Chapter Samples

Secrets of Liquid Filling

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Also By John R Henry

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CHAPTER 1
INTRODUCTION

Liquid filling is the process of dispensing a precise amount of liquid into a container without damage, contamination or spillage of the product. This book will cover liquid filling in all its variations.

No meaningful conversation can ever take place unless everyone understands what is being discussed. Liquid filling takes place across so many industries and so many kinds of products that there may be some confusion about the terms used. For clarification I will begin by defining some of the common terms and how they will be used in this book.

Let’s start with liquid. Liquids can range from non-viscous, that is water-like or thinner, to extremely viscous products such as peanut butter, grease or silicone caulk. They can be homogeneous solutions, colloids, suspensions or a mixture of liquid and solid such as a chicken noodle soup. The key characteristic of a liquid in the context of this book is that it will flow and can be pumped and dispensed in a controlled manner.

The liquid usually goes into some type of container or final package. Containers can include bottles, jars, cans, pouches, cartons, tubes, bags, buckets, barrels or anything else that will contain a liquid. Fill volumes can range from microliters to scores of gallons as in a 55-gallon drum.

Occasionally liquid fillers may be used in non-container applications. Automobile assembly lines use fillers to dispense oil, coolant and other fluids into the various reservoirs on a car. Some applications apply the liquid onto a surface rather than into a container. An example of that could be depositing an antiseptic onto a bandage or drawing electrical circuits of conductive ink on solar panels. Although not filling *per se*, standard filling technologies can be used in these and other non-"filling" applications.

The term "product" will be used generically to refer to the liquid being dispensed into the container.

The machine used to dispense the liquid is called, generically, a liquid filler. In addition to liquid fillers, there are fillers designed to fill non-liquids. These are outside of the scope of this book. "Filler" as used in this book refers to liquid fillers unless otherwise stated.

The term "head" is often used to refer to the number of filling nozzles that a filler has. A 4-head filler will have four filling nozzles. "Head" can also refer to the infeed or discharge pressure at the filler. This head is usually positive (with pressure) but can be negative (in a vacuum) or neutral.

"Machine builder," "machine supplier" or simply "builder" will be used to refer to the company that designed and fabricated the filling machine.

Many plants work multiple shifts or other schedules. For simplicity, this book, unless otherwise stated, will assume single shift operation of 8-hour shifts, 5 days per week, 50 weeks per year. This is 2,000 annual operating hours. Many plants will work other schedules and should adjust any calculations accordingly.

Filling machines typically combine two main functions:

Filling is the actual dispensing of the product. There are a variety of architectures. I have tried to present all in this book but there may be rare technologies I have missed.

Automatic fillers are usually, though not always, combined with a container handling system that positions the container(s) under the nozzle(s) for filling. Low-speed, low-volume fillers may be configured for manual tabletop or benchtop use. The operator places the container under the nozzle, triggers the filler dispensing cycle and, when finished, repeats the process.

Chapter 1 - Introduction

Fillers may also be mounted on other machines such as form-fill-seal machines. Laundry detergent is filled into bags this way. They can be used to dispense five quarts of oil into an engine on an auto assembly line. In one application, a precise piston filler dispenses a conductive ink as a sheet of glass is manipulated under it. This draws electrical circuits onto glass solar panels. The company was having problems and did not realize that they actually had a filler and that their problems were common filling machine problems. Addressing the system as a filler, rather than an exotic custom machine allowed the issues to be readily resolved.

In addition to the liquid handling portion, automated fillers need a container handling system. Depending on the container, speed and other factors, there are as many ways to handle containers as there are ways to fill them. These will be discussed in detail in subsequent chapters.

Some filling systems are combined with other machines in a “monobloc” configuration. High-speed bottling lines may combine a bottle washer/rinser, filler, capper and sometimes even a labeler on the same frame enclosed in a single cabinet.

Every filler must meet two basic criteria:

1. First, it must preserve the integrity of the product such that it is transferred from the bulk reservoir to the container without damage, contamination or spillage.

Some products, such as water, are relatively easy to handle. Others can be much more difficult. Cherry pie filling is thick and contains fragile, whole, cherries that must not be broken in the process. Suspensions need to be kept in constant circulation to prevent setting. Pharmaceutical and food fillers have particularly stringent requirements to prevent bacterial, particulate and other contamination. Other products are flammable or explosive and the filler must be designed to address the fire hazard.

Many different filling architectures exist. Though some are more versatile than others. There is no universal filler. One size does not fit all. Fillers and filling technologies must be carefully matched to the product and container to be filled.

2. The second key criteria that the filler must meet is to dispense the correct amount of product into the container. It must do this precisely and repetitively fill after fill after fill.

THE FUNCTION OF THE FILLER IS TO MEASURE THE PRODUCT, NOT TO PUMP OR MOVE IT.

Precision and Accuracy

Precision and accuracy are two terms commonly used in discussions about liquid filling. Although related, they are different.

Accuracy refers to the ability to achieve a specific value. A digital thermostat set for 350 degrees should be able to maintain a temperature of 350 degrees, plus or minus some amount of variation.

A thermostat that maintains the set temperature at 350 degrees, plus or minus 10 degrees is accurate since it is holding the 350 degrees average temperature. Because it covers a 20-degree span in maintaining that temperature, though, it not very precise.

An inaccurate version of that thermostat may hold a temperature of 345 +/- 1 degree when set for 350. It is not accurate, as it does not maintain the 350-degree setpoint. But it is precise because the temperature only varies over a 2-degree span rather than 20. The ideal, of course, is to have both accuracy and precision. Set the thermostat to 350 degrees and it should hold 350 degrees +/- 1 degree.

Some fillers allow a more accurate volume setting than others. Even when this is the case, there are other variables; so the initial setpoint may be close but seldom exact. Fine adjustments after setting the target setpoint may be required to achieve the exact volume. Once the filler has been dialed in to the exact volume, precision will determine how close it is to that volume on every cycle.

When we speak of filler accuracy, what we are really speaking of is filler precision. This is sometimes called repeatability. It is the ability to dispense exactly the same amount of product cycle after cycle after cycle. Having said all this, accuracy and precision are often used interchangeably when discussing filler performance.

Precision is commonly defined as a plus or minus percentage of target fill volume. A filler might be rated as +/- 1.0%. This precision can vary with product and fill volume, so it is sometimes stated as +/- 1.0% based on 10-ounce water fill (or some other volume). This means that all fills can be expected to be between 9.9 and 10.1-oz (99 to 101% of 10-oz). It is generally calculated with "six sigma," shorthand for plus or minus 3 standard deviations. This means that a small percentage of fills, 0.034%, may fall outside of the +/- 0.1-oz limits. This is based on the "normal" or Gaussian statistical distribution also known as the "bell curve" due to its shape.

