Can a surface be too hydrophilic?

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Frequently, customers come to us with a simple request, "*Make our device as hydrophilic as possible*". Usually, they have tried numerous things to make the device hydrophilic, without much luck. Their device still form air bubbles and capillary flow is still too slow. In their mind the solution is simple, the device must be more hydrophilic to solve the problem.
Often, the device is genuinely not sufficiently hydrophilic, and our P100, S100 and H100 hydrophilic coatings will make the device as hydrophilic as needed. However, it is overly simplified to think that a device can only benefit from being even more hydrophilic. For virtually all devices and applications there is an optimum hydrophilicity.
The one notable exception is fog prevention on bathroom mirrors and diving masks. These surfaces should be superhydrophilic or wetting, meaning a zero degree contact angle (*CA*). This is the only way to form the thin water film on the surface, which prevent the light scattering tiny droplets to form.
For all liquid handling devices, there is an optimum hydrophilicity, it shouldn't simply be as hydrophilic as possible.

So, what is the problem?
A device with a surface more hydrophilic than the optimum, will generate MORE air bubbles (not fewer) and capillary flow will be out of control.

Capillary flow
A liquid handling device intended to be filled by capillary flow, must be hydrophilic on the inside. The more hydrophilic the channel or fluidic pathway is, the faster the flow. This is true and the reason many people make the over simplifying conclusion; "*the flow is too slow, so the device must be more hydrophilic*". Capillary flow is controlled by how hydrophilic the surface is, AND by the geometry of the liquid pathway. Just focusing on the hydrophilic surface, ignores the importance of the geometry, and it give a set of new problems.
Capillary flow is governed by two aspects:

Driver: Flow is driven forward because it is energetically favorable to wet the hydrophilic surfaces.
Control: Flow can be controlled because it is energetically favorable to minimize the liquid to air surface area.

An experienced device designer, will use the internal device geometry to balance these two opposing forces, to get the desired fluidic function. In medium hydrophilic systems (*CA 25°-50°*), this balance is easy to work with, and it is relatively simple to get both fast flow and flow control.
In very hydrophilic systems the balance is disrupted, because the driver is so strong that it overpowers the control. The flow is fast but not controlled. Capillary stops and delays become unreliable or simply doesn't work, and staged and parallel flows become unpredictable. A very hydrophilic surface can "rip the liquid apart" and make it spread all over the internal surface of the device. The liquid will not try to stay together (cohesion), but will try to wet as large an area as possible. The result is very often large pockets of air being trapped as the liquid flows around the air while wetting all chamber walls. The result is thus more air bubbles, not fewer.

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Optimum hydrophilicity

The optimum contact angle depends on the geometry and requirements of a specific device. There is no simple answer to how hydrophilic a device should be, but it should be as hydrophilic as possible without losing control. So, we want the surface to be hydrophilic, but not too much. Obviously, zero degree contact angle is too hydrophilic, but at what contact angle do the issues start?
An early and very visible issue occur in 90° channel corners, where there is packed more hydrophilic surface per liquid volume. This effect is seen in the channel system in figure 1.

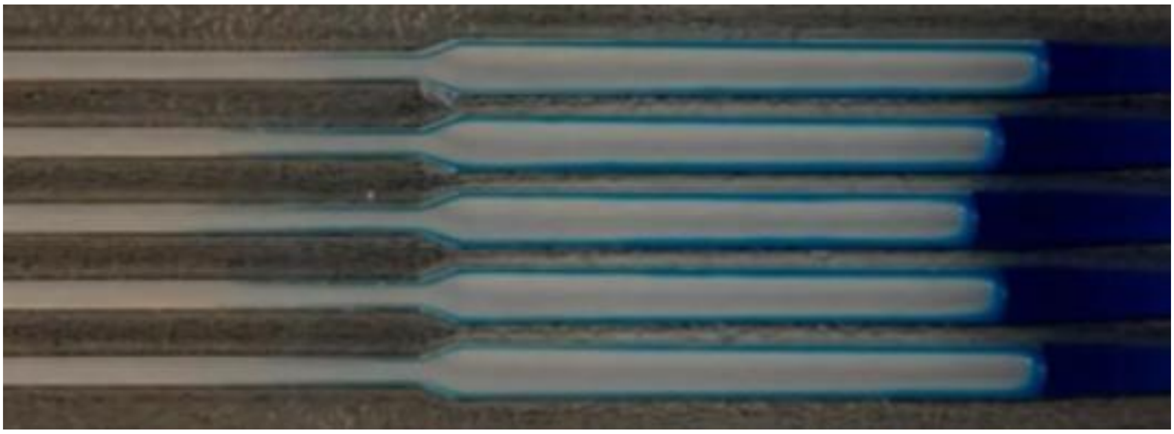

Figure 1. Five parallel channels filled from the right by a blue test liquid (TL1). The pre-shooters at the channel corners are easily seen. For geometrical reasons the channel corners are effectively wetting.

In theory sharp 90° corners become effectively wetting (*CA=0°*) at $CA = cos^{-1}\left(\frac{1}{\sqrt{2}}\right) = 45°$. Due to surface roughness and imperfections, this effect is usually only seen for contact angles less than 30°.

Control issues are highly dependent on the specific device geometry, but this table summarizes the most common behavior for different contact angles.

Contact angle	Capillary behavior
0°	Out of control flow.
0°-30°	Fast flow but may have control issues. Expert knowledge is needed to get the geometry right.
30°-75°	Controlled but slow capillary flow.
75°-90°	Flow unlikely due to surface “friction”.
90°-150°	Capillary flow impossible.

The optimum range for contact angles are usually in the range 10° to 45°.

Joninn products and services
Our P100, S100 and H100 hydrophilic coatings are in the low end of the optimum range, 10°-15°. Our X100 hydrophilic coating complements P100 and S100, by enabling tuning of the contact angle between 10° and 45°. Our coatings can thus match the full optimum range, and the needs of a specific device geometry.
Our Tensistat moldable hydrophilic plastic is in the middle of the optimum range, 20°-25°. This is usually good for most devices, but if needed a special formulation of Tensistat can be made with any contact angle between 20° and 60°.

We have extensive experience with optimization of the hydrophilic properties of customer devices. When we have an active consulting role with a customer, we have more than 90% success rate with reaching product specifications.