Frain Whitepaper

Piston Fillers

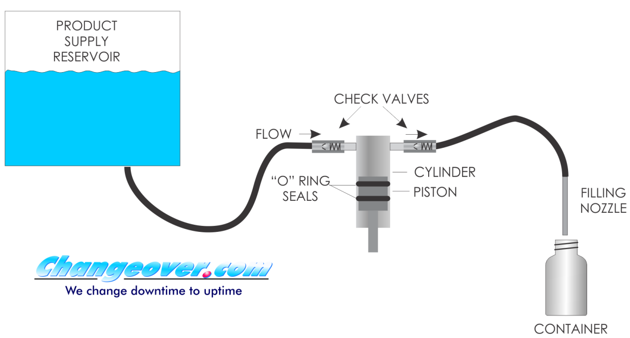
By John R Henry

Last month I discussed cosmetic or level style fillers. These fill a container to a certain level and fill volume is determined by the volume of the container. This is fine for many products, but others need more precise volume control. Volumetric fillers provide precise fills independently of the container. They do this by measuring physical volume, as in a piston filler. Other architectures measure the product by weight, mass or flow. Level filler precision is typically rated by the distance from the top of the container. Volumetric fillers precision is typically rated by percentage accuracy. A volumetric filler rated at 1% accuracy would be expected to fill a 10oz container to +/-0.1oz. Some high precision models can fill to +/- 0.1% accuracy. This precision can be critical when filling a high value product like a pharmaceutical that might cost thousands of dollars an ounce. This rating is typically expressed as six sigma. This means that 99.7% of all fills will be within specification absent any extraneous factors.

Piston filler design

The most common volumetric filling technology is based on cylinder/piston combinations of various types. Regardless of details, all piston fillers include a piston, cylinder, and inlet and outlet valves. Most pistons used for filling are single acting and that will be the focus of this paper. Single acting means that they fill and discharge one dose per stroke.

Piston filler schematic



There are a few companies that make double acting piston fillers that discharge one end of the cylinder while simultaneously filling the other. This allows them to fill 2 doses per fill cycle. This increases speed but adds complexity that is not usually necessary.

The dosage volume of a piston filler is a function of the diameter and stroke (linear travel) of the piston. A 5cm cylinder has an area of $19.6cm^2$ If the piston travels 10cm the total volume displaced will be 196cc (cubic centimeters). Fill volume is controlled by adjusting the length of the piston stroke.

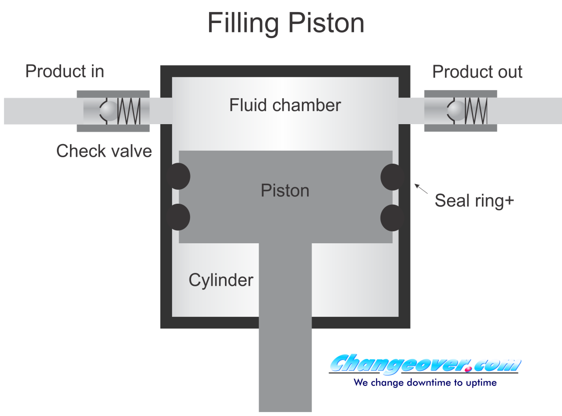
It is usually desirable to select a cylinder/piston combination that uses a relatively long stroke length for the desired fill volume. This reduces the effect of any slack or play in the drive mechanism. Some products may require a shorter stroke and larger diameter for best results.

Most filling pistons fill the entire dose on each stroke. Occasionally, it may not be possible to use a large enough piston to do this. In these cases, multiple strokes may be used to dispense the desired volume.

In other cases, it may not be possible to dispense the entire fill dose in a single stroke due to speed constraints. Multiple pistons, usually 2, each completing a portion of the desired dose, may be used sequentially.

Another technique usually for very small sub-milliliter doses uses a number of strokes, sometimes a dozen or more, per dose. This improves precision by averaging out any variation that may occur between individual strokes.

