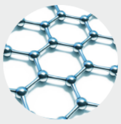
White Paper

MASTERING THE ART OF MICRODISPENSING-BASICS OF PICOLITER DISPENSING

INTRODUCTION

Microdispensing technologies, inspired by advancements in ink-jet printing, have significantly enhanced the precision and efficiency of dispensing biochemically, materially, and chemically relevant solutions and suspensions. These technologies are particularly valuable in applications requiring meticulous control over minute volumes ranging from picoliters (pl) to nanoliters (nl). By employing capillaries with piezo actuators, microdispensing offers exceptional accuracy in managing liquids with viscosities from 0.4 to 10,000 mPa·s, especially when viscosity can be reduced by heating. A notable advantage of this method is its digital scalability, capable of dispensing volumes as small as 22 pl and reaching rates of up to 2,000 drops per second. Additionally, the ability to form larger droplets by accumulating smaller ones provides flexible volume management. This dual capability of dispensing single or accumulated drops supports a wide array of applications and substrate compatibility. This white paper delves into the various benefits of different pipette features, along with substrates that can be dispensed using different modes and parameters, underscoring its versatility and precision across diverse scientific and industrial domains.



SOLVENTS WITH LOW VAPOR PRESSURE

Examples: Ethanol, Acetone, Methanol

ORGANIC COMPOUNDS

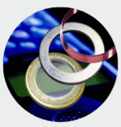
Examples: MXene, Graphene

SUSPENSION CONTAINING SMALL PARTICLES

Examples: Colloidal silver inks, cell suspensions

SOLID MATERIALS THAT CAN BE MELTED AT HIGH TEMPERATURES

Examples: Paraffin, Gallium



HYDROGELS

Examples: Alginate, Chitosan, Agarose, Matrigel

ADHESIVES

Examples: Byllux, Dymax, Conloc

LUBRICANTS

Examples: Oils, Grease

WATER LIKE SOLUTIONS

Examples: Enzymes, DNA, RNA

Figure 1: Application examples of different materials that can be dispensed in microdispensing

APPLICATIONAL SCOPE OF MICRODISPENSING

A wide variety of liquids, ranging from low-viscosity methanol (0.5 mPa·s) to higher-viscosity substances like mineral oil (100 mPa·s) and even pure mercury, have been successfully dispensed using microdrop systems. Generally they fall into different categories (see Figure 1).

CORE TECHNOLOGY: THE DROPLET GENERATOR

The core system comprises a tubular piezo actuator attached to a glass capillary, which forms the essential dispensing mechanism (see Figure 2). At one end, the glass capillary tapers into a nozzle, facilitating both the dispensing and, in the case of an autopipette, the aspiration of liquids. The droplet volume, determined by the inner nozzle diameter (ranging from 30 to 140 µm), can vary from a few nanoliters to as little as 22 pl, ensuring high reproducibility and precision. The opposite end of the glass capillary is connected to a storage bin through a ETFE or PFA tube.

OPTIMIZATIONS TO THE DROPLET GENERATOR BASED ON THE APPLICATION

To accommodate diverse application requirements, the system is equipped with distinct features tailored for specific settings (see Figure 2, highlighted in yellow circles). Depending on the design, the nozzle geometry or capillary can be optimized through several enhancements. These include:

- **Specialized nozzle geometry** is advantageous for dispensing particularly viscous solutions, like oil, or substances with particles, ensuring a clean drop detachment. This geometry is also beneficial for liquids with low vapor pressure.
- **Integrated heating elements**. The heating element plays a crucial role in reducing the viscosity of substances such as glue and paraffin by localized heating, which can be confined to the nozzle or extended to encompass the entire capillary and reservoir.
- **For low viscosities** is a adaptation in the geometry, which allows a better focusing of the shock waves from the piezo towards the nozzle, which is particularly advantageous for non-viscous liquids like water.
- Furthermore, the **nozzle** can be designed to fit into smaller cavities, like microtiter plates with an Autopipette, or enclosed in a casing, forming a compact Micro dispenser head (see Figure 3).
- The Micro dispenser head features a larger **reservoir** of 2-12 ml for more efficient dispensing without refills. Autopipettes have reservoirs between 25 µl-1 ml.

