Improvement in the measurement of the bubble point for wire mesh using numerical models

by Dominik Herper

Abstract

The bubble point test is a widely used measurement method in filter media quality control. The basic principle is that pores filled with liquid only become permeable for gas from a certain pressure level upwards. This pressure level is measured and then used to deduce the pore size. The problem is that the underlying correlation between pressure and pore size is only valid for cylindrical pores. To determine the size of pores with other shapes, correction factors are applied. Up to now, these have been determined empirically or simply estimated.

This paper describes a method using CFD simulations that makes it possible to determine a more accurate correction factor and thus a more precise pore size.

Introduction

The bubble point test is a standard test for quality control of filters and filter materials. There are numerous standards that specify the measurement principle for individual areas of application. The ISO 2942 standard, for example, specifies a bubble point test method applicable to filter elements, while the ASTM F316 standard applies exclusively to membrane filters. The BS 3321 standard stipulates the method for measurement of equivalent pore size of woven filter media or fabrics.

The idea behind the measurement method is that, by determining the size of the largest pore in the filter medium, one can make a statement about the quality of the filter. However, the determination of pore size described in the norms is only valid for cylindrically shaped pores. To be able to make a reliable statement about the largest pore in woven wire meshes, which have a wide range of different pore geometries, a correction factor is required. Up to now, this correction factor was determined empirically through laboratory measurements, or estimated, or stipulated in standards. Because of the numerous assumptions involved, the correction factor is very imprecise. Now, to enable a truly precise statement on real pore size, the company GKD - Gebr. Kufferath AG is using numerical methods. These multiphase models make it possible to establish reliable values for the required correction factors.

Theoretical fundamentals and measurement principle

To determine the bubble point of a filter medium, a sample of the material to be tested is cut, cleaned and then mounted in the test rig (see Fig. 1). The test coupon is wetted with a test fluid, and then the pressure under the filter medium is increased by pumping in a constant airflow. Because the medium is porous, as the pressure increases a bubble eventually forms at the largest pore of the wetted medium. Further intake of air into the chamber causes the bubble to burst. This completes the test. The build-up of pressure under the test coupon is measured continuously throughout the complete test procedure. The highest value measured for pressure is then recorded, marking the bubble point of the filter medium.

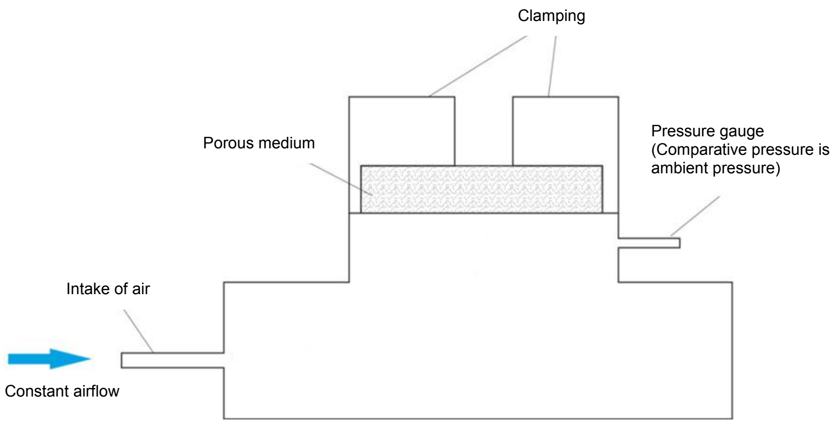


Fig. 1 Schematic diagram of the bubble point test

To deduce the diameter of the largest existing pore, a correlation must be established between the measured pressure and the pore diameter to be found. For cylindrical pores, this relationship is known under the phenomenon of capillary action. Due to its surface tension, a fluid will rise upwards through a cylindrical pore if the pore is small enough (see Fig. 2).