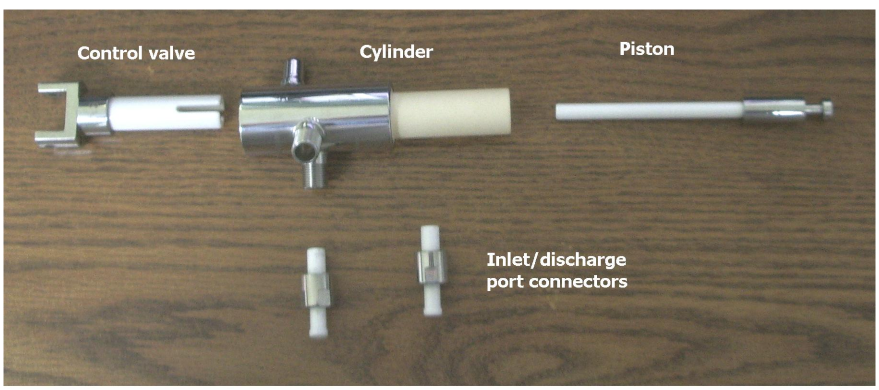
In addition to the cylinder and piston, there must be valves controlling flow in and out of the cylinder. One simple and common way to do this is with a pair of check valves. As the piston is withdrawn, product flows in through the inlet valve while the other prevents product from being sucked back from the discharge. As the piston is pushed into the cylinder, the discharge valve allows product to flow to the filling nozzle while the inlet valve prevents it flowing back to the reservoir.



Other types of valves including mechanically operated valves, pinch valves which pinch the inlet and discharge tubing closed, solenoid valves and rotating pistons with flats acting as valves.

Pistons and cylinders are commonly made from stainless steel with rubber or plastic rings to assure a good seal between piston and cylinder. Other common materials include special alloys, plastic, glass and ceramic. Tubing, valves, O rings, gaskets and other product contact materials must also be carefully chosen for compatibility.

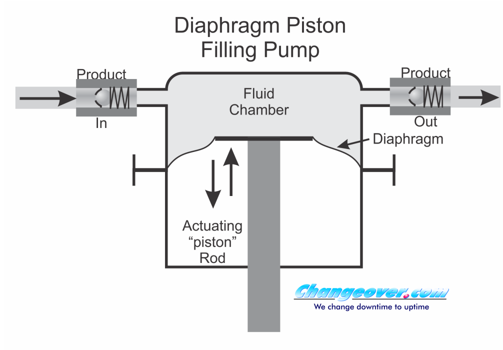
As the sealing rings rub against the cylinder wall in normal operation, they wear and generate small amounts of particulates. This is minor and not an issue in most products. Some pharmaceutical and other products do not permit any particles. One solution is to use very close tolerance cylinders and pistons of either stainless steel, glass or ceramic to eliminate the need for seals. One issue with stainless steel piston sets is that they can be easily damaged during assembly, disassembly, cleaning and storage. Even a seemingly insignificant scratch can render a set useless at a cost of thousands of dollars. When metal to metal piston/cylinder sets are used, everyone must be taught to handle them with extreme care. Ceramic piston sets as shown below eliminate the seals and are less subject to damage than stainless steel sealless piston sets. In this set all product contact parts are ceramic. Note the control valve which rotates to open and close inlet and discharge.



NEOCERAM Ceramic Piston Dosing Pump

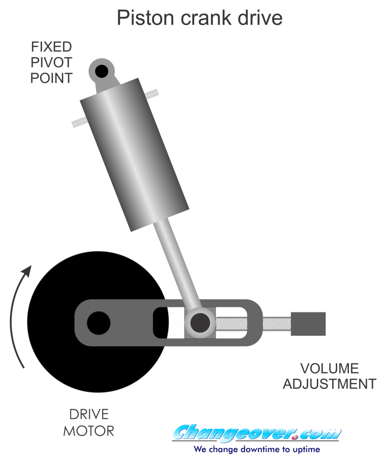
These pumps are usually made in matched. Care must be exercised not to mix components. They may either be too tight and bind or too loose and leak.

Another option when zero particulates are critical is the diaphragm pump. Operation is similar to a piston pump. Instead of a piston, the pumping chamber is defined by a flexible diaphragm. A rod moves the diaphragm in and out varying the pumping chamber dimensions. As with a regular piston, fill volume is determined by controlling the stroke length.



Piston drives

A driving mechanism is required to move the piston in and out. The simplest and most common mechanism is a crank mounted to a rotating shaft. Stroke, and fill volume, is adjusted by varying the length of the crank. The motor may run continuously or intermittently, filling on a signal. Servo motors, either rotary or linear, are becoming more popular in recent years. The advantage of a servomotor drive is that it can be controlled precisely to allow variable fill profiles. For example, it might run slowly during the 180 degrees of the piston withdrawal phase to avoid cavitation. It might then accelerate sharply during the insertion phase, finishing with a smooth deceleration to assist cutoff. This profile is controlled electronically.