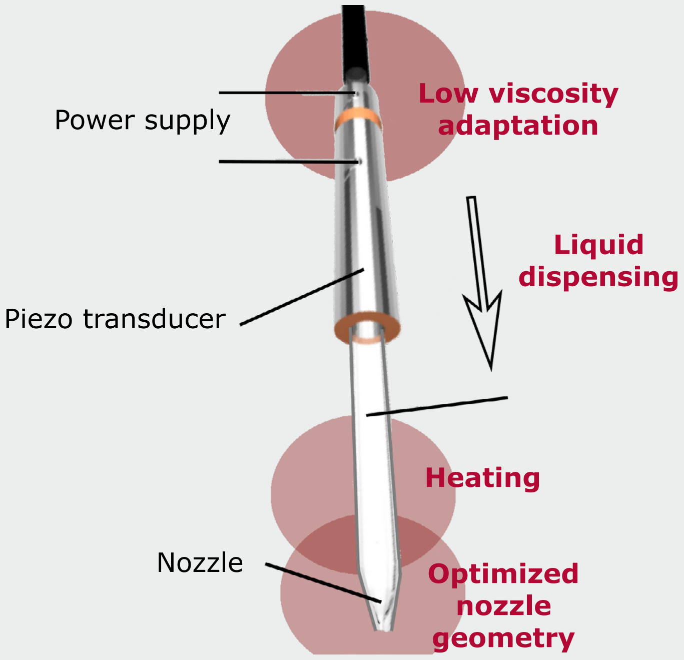


Figure 2: Basic setup of a droplet generator. Red highlights showcase potential optimizations as described in the text.

WORKING PRINCIPLE OF THE DROPLET GENERATOR

When a high-voltage pulse is applied to the electrodes on both the inner and outer surfaces of the piezo actuator, the actuator contracts in response. This contraction results in a slight reduction of the inner diameter of the glass capillary, a process referred to as the „push mode." Although the deformation is minimal—less than 0.1 µm—it is sufficient to generate an acoustic wave. This wave is transmitted through the liquid, leading to rapid acceleration in the nozzle area. As a result, a high pressure is momentarily created that counteracts the capillary force. This pressure spike forces the smallest droplets of liquid to be ejected from the nozzle. Once the pressure is released, the liquid's velocity decreases, and part of the ejected volume is constricted before being separated. This separation results in the formation of a single drop, which reaches a flight velocity of approximately 2 m/s. The remaining liquid is drawn back into the nozzle and oscillates until frictional losses bring it to rest. Due to capillary forces within the nozzle and the liquid's surface tension, the dispensed liquid volume is automatically replenished from the storage reservoir.

The drop formation process is illustrated in Figure 4.

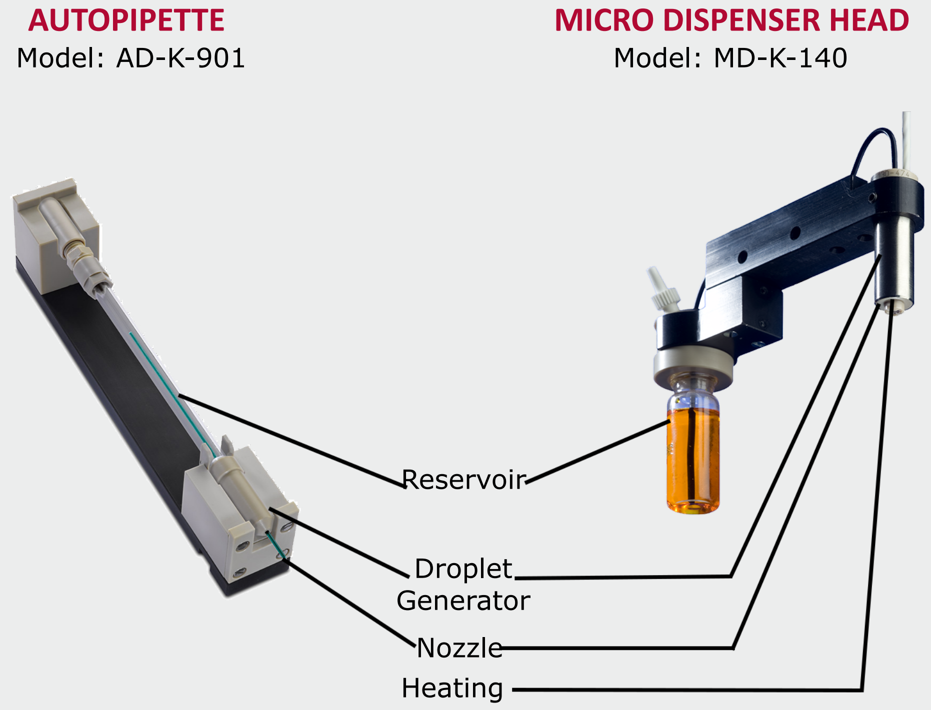
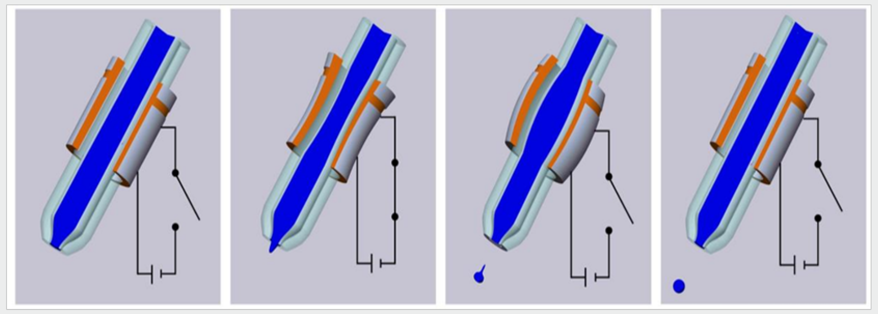