This book will use the term "precision" rather than accuracy to emphasize the need for consistency and repeatability between fill cycles.

To misquote a sign from the original Mad Max movie, "Precision is just a question of money. How precise do you want to be?" More precise fillers will cost more to build and operate. A high-precision filler makes sense for a high-value electronic paste with precious metals or an expensive pharmaceutical product. If the product is drinking water, it may be close to free. Not much precision is required and a simpler, less expensive, but less precise, filler could be used.

The legal requirement in the US, generally, is to provide at least the quantity claimed on the label. A package claiming to contain 10-oz of product ("label claim") must contain at least 10-oz of product. To satisfy this claim, most packagers overfill slightly. The 10-oz fill above might be set to a target of 10.1 ounces to assure that no fill is ever below the 10-oz label claim. Assuming +/- 1% precision, every container will contain between 10.0 and 10.2 ounces and average fill volume will be 10.1 ounces. Note that this is on a 10-oz fill. With some types of filler, much of the imprecision occurs at the beginning and end of a cycle. This filler might have greater percentage precision on a 50-oz fill and less on a 5-oz fill.

"Giveaway" refers to extra, unpaid for, product. In the above example, the average giveaway is 0.1 ounce since the average fill volume is 10.1 ounces but the customer is only paying for 10.0

ounce.

That may not sound like much, but it adds up quickly. If the filler is running at 240 cpm (containers per minute), 0.1 ounce represents 24 ounces of giveaway every minute. It's also 11,520 ounces or 1,152 bottles per shift. That's more than a quarter million bottles per year worth of lost product. Far better to bottle that product and get paid for it.

The intended use of the product also influences precision requirements. Some products must be used in specific amounts. A single-dose pharmaceutical product, for example. Overfills could cause a patient overdose.

Speed

"Speed" is a confusing term in packaging, especially when used qualitatively. Everybody knows what it means but there are many definitions. A can filler running at 1,000 cans per minute might be considered low speed compared to a high-speed can filler running 2,500cpm. A high-speed pharmaceutical filler may run 300cpm. When discussing speeds, avoid talking about high-medium-low speed or similar terms to avoid confusion and miscommunication. In my experience, it is always better to be specific, speaking of speeds in terms of containers per minute.

Filler speed is normally expressed as containers per minute or cpm. Products per minute (ppm) or bottles per minute (bpm) are also used interchangeably. Speed is how many products are filled in one minute. It can be calculated by counting containers through the filler for a measured period and normalizing it to 1 minute. For intermittent-motion fillers, it must include the indexing time.

Some builders, particularly European builders, specify their machine speeds in containers per hour. This is generally taken to be 60 times the speed per minute. It assumes that the machine runs continuously during the entire hour and does not allow for stoppages.

Cycle speed, expressed as cycles per minute, can be a useful metric but must not be confused with containers per minute. A pouching machine for freezer pops may run 50 cycles per minute. But if it runs 10 pouches across, "10 up," it will be running 500 pouches per minute. Another use of cycle speed is with intermittent fillers. A 4-head filler may run 15 cycles per minute. Each cycle produces four bottles, giving a machine speed of 60 containers per minute.

Cycle time generally applies only to intermittent-motion fillers and is the time to complete one filling cycle. It is the time between the first bottle in a filling group coming to a stop for filling until the first bottle of the next group comes to a stop.

Linear speed is generally not a concern in liquid filling machines. It is occasionally used in discussions of conveyor speeds and how fast containers are indexed. In the US linear speed is usually expressed in feet per minute (fpm) but can also be expressed in meters, inches or other linear units per minute or other time unit.

A single-head filler running 15 bottles per minute will have a cycle time of 4 seconds. Depending on the container and the filler this may be 1 second of indexing time and 3 seconds of filling time. Or it could be 3 seconds of indexing and 1 second of filling. The cycle time is the total of the two.

Indexing and cycle times are discussed in depth in Chapter 2: Container Handling.

It is important not to confuse speed with capacity, which is how many pallets of finished product go to the warehouse at the end of the day. In a perfect world that would be the speed multiplied by the number of minutes in the day. In our imperfect world, it is almost always something less.

Capacity is determined by two factors:

1. First, the filler's capacity is dependent on the capacity of the upstream and downstream machines. The filler cannot run any faster than the rest of the line. If the filler can run 200 cpm, but the capper only runs 150 cpm, the filler can run at no more than 150 cpm on average. It may run at 200 cpm in bursts, starting and stopping frequently. This is hard on any kind of machinery and must be avoided. In a perfectly balanced line, the filler will be slowed to 150 cpm, 75% of its rated capacity. In actuality, it may be set to run at 155 cpm (or so), starting and stopping as needed, but less frequently, to assure that it never starves the capper.

Ignoring these other machines for the moment, the total capacity of the filler in containers per day is normal speed times minutes in the day times efficiency. If the 150 cpm filler runs continuously at 100% the entire 8-hour shift it will produce 72,000 containers. (150 cpm X 480 min)

It is unlikely that it will run at 100% rated speed over the course of the day. Stoppages upstream and down, filler adjustment, rejected product, breakdowns, changeover, crew breaks and other occurrences will reduce the efficiency and running time. If the filler is stopped for 60 minutes out of the 8 hours (87.5% efficiency), its actual capacity will be 63,000 containers per day. This loss of 9,000 containers per day is more than 2 million containers per year.

Boosting efficiency by 1 point to 88.7% will increase daily production by 720 containers and annual production by 180,000 containers. You really do need to sweat the small stuff.

The rule of thumb for efficiency is that every 2 percentage points gain, whether from 50% to 52% or 87.7% to 89.7%, will add about 41 hours (1 week+) of annual production. It will be more on multiple-shift operations.

Another rule of thumb, what I call the 10W-40 rule, is that every 10 minutes of daily downtime will cost more than 40 hours in lost annual production. (More on multi-shift operations later.)

