per unit weight of fluid (pressure, kinetic, and potential) remains constant if no external work or energy loss occurs.	Energy cannot be created or destroyed; it can only change form within a closed system.
Scope	Applies specifically to fluid flow and relates to pressure, velocity, and elevation within that flow.	A universal law applying to all forms of energy : mechanical, thermal, electrical, etc.
Pump Operation	The pump adds energy to the fluid, increasing its pressure or velocity	Overall energy transformation : motor energy becomes fluid energy (pressure, kinetic, and potential) while accounting for losses like friction & heat.
Energy Losses	Assumes ideal flow (no losses)	Includes real-world inefficiencies and energy conversions.
Focus	Distribution within the fluid.	Conservation of total energy throughout the system.

Law of Conservation of Mass: Keeping Flow Steady

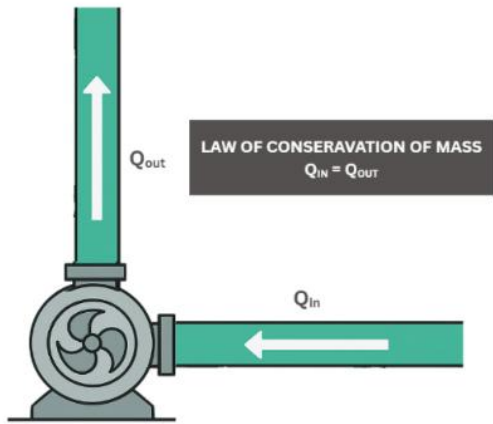
The Law of Conservation of Mass states that mass cannot be created or destroyed in a closed system. In pump operations, this principle ensures that the amount of fluid entering a pump equals the amount exiting it. This concept, often referred to as the continuity of flow, is fundamental to maintaining balanced operation in suction and discharge piping.

Mass cannot be created or destroyed in a closed system.

During operation, the pump remains full of fluid (neither draining nor filling). Its internal volume is fixed, and because the fluid is incompressible, its density stays constant. In other words, the mass of fluid inside the pump does not change. This explains that flow entering and leaving the pump is steady and continuous, supporting safe and reliable operation.

A simple analogy is a full cup of water: if the cup does not change shape and the water cannot be compressed, any water poured in must be matched by water leaving the cup. Similarly, in a pump, the rate at which mass enters the pump at the suction must equal the rate at which it leaves the pump at the discharge.





After understanding how pumps move fluids (Newton's First Law of Motion) and how energy is added to accelerate the fluid (Newton's Second Law of Motion), the Law of Conservation of Mass ensures that flow is continuous. No fluid can magically appear or disappear inside the pump!

This principle is essential for maintaining proper flow balance in suction and discharge piping. The law explains how pumps accelerate fluid through the impeller vanes and maintain consistent flow through suction and discharge piping. It governs design decisions such as pipe sizing, impeller selection, and system layout to prevent cavitation or dead zones. Essentially, it keeps the fluid "accounted for" from inlet to outlet.

Summary

The operation of pumps can be fully understood through the concepts explained by the fundamental Laws of Physics. Newton's Laws of Motion explain how pumps initiate and sustain fluid movement, converting mechanical energy into flow. Bernoulli's Principle describes the relationship between pressure and velocity in the system, guiding safe and efficient pump and pipe design. The Law of Conservation of Mass ensures that all fluid entering the pump exits at the same rate, maintaining continuous flow and proper balance in suction and discharge piping. Together, these principles provide a framework for designing, operating, and optimizing pumps to achieve reliable and predictable fluid movement.

Law/Principle	Definition	Application in Pump Operation	Key Take Away
Newton's First Law (Inertia)	Object at rest stays at rest, and object in motion stays in motion unless acted upon by a force.	Pumps must apply force to start fluid flow.	Overcoming fluid inertia is necessary to initiate and maintain flow.
Newton's Second Law (Acceleration)	Force equals mass times acceleration $F = m \times a$	Impeller applies force to accelerate fluid, converting mechanical energy into kinetic energy.	Fluid acceleration is proportional to the force applied by the pump.
Bernoulli's Principle	In a streamlined flow, an increase in velocity decreases pressure, and vice versa.	Explains pressure and velocity changes in the pump and piping system.	Helps prevent cavitation and optimize system design.
Law of Conservation of Energy	Energy cannot be created or destroyed; only transformed.	Motor energy converts into kinetic, pressure, and potential energy.	Efficient flow depends on smooth energy conversions and minimal loss.
Law of Conservation of Mass	Mass cannot be created or destroyed; what enters must exit.	Flow rate into pump equals flow rate out; fluid volume inside the pump remains constant.	Ensures continuous flow and proper balance in suction and discharge piping.

Wilo is Your Solutions Provider

Wilo is more than a pump manufacturer—it is a trusted solutions provider, delivering reliable and efficient water management systems tailored to real-world needs. By applying the fundamental principles of physics—Newton’s Laws, Bernoulli’s Principle, and the Law of Conservation of Mass—Wilo designs pumps that precisely control flow, pressure, and energy, ensuring optimal performance in every application. This deep understanding of pump physics allows Wilo to provide systems that are not only technically advanced but also energy-efficient, durable, and adaptable, making them the ideal choice for any water circulation or management challenge.

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