Archimedes Pumps

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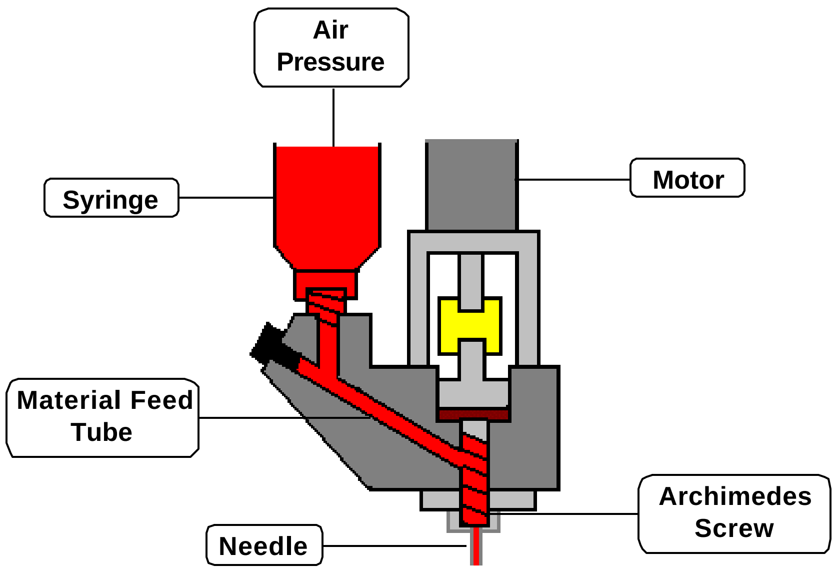
What is an Archimedes pump?

An Archimedes pump uses a screw (auger) to move material down a cylinder. The rotation of the screw creates a shearing force on the material which drives it down the threads of the screw. This technology has been around since Egyptian times, when it was used to remove water from the Nile river. An example of an Archimedes pump is shown below:



How do Archimedes pumps work?

With Archimedes pumps, constant air pressure is applied to a syringe that forces material down a material feed tube. The material comes in contact with the screw, which turns for a set length of time or rotates at a specified speed. The rotation of the screw creates a shearing force on the material, causing it to move down the threads of the screw. As the material reaches the needle hub (the area between the end of the screw and the needle shaft), it encounters resistance to flow due to the restriction in area at the needle shaft. The screw continues to turn, creating pressure high enough to force material through the needle. Any area restriction such as the needle at the output of the auger creates backflow. The amount of backflow is proportional to the pressure drop from the needle hub to the syringe. The flow out of the needle is equal to the pump shear flow minus the backflow. If the needle requires a higher pressure to flow than the screw can deliver, then back pressure is created and material will not flow out of the needle.

What is drool?

When the screw is at rest and the air pressure to the syringe is off, low viscosity materials drip from the needle due to gravity pressing down on the material. This is drool. Drooling is similar to the behavior of water in a straw. If a straw is not blocked, water empties out of the straw. Analogously, if the material flow path through the syringe, down the auger, and out the needle is not blocked, then low viscosity materials flow out of the needle. Viscosity is required to keep the material in the screw and the needle. Drooling can also occur between dispensing cycles, when the air pressure to the syringe is still on. In some cases drooling causes noticeable differences in the amount of material dispensed when placing dots with varying times between placements. Air pressure set too high for a given viscosity material accentuates drooling and other dispensing defects.

What is cavitation?

Cavitation is a defect that occurs when the material feed is insufficient for the screw speed. Insufficient material feed results in a screw thread that is not completely filled with material. Since the material forced down the auger into the needle shaft is inconsistent, the resulting flow out of the needle is also inconsistent. This causes cavitation. Cavitation can be corrected by increasing air pressure to the syringe, but this can cause drooling. The best solution for maintaining consistent dispensing without cavitation is to reduce screw speed so the air pressure doesn’t have to be increased.

Why is constant air pressure important for Archimedes pumps?

Since air pressure is responsible for presenting the screw with the correct amount of material, constant air pressure helps ensure an even flow of material to the screw. If the air pressure varies, then dispensing consistency cannot be maintained. With Archimedes technology, presenting the screw with a consistent flow of material without overdriving the screw is necessary to maintain dispensing consistency.

- **Air pressure –** A constant air pressure, usually between 10 and 20 psi, is applied to the syringe to supply the screw with material. The value of air pressure required to supply the screw with material without causing cavitation or drool depends on several parameters, some of which are material viscosity, screw rotation speed, screw diameter, and screw cut depth.
- **Low air pressure** – If the air pressure is too low, the screw will cavitate, causing inconsistent material deposition and missed dots. Inconsistent depositions due to cavitation are difficult to track since these defective depositions usually look good at first, but deteriorate over time. Air bubbles trapped in the material or inconsistent board heights are often incorrectly blamed for defects actually caused by cavitation.
- **High air pressure** – If the air pressure on the syringe is too high, material is forced down the screw when the screw is not turning, causing material to drool from the needle. This results in inconsistent dispensing, due to the material creeping up around the needle and bridging the gap between the mechanical standoff.