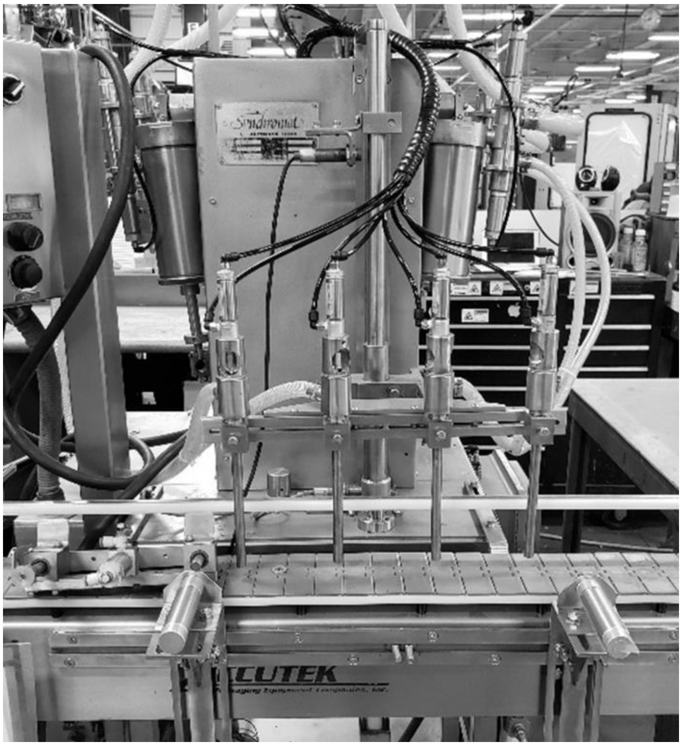
Filler Classification

Fillers can be incorporated into other machines, such as a filler mounted on a vertical form-fill-seal machine to dispense laundry detergent into a pouch. More often they will be designed as integrated machines that combine container handling and filling on one frame. In some cases, they may incorporate other functions such as orienting, rinsing, capping or labeling into the same machine. These multi-function machines are called, generically, monobloc machines.

Fillers can be classified (1) by container handling, (2) by motion and (3) by general fill type.

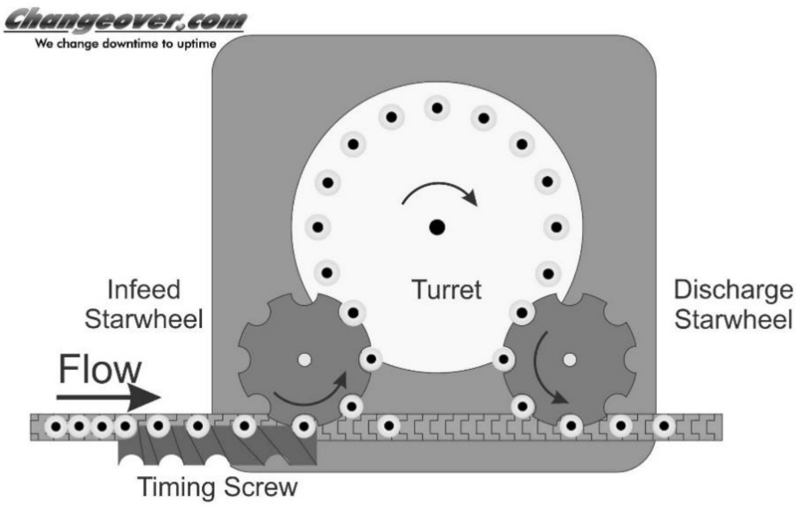
1. Classification by Container Handling

• **Inline:** Inline fillers run the containers through the filler in a straight line. Some fillers index sideways in the filling station to reduce cycle time. These are still considered inline.



1.1 Four Head Intermittent Motion Piston Filler
Courtesy Frain Industries

• **Rotary:** Rotary fillers transfer the container from the conveyor to a rotating turret or starwheel. As the containers rotate around the turret or starwheel, they are filled and discharged to the next process such as the capper. During filling, containers may be held in a starwheel, placed on a platform or both. Modern high-speed beverage fillers grip the bottle by the neck. Provided all bottles have the same neck finish, this allows any size bottle to be run without changeover.



1.2 Typical Rotary Machine Layout
Courtesy Changeover.com

2. Classification by Motion

• **Intermittent motion:** Intermittent-motion fillers stop the container while it is being filled.

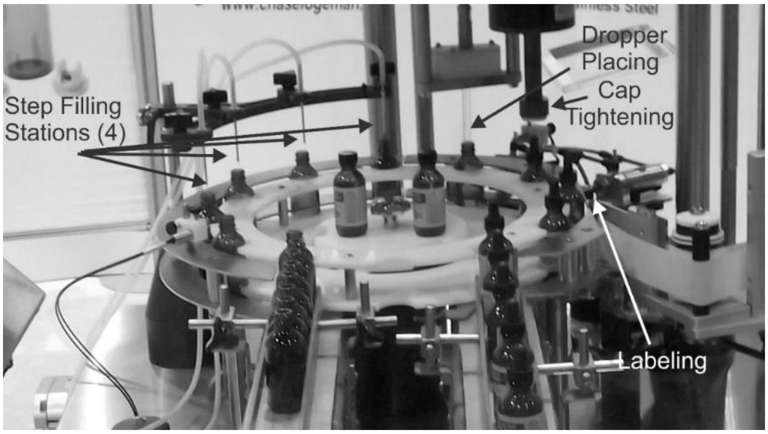
• **Continuous motion:** The containers never stop in a continuous-motion filler. The filling nozzles are synchronized with the container, filling them while they move.

This picture shows a typical continuous-motion rotary bottle filler. Bottles enter on a conveyor, are synchronized to the infeed starwheel with a timing screw and are transferred onto the filling turret. Once filled, they transfer into the discharge starwheel, then onto the takeaway conveyor. In normal operation, the filler runs at a constant speed without stopping.

Inline machines tend to be intermittent motion and rotary machines tend to be continuous motion. There are exceptions to this with continuous-motion inline fillers and intermittent-motion rotary machines.

Monobloc machines perform multiple operations in a single machine frame. This picture shows a machine that fills, caps and labels the bottle in the same starwheel. Bottles are captured by the starwheel and indexed, one at a time, through four filling stations. At each filling station, the bottle receives 25% of its total dose.

In this machine, the 4-step fill is used to balance speeds between filling (relatively slow) and capping (relatively fast). In other applications, a multi-step fill may be used to control foaming and splashing or to fill a 2-part product. A cosmetic makeup product might be filled with a generic base on three stations and the colorant added at the fourth station. A food coloring kit, in one instance, is filled four bottles at a time with a different color in each bottle.

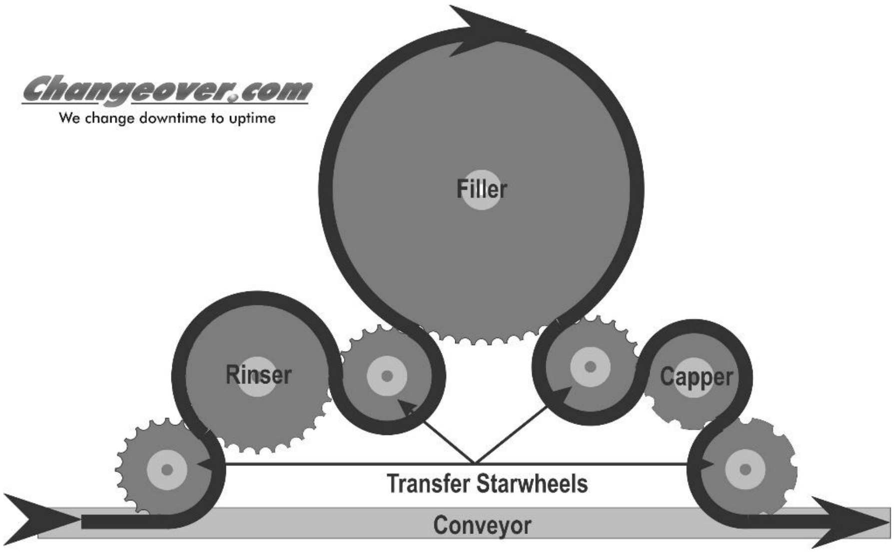


1.3 Mono-Bloc Filler-Capper-Labeler
Courtesy Chase-Logeman Corp

Inline fillers may also be continuous motion to allow higher throughput. This picture shows robot-mounted filling nozzles that track and fill the bottles as they move at a constant speed on a synchronized conveyor.