Figure 3: Different design of an Autopipette and a Micro dispenser head.

A. SCHEMATIC OF DROPLET FORMATION



B. KEY FRAMES OF DROPLET FORMATION

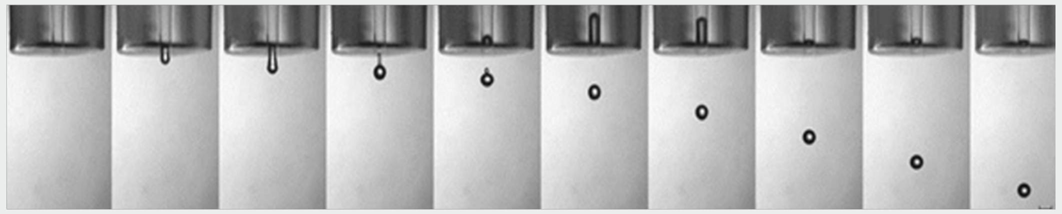


Figure 4: Droplet formation process (a) schematic of the push modus for droplet formation and (b) droplet dispensing process on a real capillary

USING DIFFERENT PULSE MODULATIONS TO DISPENSE DIFFERENT LIQUIDS

Besides the physical properties there are various dispensing settings that can be used with the droplet generator to produce different types of droplets with the piezo actuator. The easiest is a single pulse that can be administered in the push or the pull mode.
The push mode, as shown above, is typically used for water or other low-viscosity liquids with viscosities close to 1 mPa·s. In this mode, negative pressure separates the liquid volume, forming it into a drop. The size of the drop in flight is about 10-20 % larger compared to the pull mode. However, for liquids with higher vapor pressures (e.g., ~24-40 mbar for isopropanol at 20°C), cavitation bubbles may form in the glass capillary near the nozzle tip, potentially disrupting the dispensing process.

The pull mode is designed for higher viscosity liquids (over 10 mPa·s). In this mode, the piezo actuator initially expands and then contracts upon deactivation, creating acoustic waves that generate alternating negative and positive pressures at the nozzle tip. This causes the meniscus to first retract into the capillary and then be pushed forward by the subsequent pressure wave, operating opposite to the push mode. Precise adjustment of pulse width and voltage is critical in this mode to ensure proper drop formation.
Using the single pulse the droplet volume is primarily determined by the inner diameter of the nozzle on the Micro dispenser head or Autopipette and is similar between single pulse push and pull modes (see Figure 5). The repeatability of the dispensed drop volume is very high, with a deviation of less than 1% if ambient conditions and the liquid properties remain constant.

With pulse modulation, smaller droplets can be produced compared to the standard single pulse. A reduction of up to 50% in droplet diameter is possible, depending on the liquid used and the type of dispensing head (see Figure 5). This is achieved by applying up to three successive pulses with different amplitudes to the piezo, causing vibrations that