What is viscosity and how does it affect dispensing consistency?

Viscosity is a measure of a material’s resistance to flow. It is a dynamic rheological property of a material that can be measured in different ways and give different results. Viscosity is commonly measured using a Brookfield viscometer, which correlates shear stress to shear rate. These viscosity measurements are not absolute since the values obtained will vary with temperature and shear rate. In general, as the shear rate increases, the viscosity of the material decreases.

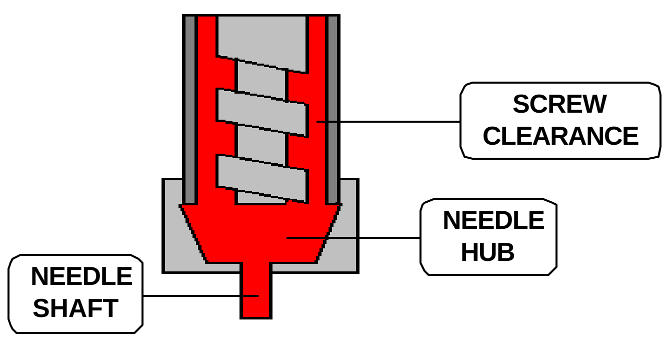
Archimedes pumps rely on material flow characteristics such as viscosity and shear behavior to force material down the screw and out the needle. Material viscosity affects the volume of material dispensed, and is itself affected by the dispensing temperature and the rate of shear due to the rotation of the auger screw. Any changes in material flow characteristics affect the volume of material dispensed. Therefore, when using Archimedes pumps, it is important to maintain stable dispensing cabinet and material temperatures to maintain consistent material viscosity.

How does syringe level affect Archimedes screw systems?

Fluid level changes in the syringe affect the volume of material being dispensed by changing the surface area of the material against the syringe's side wall. This change in surface friction affects the amount of pressure required to move a consistent volume of material through the end of the syringe. As the syringe empties, it requires less pressure to get the same flow rate out the end of the syringe as it did when it was full. This syringe level effect can account for as much as a 10 percent change in the volume of depositions from the beginning of the syringe to the end of the syringe, and is more noticeable when using low, constant air pressures. This trend is completely opposite of air over systems in which air pressure is pulsed. With constant pressure, the air in the syringe is always compressed. With pulsed air pressure, the air between the syringe plunger must be compressed before it reaches the same pressure as the input pressure.

How does the screw design affect the flow characteristics of epoxies?

Important parameters of Archimedes screw technology that affect the efficiency of Archimedes pumps are screw rotation, surface finish, pitch, and the shape of the screw. Some of these features can be seen in the drawing below.



- **Screw rotation** – Screw speeds must be matched with the material supply pressure to prevent cavitation or drooling. Motor speeds that are too fast (above 800 rpm) require that higher air pressure be applied to the material supply to ensure the screw threads are completely filled while turning. To get the resolution needed for smaller depositions (such as those for 0402 type components), the motor speed should be reduced to 200 rpm or less.

- **Surface Area** – The surface area of an Archimedes screw is one of the determining factors of material flow rates in Archimedes pumps. The flow of material down the screw is similar to the flow of water down a pipe. Water moving down a pipe always travels fastest in the center of the pipe and slowest around the pipe surface areas. In Archimedes pumps it is possible to get a higher material flow rate out the needle with a shallow cut screw than a deeper cut screw because it is easier for material to backflow up the center of the screw thread.
- **Surface finish** – Rough surfaces tend to move more material than highly polished surfaces.
- **Depth of cut** – Deep cut screws have a larger cross-sectional area which can help increase material flow rates when not restricted at the needle. Deep cut screws tend to drool more than shallow cut screws, and are less able to create high pressures at the needle due to a tendency for the material to backflow up the center of the screw.
- **Contour** – With other parameters the same, rounded screw cuts provide more contact surface area (allowing more material to be delivered per rotation) than screws with sharp cuts.
- **Pitch** – The pitch of the threads on the Archimedes screw affect the screw's ability to create the necessary needle pressure and retain the material when the screw is not turning. Finer pitch screws have more material retention and are able to create higher needle pressures than screws with coarser pitch.
- **Screw material** – Metal and plastic materials have different porosity and other characteristics that affect how epoxies are attracted to them. These material characteristic differences produce different material flow rates.
- **Clearances** – The clearance between the OD of the screw and the ID of the screw housing is one of the factors in determining maximum flow rate of material. With a tight clearance of less than 1 mil, the screw can build higher pressure in the needle hub (the area between the end of the screw and the needle shaft). Screw systems that have larger clearances cannot build up as much pressure in the needle hub due to the tendency of the material to backflow up the side wall of the screw. Tight clearances and tolerances, however, are not always good. For instance, screw systems that have tight tolerances have problems with malleable materials such as solder paste. Small particles get lodged between the screw and the screw housing, causing the solder balls to flatten. Eventually, these metal particles work their way to the needle shaft and clog the needle.