1.4 Robotic Liquid Filler
Courtesy FG Robosys BV

Many beverage bottling lines combine individual machines onto a single frame. For example, a rinser-filler-capper. Bottles enter the machine and are processed through the rinser. The rinser turret transfers the bottles to the filler turret. After filling, they are passed to the capper turret and, finally, the capped bottles are discharged for labeling and further processing. Once captured at the rinser infeed, the bottle is not released until discharged from the capper.



1.5 Rinser-Filler-Capper Flow
Courtesy Changeover.com

Generally speaking, intermittent-motion inline machines will be the least complex/expensive while continuous-motion rotary machines will be the most complex/expensive for similar speed and container capabilities. In general, continuous-motion machines will have higher throughput than intermittent-motion machines. Most, though not all, applications requiring speeds in excess of 200-300 cpm will require continuous-motion fillers, usually rotary but sometimes inline.

3. Classification by Fill Type

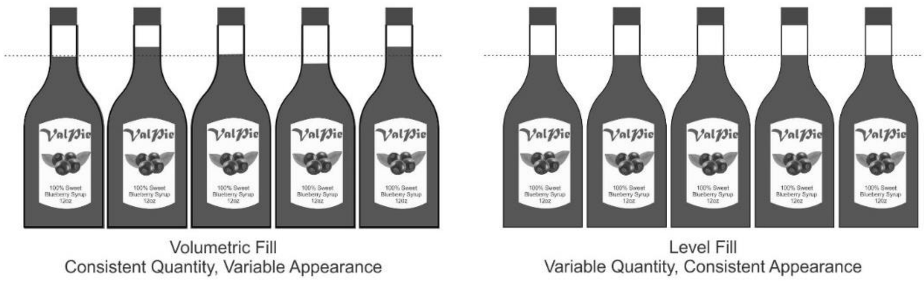
All fillers, whether standalone or integrated into another machine, will be classified as volumetric or level (sometimes called cosmetic) fillers.

Volumetric fillers measure the amount of product independently of the container. A volumetric filler will dispense 1 ounce of product, with equal precision, into a 2-ounce bottle or a 5-gallon bucket.

Level fillers fill to a consistent level in the container. This level is often measured from the container neck. Some fillers measure the distance between the bottom of the container and the liquid surface. The amount of product is determined by the internal volume of the container.

Internal volume variation is especially common in glass bottles. If precisely 12 ounces of oil are filled using a volumetric filler, the fill level will vary with depending on the internal container volume. This will give a cosmetically unacceptable appearance on the store shelf. Level fillers, on the other hand, provide the *appearance* of consistent fill volume. Hence the term "cosmetic" filler.

This picture shows the effect of filling precisely 12 ounces into five bottles with variable internal volume. The consumer, seeing these on the store shelf, would think that some of the bottles were underfilled, leading them to think they were being shortchanged. The perception of overfilled bottles leads to a perception of poor quality.



1.6 Glass Bottle with Varying Internal Volume
Courtesy Changeover.com

Level filling and volumetric filling each have advantages and disadvantages, as well as a variety of architectures and technologies within each type. Subsequent chapters will discuss each in detail.

Selection Criteria

There are a number of factors to consider when choosing a filler. Chapter 8 discusses these in detail.

Chapter 1 - Introduction

1. Product Characteristics

Product viscosity, stringiness (honey or shampoos, for example), surface tension, entrained solids (such as cherry pie filling), suspended particulates, sterility, carbonation and flammability are a just a few of the product characteristics that make liquid filling projects so interesting.

I've had people tell me "The product is just like water." Or "The product is a typical sauce." While they may seem typical, it is rare that they are "just like." Usually they are "not quite like" and frequently "nothing at all like." This will cause problems in selecting and designing the proper filler. It is always important to know the specific product and to know how it will run in production. One product tested well in the machine builder's plant both for initial concept and factory acceptance test (FAT). When the filler was commissioned in the client's plant, it was problematic, dripping and stringing. The problem was that the product tested had aged during shipping. Although it was only a few days, this had changed the product characteristics dramatically.

2. Required Precision

Filling precision requirements will determine what type of filler to use and how sophisticated it must be.

3. Container

The container to be filled is critical. Consideration must be given to how the displaced air will escape as the product enters. In some cases, this escaping air can blow through the product aerating it and causing foaming. The escaping air may have sufficient velocity to blow product out of the bottle. A smaller nozzle or a deeper dive into the bottle may solve this problem but at the expense of extending the fill cycle time.

1.7 Long Neck Bottle
Courtesy Changeover.com

Filling into a jar, with the neck opening about the same diameter as the body, avoids the venting problem. A large nozzle and high flow rate with no diving will shorten the cycle time. A drawback is that the combination of the high flow rate and open mouth may result in splashing.