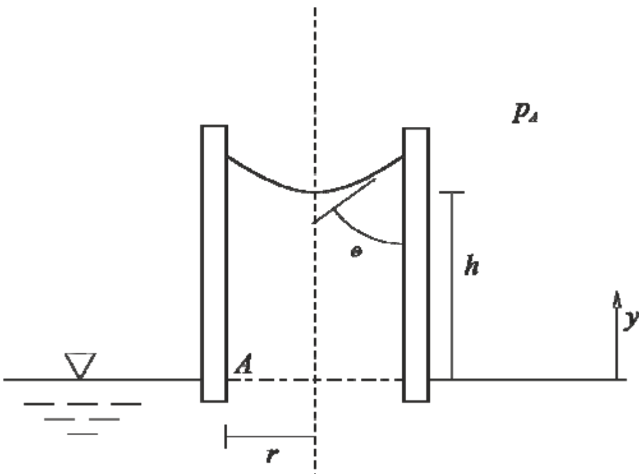


Fig. 2 Capillary action

If we assume a balance of forces in this construction, we get the following equation:

$$\underbrace{p_A \pi r^2 - p_A \pi r^2}_{=0} + 2\pi r \sigma_s \cos(\theta) - \rho g h \pi r^2 = 0 \qquad \text{(Eq. 1)}$$

If we transpose this equation for the radius of the pore, we get:

$$r = \frac{2\sigma_s \cos\theta}{\rho g h} \qquad \text{(Eq. 2)}$$

Now we replace the radius with the diameter to be found and assume a completely wetting fluid $(\theta = 0)$. In addition, we acknowledge that the expression in the denominator in Eq. 2 is a pressure. So Eq. 2 becomes:

$$d = \frac{4\sigma_s}{p_K} \qquad \text{(Eq. 3)}$$

We know from the derivation of Eq. 3 that this formula only applies for a cylindrical pore. To allow this simple correlation between pressure and pore diameter to be applied to any pore geometry, the usual practice is to introduce a correction factor C that comprises all the deviations from a perfect cylindrical form. The pressure in the denominator equals the measured pressure difference. So Eq. 3 simplifies further to:

$$d = C \cdot \frac{\sigma_s}{\Delta p} \qquad \text{(Eq. 4)}$$

The dimensionless correction factor C is also known in the literature as the capillary pressure constant. The ASTM F316 standard, for example, stipulates the constant for membranes as 2860, for Δp in Pa and σ_s in mN/m. In this way, an equation was established that translates measured pressure values into pore sizes. But because, by definition, the capillary pressure constant is only valid for one specific pore geometry, it has to be recalculated for each different pore shape. This procedure is too time-consuming for the empirical approach. For this reason, up to now it is mostly averaged or estimated values that have been applied for the correction factor – values that sometimes exhibit large deviations of measured pore size from the real pore size.

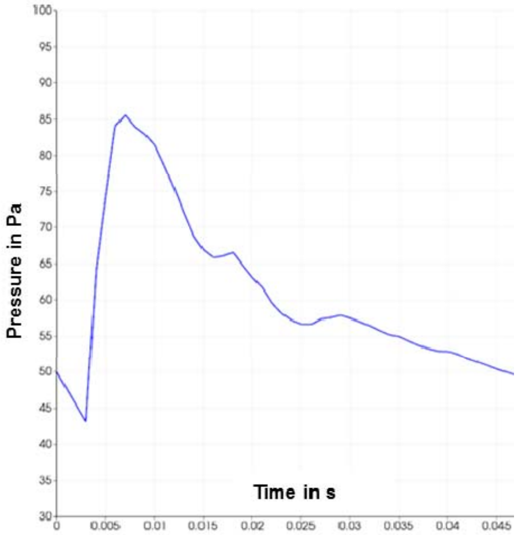
Modelling

The deviation that occurs through averaged capillary pressure constants is not acceptable for some mesh types, but has nevertheless been accepted up to now due to the lack of alternatives. This is what prompted the idea of creating a virtual simulation of the process of the bubble point test to allow conclusions to be drawn from the numerical experiment about the reality, and thus about the correct capillary pressure constant. The fact that the test is a multiphase system (air + test fluid) meant that the simulation would also have to be conducted as a multiphase simulation.