How often must the Archimedes pumps be cleaned?

Materials left in Archimedes pumps tend to dry on the screw, causing layers of dry material that flake and clog the needle. Regular maintenance is necessary to ensure best results. Most manufactures recommend cleaning at least once a week.

Definition of positive displacement

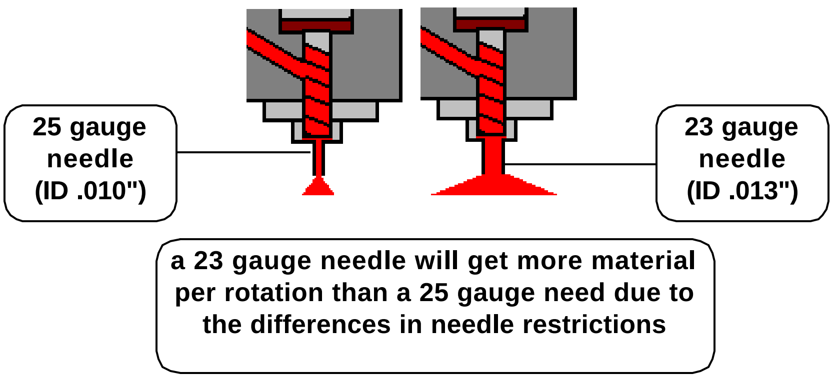
Positive displacement implies that a specific volume of material is displaced within a specific mechanical actuation. Positive displacement is not influenced by changes in temperature or viscosity. The Archimedes screw pump is very consistent, but this consistency depends on the viscosity and flow characteristics of the material. Archimedes screws have been marketed as positive displacement pumps, but "viscosity metering pumps" is a better definition.

Limitations of Archimedes pumps

Small dot sizes are limited to the minimum actuation times for the motors and clutches which are turning on and off. The electrical and mechanical actuation times are around 10 ms. As the dispensing actuation time approaches this limitation, dispensing consistency is noticeably reduced. It is common for machines running Archimedes pumps to reduce voltage to the motor, which reduces the motor speed. Reducing the screw speed helps increase the resolution of the theta rotation by increasing the length of time the clutches and motors are engaged. This added resolution helps increase the flexibility of the pump when approaching mechanical actuation limits. The disadvantages of running the motor at a reduced voltage are that it affects how much torque the motor can supply and can result in the motor stalling.

Why does the volume of material change in Archimedes pumps when the needle size changes?

This characteristic can be defined by the material flow characteristics of the Archimedes pumps. The needle creates a resistance to flow. As the needle characteristics change, such as the needle shaft length or the ID of the needle, the resistance to flow increases. This increase in flow resistance or needle pressure is offset by increased back pressure. The screw is limited as to how much pressure it can create at the needle hub by parameters such as the material viscosity, the screw design, and rotation speed.



Summary

Although there seem to be many drawbacks to using Archimedes technology, the alternatives in high speed dispensing are limited. These alternatives can be classified in three categories: the Archimedes metering screw pump, the positive displacement piston pump, and time and pressure dispensing. Archimedes pumps have a definite advantage over time and pressure dispensing—dispensing consistency. The advantage Archimedes pumps have over piston pumps is a little more sublime, however. The major advantage is the flexibility of unlimited dot sizes. With Archimedes pumps, dot size is simply adjusted through the software, and is proportional to the length of time the screw is allowed to rotate. Throughput is compromised with Archimedes pumps when there is a need for dispensing larger components such as SOICs. This is because the screw has to turn longer to get the necessary volume of material. The limitations for screw pumps in getting smaller dot sizes relate to the electrical and mechanical abilities of the clutch or motors to turn on and off. Actuations of 10 ms or less are approaching the mechanical limitations, and repeatability can be a problem.

Glossary of terms

Archimedes screw – a threaded screw encased by a cylinder and used to move liquid materials

Auger – a device with helical shaft for moving loose materials; Archimedes screws are usually referred to as augers

Back pressure – the pressure that is created when the needle pressure and the material screw pressure are not identical

Drool – material that oozes out of the needle unintentionally

ID – inside diameter

Needle pressure – the pressure in the needle hub that is required for the material to flow out of the need shaft

OD – outside diameter

PDP – positive displacement pumps

Pitch – the number of screw threads seen over a set length

Shear – action or stress resulting from applied forces that cause two contiguous parts of a body to slide relatively to each other in a direction parallel to their plane of contact

Surface tension – attractive force exerted on molecules of liquid by molecules below that tends to draw the surface molecules into the bulk of the liquid

Thixotropic – a property of adhesive systems that allows thinning upon agitation and thickening upon subsequent rest

Viscosity – resistance to flow; the ratio of shear force to velocity