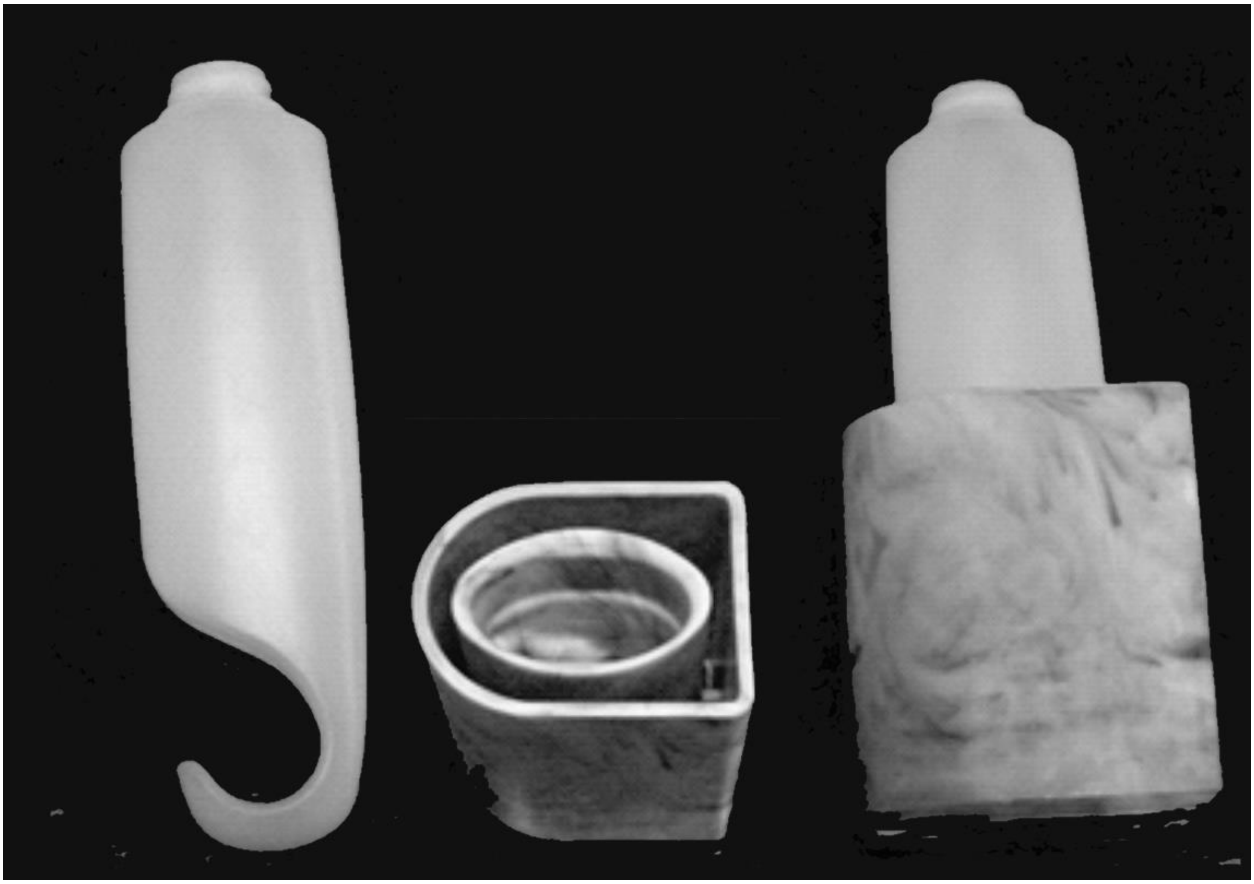
A slower fill rate may be the answer. A flange sealed to the jar during filling will prevent splashing. Venting will be needed to avoid pressurization. Alternately, a larger diameter filling nozzle can fill at a lower velocity, reducing splashing, while maintaining a high flow rate.

Container stability must be considered. Lightweight polyethylene terephthalate (PET) water bottles are unstable when empty. You might want to handle these by the neck rather than by the base as is common with most plastic bottles.

Some containers have angled necks and will require special, angled, nozzle arrangements. An alternative is to run the bottles in a plastic cup, called a puck. Pucks present the bottle on an angle with the neck vertical.

1.8 Angled Neck Bottle
Courtesy Changeover.com

Other products have odd bottoms that will not stand up. This soap product is designed to hang from the consumer’s shower head. A puck can be used to handle the bottle through a standard filling line.



1.9 Bottle Handling Puck
Courtesy State Manufacturing

Normally, a round puck will be used for ease of conveying. If the bottle is symmetrical the neck will be centered regardless of axial orientation. The bottle shown is asymmetrical and must maintain orientation for labeling. A rectangular puck could be used here. However, the flat ends of a rectangular puck could jam as they go around conveyor curves. The rounded end avoids the jams. The asymmetric puck design also provides easy visual confirmation of proper orientation. Pucks are typically color coded for instant visual confirmation. If pucks for the 12-oz bottle are identical in shape and size to those for the 18-oz bottle, making the 12-oz pucks from orange plastic and the 18-oz pucks from blue prevents mix-ups during changeover and production.

4. Special Requirements

Other special requirements impacting filler design can include the need for gas, steam or vacuum in the headspace. Some products are oxygen unfriendly and need to be flushed with nitrogen prior to capping. This replaces oxygen in the headspace to extend product shelf life. Sometimes the flushing is prior to filling, sometimes after, sometimes during. In some cases, flushing takes place throughout the filling.

Baby foods and juices are typically vacuum packed. One way to create the vacuum is to inject steam into the container just before capping. The steam condenses in the closed container creating the vacuum.

Sometimes, a vacuum is required but steam is unavailable or would contaminate the product. A special capping chuck can seal to the neck, create a vacuum and apply the cap.

Other special requirements can include the need to run hot, cold, flammable, explosive, sterile or light-sensitive products.

5. Location and Space

The location of the filler impacts selection. If the available space is relatively long and relatively narrow, an inline filler may be all that fits even though a rotary machine might otherwise be preferred. A short, relatively wide, space may influence a decision to select a rotary filler though an inline filler might be preferred for other reasons.

6. Budget

There is often a tradeoff between purchase cost and operating cost of a machine. It is generally preferable to spend more upfront to keep ongoing operating costs — including product giveaway — lower. On the other hand, if sufficient capital is unavailable, it may be necessary to purchase a less expensive machine and accept the higher operating costs. For example, a semi-automatic level filler rather than a fully automatic volumetric filler.

It is not only the financial budget that must be considered. The time budget is often even more critical. Simpler, more standard, machines may be available with shorter lead times. This allows production, and more importantly, revenue to begin sooner. Ability to meet a production deadline may be a determinant in filler selection.

Some companies, such as Frain Industries, maintain inventories of new and used machinery for rental or sale. This allows short, even off-the-shelf in some cases, deliveries.

7. Labor Force

A sophisticated machine does no good if the labor force is not available to operate and maintain it. In many US metropolitan areas, it will be possible to find the skilled operators and technicians required to operate and maintain a technologically advanced filler. In other areas of the country and especially outside of the US, it can be difficult or impossible. The filling technology chosen must match the ability of the workforce to operate and maintain it.

Many fillers can handle a range of products and containers but there is no universal filler. Every filler is application specific to a greater or lesser extent. It is critical to match the machine to the application for best results. Failure to do this will result in decreased efficiency. And even small efficiency losses can have huge impacts. The difference between 85% efficiency and 83% efficiency is the equivalent of losing one week, 41 hours, of annual production on a single-shift operation.

The next chapter will explain some of the peripheral components associated with fillers and filler design. Subsequent chapters will get into the nuts and bolts of all common types of fillers.

CHAPTER 4
VOLUMETRIC FILLERS – PISTONS

Liquid fillers can be grouped into two broad classes: Volumetric and level filling.