The computation library OpenFOAM was selected as the simulation tool. It already contains a wide range of multiphase flow solvers. To test the suitability of the solvers for the problem at hand, first a test simulation was created to replicate the bubble point test for a cylindrical pore. Because an analytical solution to the problem already exists, in the form of Eq. 3, deviations of the simulation from this solution can be easily identified. A simple geometry was selected consisting of a plate with a bore hole measuring 1 mm in diameter. This configuration was wetted with isopropyl alcohol as test fluid, and the test process calculated.

The results of this test simulation were very promising. The calculated pressure value for this test construction using the selected solver was 85.54 Pa, which by means of Eq. 3 translated to a pore size of 0.996

mm. In other words, the deviation in this test example between simulation and analytical solution was under 0.4 %, and the consistency of the selected solver was considered assured.



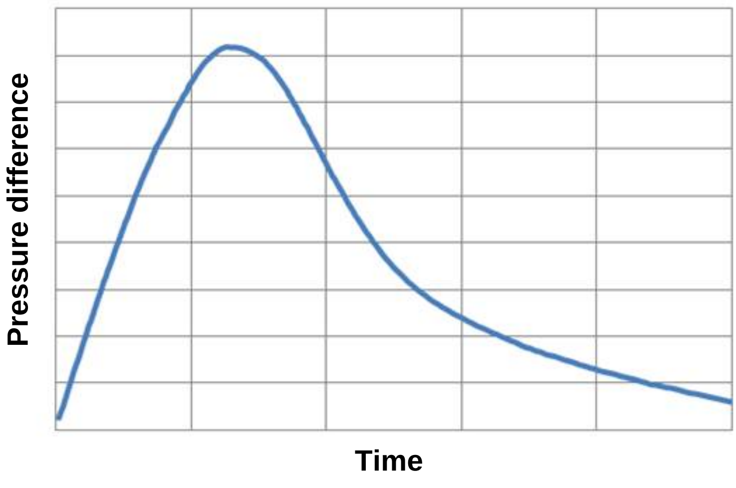


Fig. 3: Comparison of pressure curves for test simulation (top) and analytical solution (bottom)

The next step was to adapt the simulation to the substantially more complex geometry of woven wire mesh. The decision was made to develop the model on the basis of GKD's mesh family of optimised dutch weaves (OT), because the geometries occurring in these mesh types are still relatively simple, and also because lots of measurement data on them are available in the company's database. To generate the 3D mesh model, the WeaveGeo module of the software package GeoDict from the company Math2Market GmbH was used. With the meshing tool snappyHexMesh, which is integrated in OpenFOAM, an appropriate computational grid was created.

Simulation

Simulation parameters and boundary values were selected so as to achieve a modelling of the bubble point test that was as realistic as possible. The mesh in the simulation was wetted with isopropyl alcohol and then the pressure under the mesh was continuously increased by means of a constant airflow.

It turned out that the computational grid had an extreme effect on the runtime and stability of the simulation. As a result, a large portion of the model development work was devoted to the topic of grid generation. The outcome was that computation time was successfully reduced from an initial six weeks to approx. ½ to two days. The computation itself was performed on GKD's own in-house computer cluster. Here, 12 or 24 computation kernels are used, depending on the complexity of the model. The basic course of a simulation is shown in Figure 4.

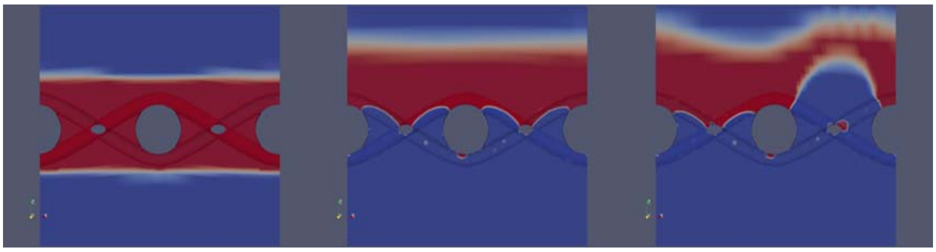


Fig. 4: Course of a bubble point simulation for an optimised dutch weave (OT 38)

After successful computation, the numerical model delivers a pressure value, just like the real measurement method does. The difference to laboratory measurement is that, here, the pore openings of the 3D mesh model are defined in advance through its known geometry. This was done using the GeoDict module PoroDict. The data now available are, first of all, a (simulated) bubble point pressure value, then the pore size determined using GeoDict, and finally the surface tension of isopropyl alcohol. With these parameters, Eq. 4 can be transposed to calculate the capillary pressure constant that matches to the simulated mesh. This calculated constant is then used in the real measurement method to determine the size of the largest pore.