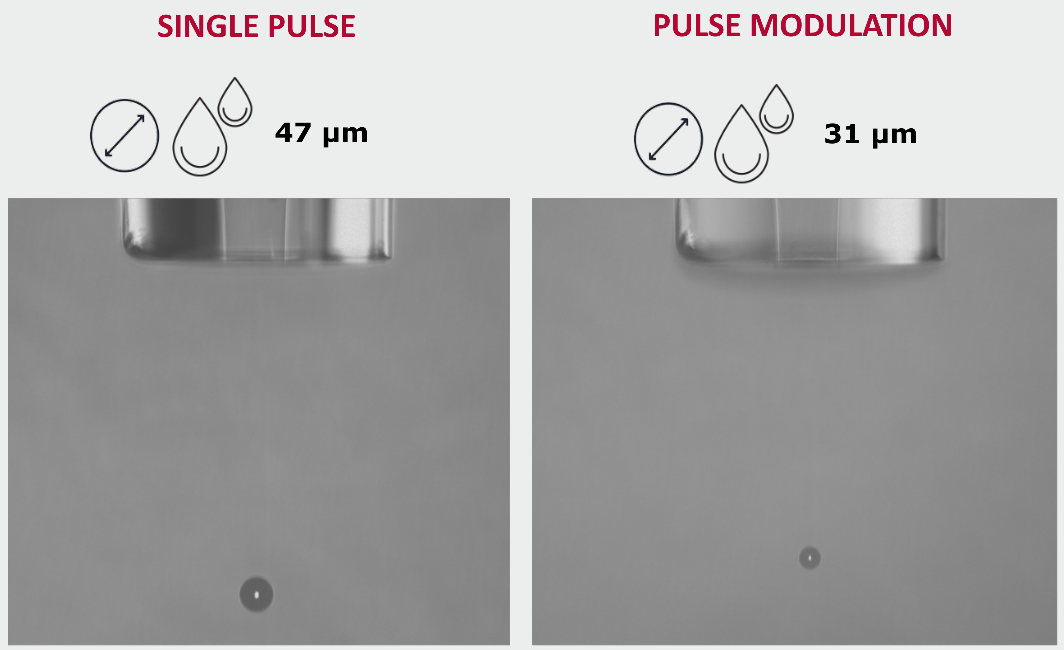


Figure 5: Average droplet diameter of AD-K-901 with inner nozzle diameter of 30µm showing different droplet sizes at different pulse settings. Note: Click on image to see a video of the droplet fromation.

form smaller drops. Fine-tuning the exact parameters for this modulation requires much more delicate adjustments compared to single pulse push and pull operations.

CONCLUSIONS

In conclusion, the versatility and precision of the microdispensing system are evident in its ability to handle a wide range of materials with varying viscosities and properties. Table 1 highlights the optimized dispensing heads for each of the eight types of materials, showcasing tailored solutions for applications ranging from low-viscosity liquids like water and ethanol to high-viscosity substances such as adhesives and gels. The adaptability of the system, including features like push and pull modes, pulse modulation, and specialized nozzle designs, ensures high reproducibility and minimal deviation in droplet formation. This flexibility makes the microdispensing system an invaluable tool in fields requiring precise liquid handling, from biochemical assays to industrial applications. For further information please contact our dispensing experts, who can advice you on how to find the optimal system for your needs.

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Table 1: Suitability of different Micro dispenser heads and Autopipettes for dispensing different liquids. ●: Denotes the presence of a certain element; +: Suitable; ++: More suitable; +++: Very suitable; +*: Possible depending on configuration. Note: Liquid properties can vary even within the same class of liquids. For optimal results beyond initial orientation, please contact microdrop Technologies GmbH.

Head		Parameters of dispensing heads						Applications of microdispensing								
		Inner nozzle diameter [µm]	Type	For lower viscosity	Optimized nozzle geometry	Temperature regulation	Storage reservoir	Solvents with low vapor pressure	Suspensions	Hydrogels	Lubricants, oils and grease	Organic compounds	Molten materials	Adhesives	Water like solutions: Lower viscosity	Water like solutions: Higher viscosity
Micro dispenser head	 MD-K-130	30	30	●		None	up to 12 ml	+	+						++	
			930	●	●			+							++	
		50	40	●				+	+						++	
		70	50	●				+	+						++	
	 MD-K-140	50	40	●		Heated nozzle	up to 12 ml	+	+						+	+
			800						+		+	+		+		++
			900		●				+		+	+		+		++
			940	●	●			+	+						+	+
		70	50	●				+	+						+	+
			800						+		+	+		+		++
			900		●				++		+	++				++
			950	●	●			+	+						+	+
		100	800						+	+	+	+		+		++
			900		●				+	+	+	+		+		++
		120	900		●				++		++	++				+++
		140	900		●				++		++	++				+++
	 MD-K-801	70	800			Heated nozzle, fluid supply and reservoir	4 ml		+		+	+	+*	+		+
		100	800						+	+	+	+	+*	+		+
			900		●				+	+	+	+	+*	+		+
Autopipette	AD-K-901 & AD-K-902	30	30	●		None	AD-K-901: ~37 µl AD-K-902: ~1 ml	+	+						++	
		50	40	●				+	+						++	
			940	●	●			+	+	+	+				++	
		70	50	●				+	+						++	
			950	●	●			+	+	+	+				++	
		100	800						+	+	+	+		+		+
			900		●				+	+	+	+		+		+
	 AD-KH-501	30	30	●		None	~25 µl	+	+						++	
		50	40	●				+	+						++	
		70	50	●				+	+						++	

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