Volumetric fillers measure the amount of product to be dispensed independently of the container. Common volumetric filler architectures include:

1. Pistons
2. Gear pumps
3. Flow meters
4. Time pressure/time gravity
5. Weight
6. Standpipe

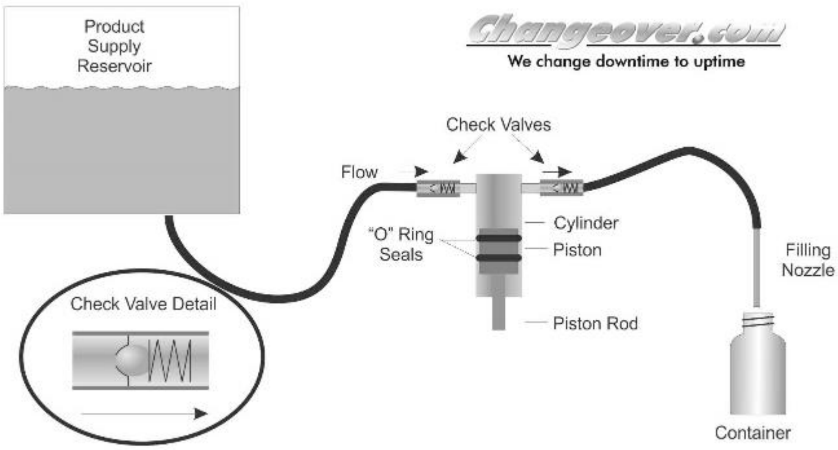
Volumetric fillers should be used when precise fill volumes are required or where the container does not lend itself to level filling.

This chapter will focus on the most commonly used architecture: piston fillers. The next chapter will cover other volumetric architectures.

Piston fillers are a well understood, proven, technology. They can be used to precisely fill volumes from sub-milliliter to drums and tanks. They can be used to fill any viscosity at product temperatures from below freezing to near boiling. These factors help make them the most common of all volumetric filling architectures.

The basic piston filling system consists of a piston and a cylinder, valves to control flow into and out of the cylinder and a drive mechanism to move the piston in and out of the cylinder.

Piston fillers work by using a piston to change the internal volume of a cylinder.



2.1 Piston Filler Schematic
Courtesy Changeover.com

Pistons may be mounted in any orientation. For the purpose of this book, the top of the stroke will mean that the piston is fully inserted regardless of pump orientation. The bottom of the stroke means that the piston has been retracted to the desired volume.

At the beginning of the cycle, the piston is at the top of the cylinder, often but not always with a minimal internal volume. The cycle begins by pulling the piston partially out of the cylinder. Some designs reverse this, holding the piston stationary and pulling the cylinder partially off the piston. As the piston is withdrawn, the inlet valve is opened and the discharge valve closed. This allows product to flow from the product reservoir into the cylinder.

When the piston reaches the bottom of its stroke, the cylinder contains the quantity of product to be dispensed. The inlet valve is closed and the discharge valve opened. The piston is pushed back into the cylinder forcing the product through the discharge valve to the filling nozzle and the container.

The partial vacuum created by withdrawing the piston is sometimes used to pull product into the pump. This is not a good practice. It is generally preferable to maintain a slightly positive head pressure at the pump infeed to push the product into the pump. The primary function of the filling pump should be measurement, not product movement or pumping. If it is used to pull the product, the cylinder may not fill completely and inconsistent volumes will result.

If a light-duty flexible tubing is used to connect the reservoir and piston, the vacuum caused by pulling the product into the cylinder can collapse or partially collapse the tubing. This will restrict flow, resulting in an incomplete fill.

In the case of products with a low vapor pressure, such as some hot-filled products or alcohol, the negative pressure on the surface of the liquid can cause it to flash to vapor. This too will cause inconsistent fill volumes.

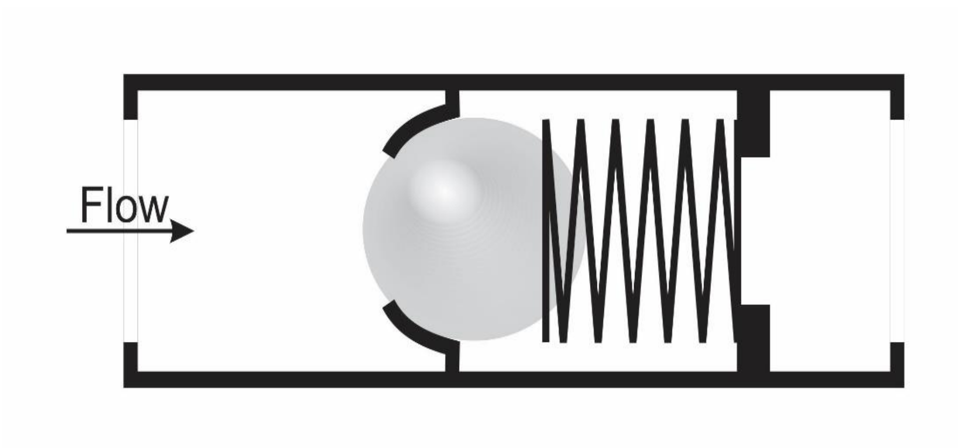
High-viscosity products, such as grease or peanut butter, require positive infeed head as no amount of vacuum will “suck” them into the cylinder.

If the fluid path is under negative pressure at any point and leakage occurs, air infiltration will occur. This will aerate and contaminate the product. Leakage of air into the system will cause inaccuracy as the volume dispensed will include air bubbles and less product. Finally, entrained air bubbles may cause foaming inside the container being filled. It is generally preferable to have product leaking out than air leaking in. An exception will be with a messy, hazardous or flammable product. If these leak out, they can create a problem. Air leakage in may be preferable in these cases.

In many cases, especially for non-viscous or free-flowing liquids, raising the reservoir above the piston will create sufficient positive head. Sometimes it may be necessary to pressurize the product reservoir with air, nitrogen or mechanical pressure. Generally, the use of pressurized reservoirs to the filler should be avoided if possible since they introduce another variable, pressure, into the filling process. If this pressure varies, it can cause variation in fill precision. Reservoirs and product supply systems were discussed in depth in Chapter 3.

Flow Control Valves

Several types of valves are available to control flow. The simplest, shown in the schematic below is a pair of spring-loaded check valves.



2.2 Ball Check Valve
Courtesy Changeover.com

Check valves permit flow in one direction only. As the piston is withdrawn, the differential pressure across the inlet check valve permits product flow into the cylinder. During this part of the cycle, the discharge valve is held closed by a combination of spring and negative pressure. When the piston reaches the end of its stroke and product stops flowing, the spring causes the inlet valve to close. As the piston discharges the product, the now higher internal pressure helps the spring force the inlet valve closed. The same pressure forces the discharge valve open.