Linear servo motors have the same functionality but have the advantages of eliminating mechanical linkage. Stroke is adjusted electronically.

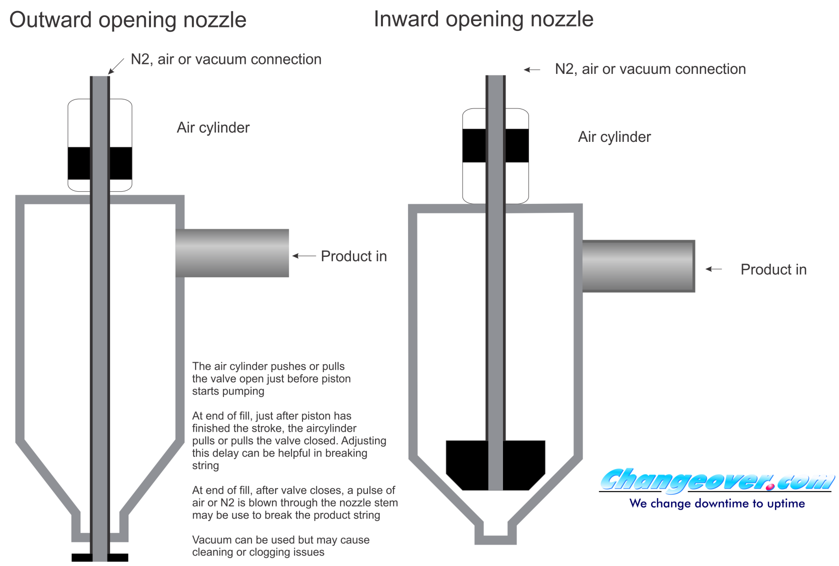
Pneumatic cylinders can also be used to actuate the piston with stroke controlled by mechanical stops. These are inexpensive as well as inherently safe for flammable or explosive environments. (Provided that controls are safe as well)

Nozzles

Capillary nozzles are common with volumetric fillers. These are essentially straight sections of tubing, connected to the filler via flexible tubing. The capillary action of the product at the tip of the nozzle prevents it from dripping. It is important that the valving in a system using capillary nozzles provide a tight seal. Any leakage will cause either backward or forward flow of the product when not filling. Forward flow will cause dripping, backward flow will cause air contamination and inaccurate filling.

Variations on the standard straight nozzle include sideshooting designs that shoot the product against the container wall to reduce foaming and splashing. Multi-channel nozzles are sometimes used to introduce a gas, such as nitrogen or oxygen, before, during and/or after the fill cycle.

Some products do not lend themselves to capillary nozzles. Positive shutoff nozzles must be used in these cases. These may open inward or outward opening depending on the product. Some nozzles have internal channels that can be connected to vacuum to prevent dripping. A pulse of air or nitrogen can also be blown through the channel at the end of the fill cycle. This can aid in breaking loose a stringy product like honey or shampoo.



Reservoirs

The product reservoir is a key component of any liquid filling system. It is important that the reservoir be located higher than the fill nozzle. If it is located below the filler any leakage of the valves will result in air being sucked into the nozzle. This may result in contamination of the inside of the nozzle. It will also result in a short fill on the first cycle after the filler has been paused.

The second reason for the elevated reservoir is to provide a positive inlet head to the piston. By design the filling piston is a pump as well as a measuring device. However, using it to pump as well as measure the product can, in some cases, cause problems with accuracy. If there are any leaks in the fluid path, the negative pressure will suck air in. This will cause contamination and the entrained air will cause foaming of the product in the container. When filling hot or volatile products, the negative pressure may cause cavitation resulting in inaccurate fill volumes.

For best results the inlet head pressure should be kept constant. The actual pressure is not as important as its constancy. Some applications may fill directly from a large bulk tank. At the start of the job, with a full tank, there may be 5-10' of positive inlet head. At the end of the job, with a nearly empty tank, there may be 1-2' of negative inlet head.

For maximum accuracy it is a good idea to use an intermediate filling reservoir. The bulk tank feeds the reservoir and maintains it at a constant level.

Conclusion

Piston fillers are the workhorse of liquid filling, used for all types of products, fill volumes and viscosities. They can be used for low or high speeds, inline, rotary form-fill-seal and many other applications. The article above describes the typical piston filler. As with everything else in packaging, there are many non-typical applications. You need to know what the best practices are before deviating. Whatever arrangement may be used, consistency of operation is the key to accurate filling.