The Correlations Between Viscosity, Needle Diameter, Flow Rate and Dose Accuracy in a Patch Pump Therapy

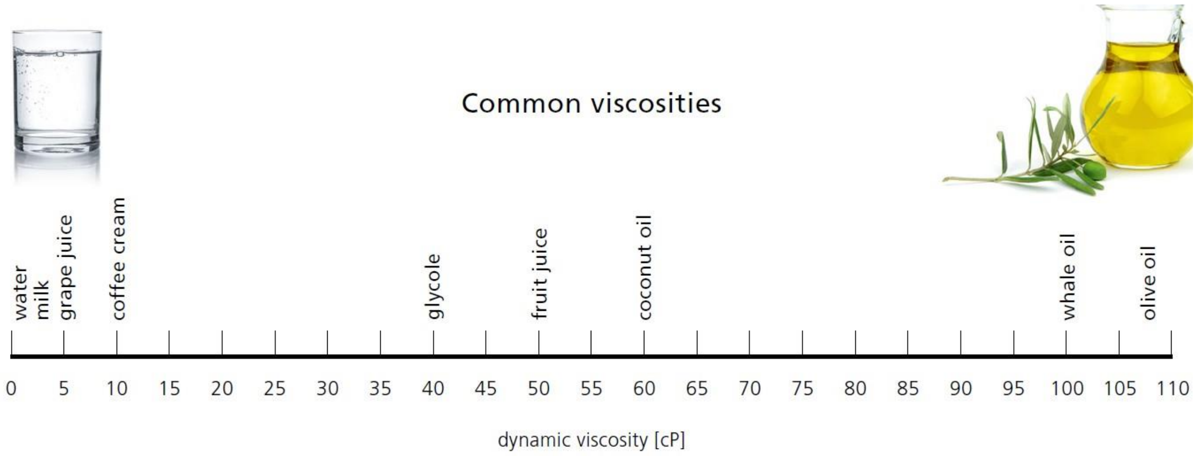
Introduction

Patch pump therapy is a convenient way of drug administration. The devices can be worn directly on the body, no tubing has to be attached and the cannula or needle is inserted automatically. They are often equipped with programmable delivery patterns, which allow high flexibility and rational adjustment to the patient's needs. In turn, the patch pumps must fulfill highest criteria in dosage accuracy and safety. The fluidic path through the whole device including body resistance at the injection site, combined with the physical properties of the drug define the pressure loss that the pump needs to overcome. Since smaller needles are more comfortable and therefore preferred, they often represent the bottleneck of the system. The dependencies thereof are depicted hereafter.

Viscosity range of suitable medication

Many common drugs for patch pump therapy are aqueous solutions in the range of 1 cP to

30 cP. Fluids with higher agent concentration or larger molecules might reach up to 50 cP or even higher. This often requires large needle diameters or significantly lower flowrates.



Needle limitations

To limit pain at needle insertion, small needle diameters are a preferred option. Typical needle diameters for patch pump therapy range from 27G up to 31G. While thinner needles are desired, the pressure loss over the needle increases with smaller inner diameter, higher viscosity and flow rate. Depending on the available maximum pressure of the patch pump and the drug viscosity, a 31G needle might be preferred and suitable for low flowrates but may not be suitable for high viscosities.

Penetration depth and insertion angle define the needle length, which linearly scales up the pressure loss. A common range for subcutaneous injection is 8 mm to 13 mm.