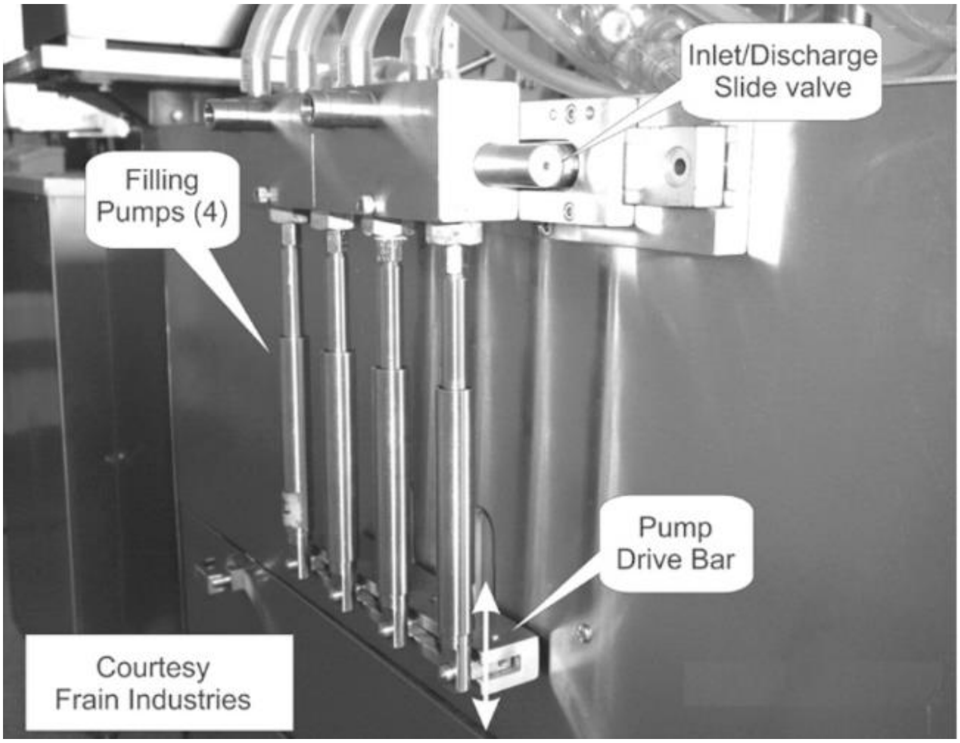
Check valves are simple and useful in many applications but do have a few drawbacks. One is that the timing of the valve closing is wholly dependent upon product flow and cannot be altered. The check valve spring that is weak enough to open fully under flow may not be powerful enough to fully close when particulates or solids are present. These may block the check valve open, allowing forward or backward leakage. Any leakage in inlet or discharge valve can cause imprecise fill volumes, dripping and other problems.

Check valves generally should not be used with viscous products. The thickness of the product can cause them to close slowly and inconsistently, causing variability in fill.

Other valve architectures include:

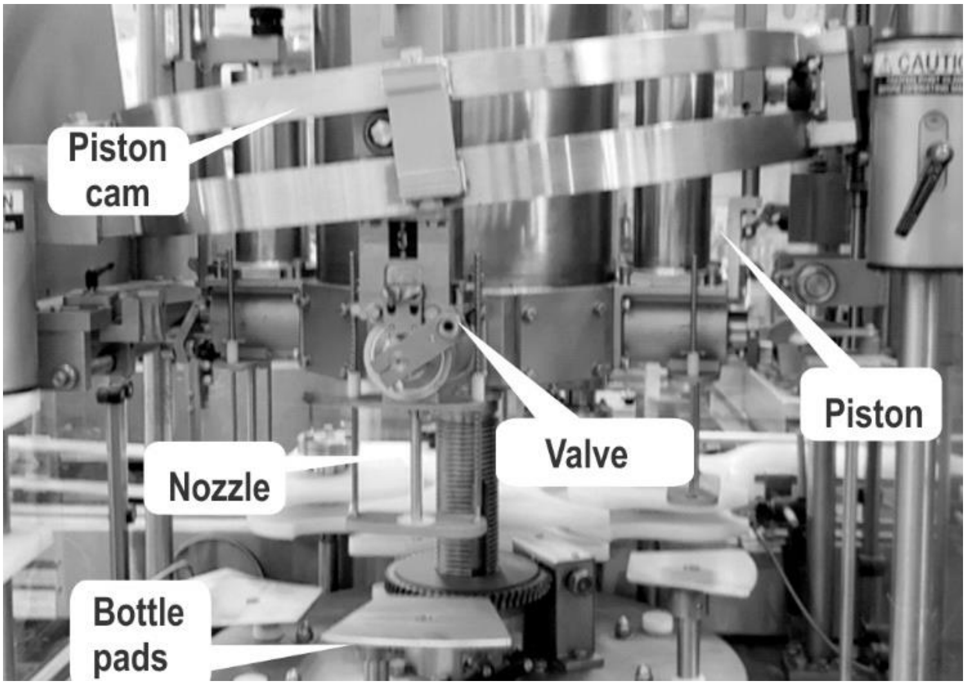
External mechanical valves: Mechanical valves can take a variety of forms. In some designs, they may be external to the pump and operated pneumatically, electrically or mechanically.

One style uses a manifold with an internal shuttle valve to control the flow from multiple pumps. The shuttle bar is linked mechanically to the pump drive and may either rotate or move laterally to open and close all inlet and discharge channels simultaneously. The photo below of ganged pistons shows a system where the cylinders move up and down while the piston remains fixed. The cylinder has no ports. Infeed and discharge are both through a central channel in the piston and connecting rod. The inlet/discharge valve slides back and forth to control the flow



2.3 Ganged Pistons
Courtesy Frain Industries

Rotary piston fillers typically have a rotating valve. As the turret, with filling pistons, rotates, a mechanical actuator (not shown) opens and closes the valves. This actuator is normally pneumatically or electrically actuated. In the event there is no container present, or no filling is desired (during a setup for example), the actuator retracts, preventing product flow.



2.4 Rotary Piston Filler
Courtesy Frain Industries

An advantage to mechanical valves is that they can operate independently of the piston. Normally the inlet valve should open and the discharge valve close when the piston starts its withdrawal. In some cases, it may be desirable to delay the valves. Some products, especially some highly viscous products, may want to drool from the end of the nozzle. Leaving the inlet valve closed and the discharge valve open momentarily when the piston begins withdrawal allows it to suck the drool back into the nozzle. This function is called “suck-back.”

Pinch or peristaltic valve: Pinch valves stop flow by squeezing the flexible tubing shut. Silicone tubing is common with pinch valves but other elastomeric tubing may be used. The key is that the tubing must be able to withstand repeated crushing, always returning elastically to its original shape.

One valve style consists of a pair of bars that pinch the tubing closed. Actuation may be pneumatic, electrical or mechanical. A major advantage, especially with sterile or hard to clean products, is that the valve is outside the fluid path. This eliminates the valve as a potential source of contamination or leakage. It also eliminates the need for cleaning as the tubing can be discarded after use. At one adhesive manufacturer, the product needed to be cleaned with an expensive and difficult to dispose solvent. They remove the entire tubing, seal both ends closed and dispose of tubing and residual product with no cleaning.

Another advantage, if there are solids in the product, is that the tubing is soft enough to close around them forming a leak-tight seal.

2.5 Peristaltic Pinch Valve
Courtesy Changeover.com

A disadvantage is that a suitable resilient tubing must be used to allow it to pinch shut and reopen repeatably. Silicone rubber tubing generally works well in these systems and is compatible with most products. Where not compatible, other tubing materials are available. Elasticity of the tubing will weaken over repeated cycles. It may be necessary to implement a procedure whereby the tubing is moved an inch or two every given number of cycles, Perhaps 25 or 50,000. This will expose a fresh section of tubing to the clamping forces.

Other Valve Styles

In other designs, the valves are located inside the pump. This ceramic pump uses a hollow slotted control valve inserted in the opposite end of the cylinder from the piston. As the piston cycles, this valve is rotated 45 degrees to shift flow between the inlet and discharge ports. Note that in this pump all wetted or product contact parts are ceramic. Stainless steel is only used for non-contact parts where greater mechanical strength or more complex shape is required.

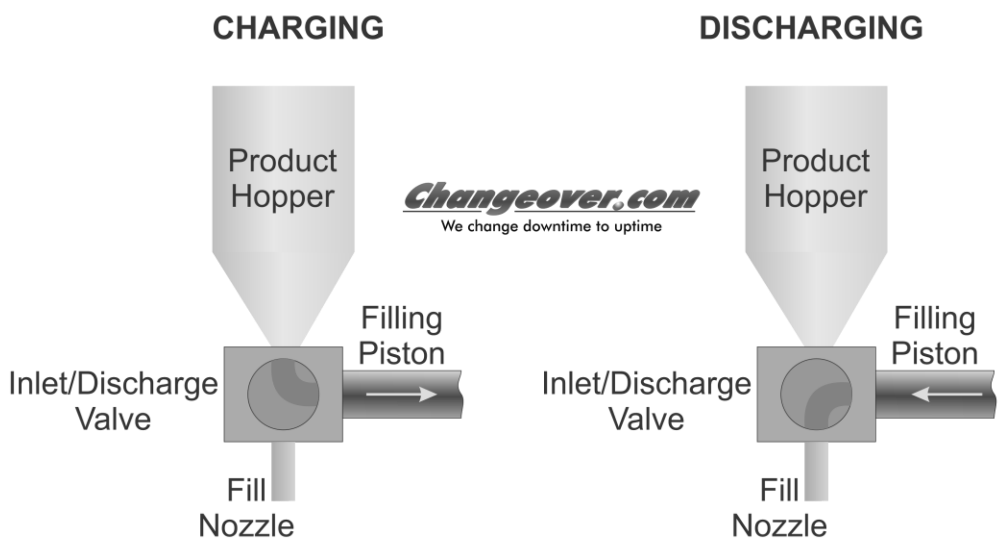
2.6 Ceramic Piston Pump With Rotating Internal Valve
Courtesy Changeover.com

Another design uses a valve rod with a flat on it. The rod rotates continuously in sync with the piston to direct flow as the piston charges and discharges.

A similar concept puts the flat on the piston itself. As the piston reciprocates it rotates continuously. The flat opens and closes the fluid ports to direct fluid flow appropriately.

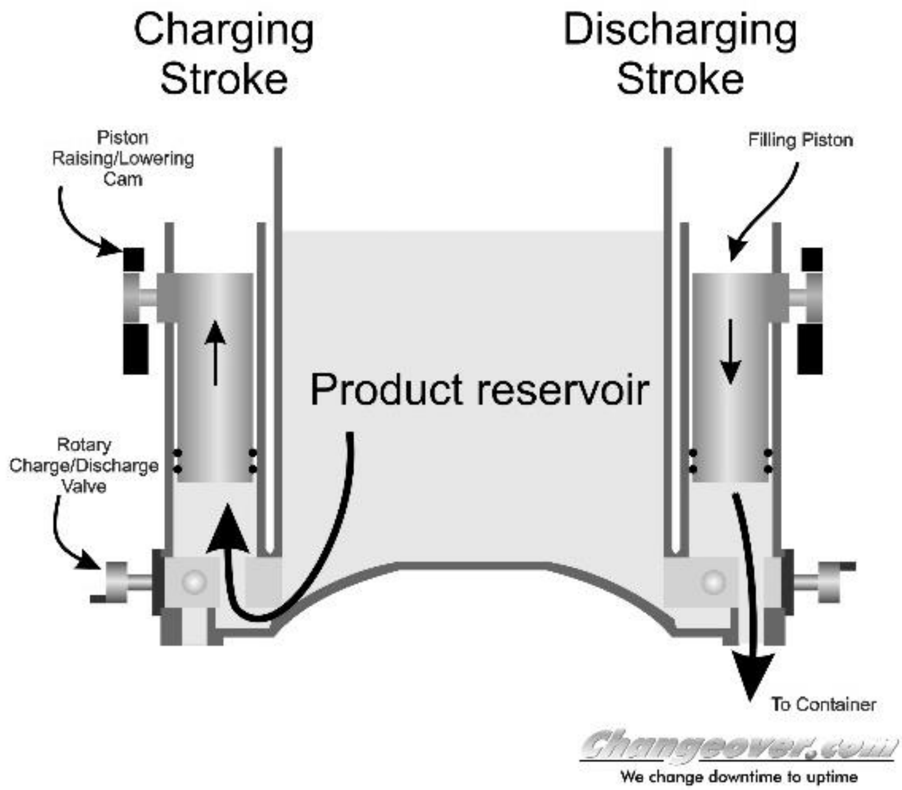
2.7 Rotating Piston With Valve Flat
Courtesy Changeover.com

Rotary valves: Rotary valves are often used on continuous-motion rotary fillers and for viscous products. They are common on collapsable tube fillers covered in Chapter 7. The valve consists of a shaft with an "L" shaped channel. During the charging cycle, the valve is rotated to connect the hopper to the piston. Once charged, the valve rotates 90 degrees and to allow the piston to discharge product through the fill nozzle.



2.8 Rotary Valve
Courtesy Changeover.com

Continuous-motion rotary fillers array pistons, with their valves, around the filler turret. As the turret rotates, the valves are opened and closed by a stationary cam. This schematic shows a slightly different style valve. Instead of a single "L" channel, the rotating shaft has two straight-through channels. The principal is the same in both cases.



2.9 Rotary Piston Filler Flow Schematic
Courtesy Changeover.com

This is the end of the sample but not the end of the chapter or book