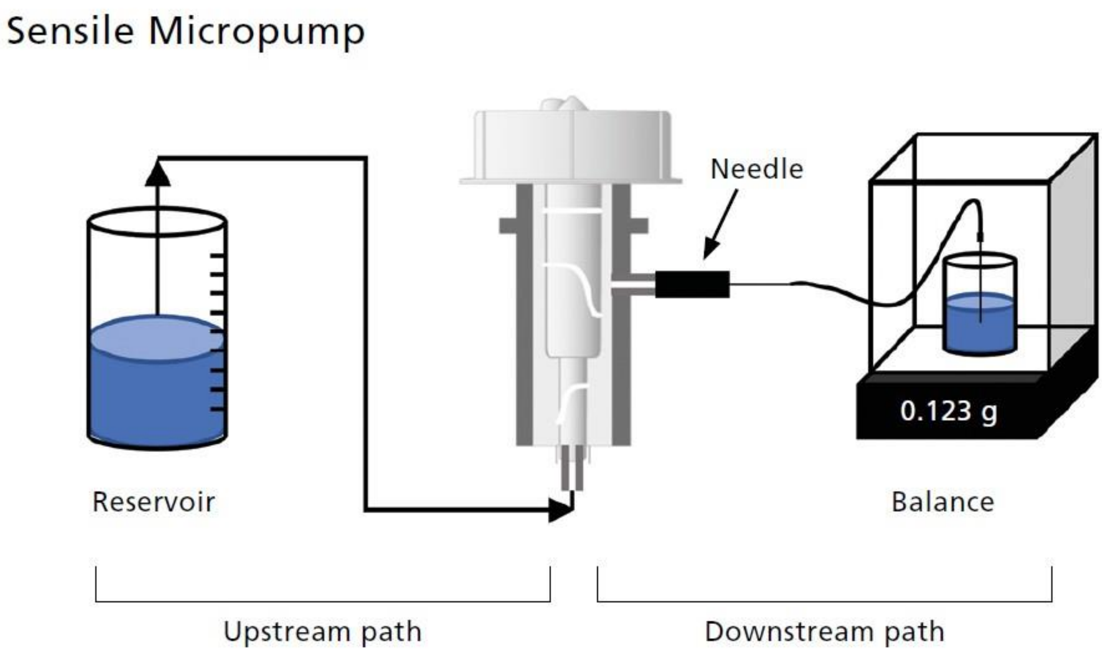
Limitations of flowrate

If for certain therapies, pharmaceutical companies desire shorter dose delivery durations and therefore higher flowrates, this can result in pressure variations and therefore in possible dosage deviations. Choosing adequate pump size, internal tubing and needle is key for high dosage accuracy. The chosen needle usually defines the maximum flow rate.

In this study, maximum flow rate is assumed to be in continuous delivery mode (worst case). Lower flow rates can always be achieved by delivery patterns with certain pauses or slower motor rotation. The selected pump size defines the minimum partial dosage increment that can be delivered and results in a possible limitation of the maximum flow rate.

Influence of total fluidic resistance on Delivery Volume Accuracy (DVA)

Each fluidic part in the up- and downstream fluidic path (bends, tubes, transitions, etc.) adds to the total fluidic resistance of the system, resulting in higher pressure loss and potentially lower DVA. Flexibility in the fluidic connection between pump and needle allows the dampening down of pressure peaks and acts as fluidic buffer, enhancing the pump's functional zone. However, in most applications, the flow situation inside the needle primarily dominates the pressure loss of the complete fluidic system.



Correlation of needle diameter and viscosity at different flow rates

In the following figures, calculated pressure losses for several needle diameters and a range of viscosities are correlated to measured delivery accuracy of two Sensile micro pumps (2 µl and 10 µl volumetric pumps). The green and yellow areas represent the pumps' pressure capability at ±5% and ±10% DVA in continuous delivery mode for tested viscosities.

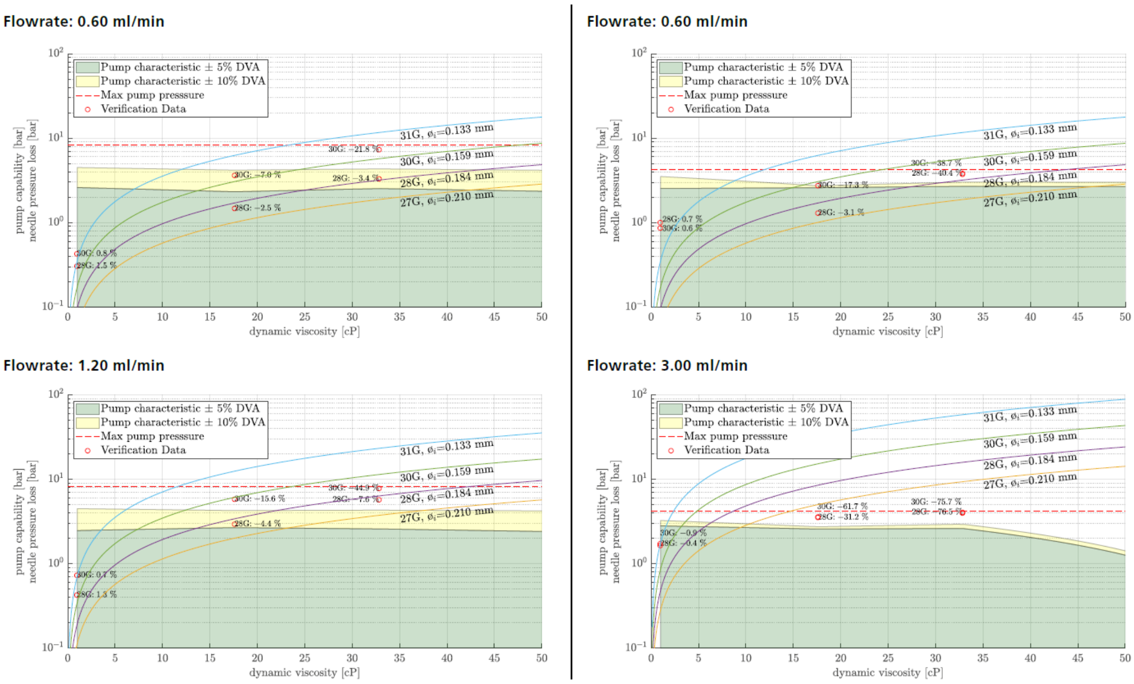


Table 1:

Table 1: Pump characteristic for a 2 µl pump (left) and a 10 µl pump (right) at different flowrates (pump rotational speeds). The lines indicate the calculated pressure loss for different needle diameters with needle length 12.7 mm (calculated length 22 mm). Density assumed 0.997 g/cm3. To achieve a desired accuracy (DVA) of ±5%, the needle pressure loss needs to be in the green area.

The maximum feasible operation points at ±5% DVA (intersection points of needle pressure loss curves and green area boarder) are extracted and plotted in the figures below. These graphs can be used to predict needle limitations for flowrate and viscosity combinations.

For example, for a 31G needle, a liquid with 10 cP would flow well up to 0.5 ml/min but could not be delivered at higher flow rates with a DVA of ±5%. For scenarios resulting in operation points above the green area, a reduction of flow rate is the best option.

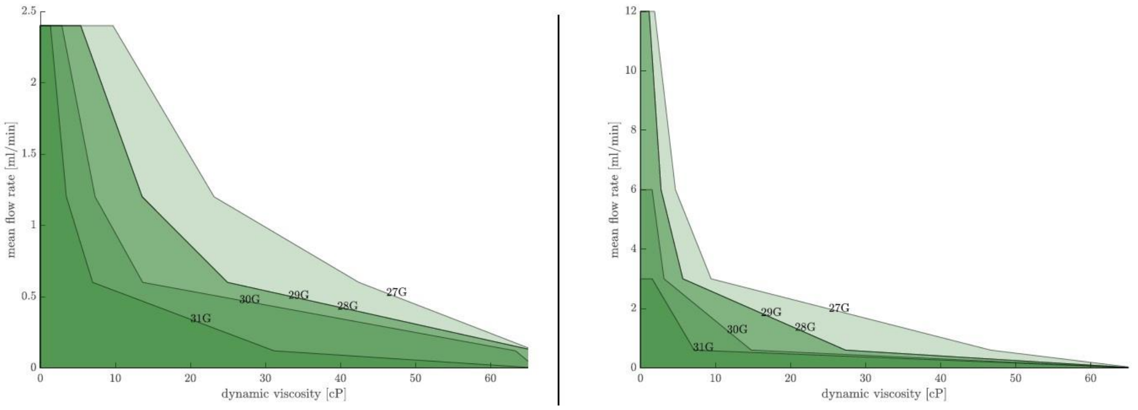


Table2

Table 2: Flow rate vs dynamic viscosity for Sensile 2 µl pump (left) and 10 µl pump (right). The green areas' shadings represent the ±5% DVA functional zone for several needle diameters. (Needle length 12.7 mm, fluid density 0.997 g/cm3).

For this study, all assumptions were chosen conservatively so that sufficient performance is probably reached even when choosing points somewhat over the presented limitations. The results were verified at different flowrates, viscosities and needle combinations.

Conclusion

The correlation between flow rate, viscosity and needle diameter delivers a horizontal and vertical asymptotic pattern. Delivering viscosities greater than 50 cP can still be managed with large needle diameters and very low flow rates to meet dosage accuracy targets. On the other end of the scale, flow rate is limited by the fluid's viscosity and the mechanical limitations of the pump. Here, the larger 10 µl pump's limit is at 12 ml/min where viscosities up to 2 cP can be delivered with a 27G needle. The performance scales linearly with the needle length.

Author

Michael Girschweiler | Technology Manager

Sensile Medical AG | Solothurnerstrasse 235 | 4600 Olten | Switzerland