Comparison of measurement and computation

To validate the results of the simulation, numerous tests were conducted in the laboratory with a range of different mesh types that had previously been simulated in the model. For measurement of the bubble point, GKD uses the Porometer PSM 165 made by the company Topas GmbH. Figure 5 shows example results for three tested mesh samples with different weaves. It is immediately noticeable that the deviation between the physically measured and numerically calculated value is very low. On average, the discrepancy is 1% to 2%, rising to 4% in individual cases. It is also evident that the calculated values are always slightly higher than those yielded by measurement. This is due to the fact that the tolerances in wire diameter manufacture and in the weaving process could not be taken completely into account in the generation of the mesh model. The largest pore in real mesh will always be slightly larger than the largest pore in the mesh model. Therefore, in line with Eq. 4, the physical measurement will always yield slightly lower pressure values than the numerical calculation.

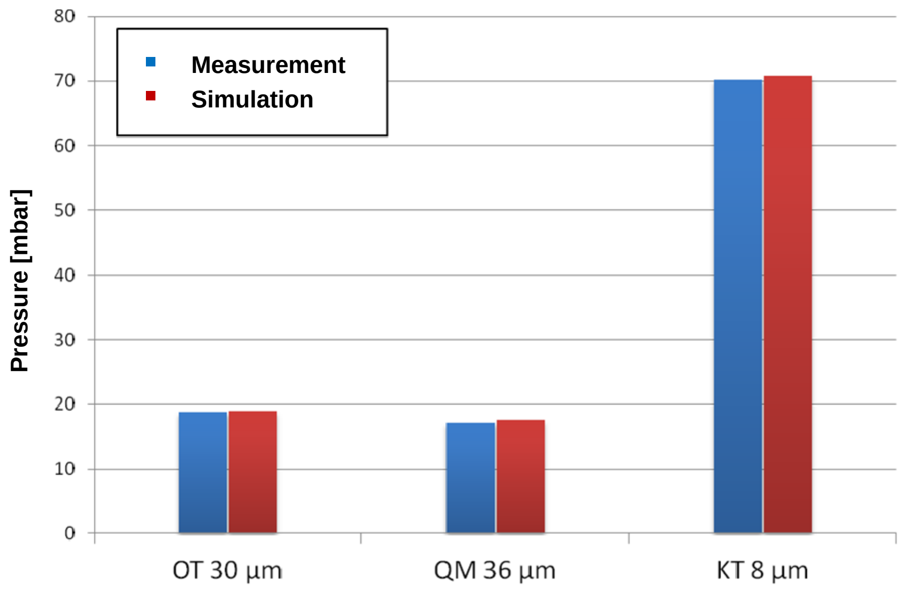


Fig. 5: Comparison of simulation results with measured values for different mesh types

The simulated pressure values and the respective apertures of the 3D mesh model were used to calculate capillary pressure constants for each mesh type. These correction factors were then applied in real experiments to determine the largest pore in the mesh by means of the bubble point test. The results here showed extremely high correlations to the pore sizes determined in screening experiments. Comparative testing with a particle counter yielded similar results (see Table 1).

Measurement method	Largest pore [µm]
Bubble point (numerically assisted)	7,42
Particle counter	7,26
Screening	7,50

Table 1: Comparison of different measurement methods with the improved bubble point method

In terms of quality assurance, the advantage of the bubble point method relates primarily to the time factor. Evaluation by means of a particle counter requires approx. three to four working hours; screening takes about 30 minutes. In contrast, measuring the bubble point and translating the measured pressure into pore size takes less than a minute.

Results and application of the model

With numerical computation of capillary pressure constants, GKD has acquired a powerful new tool for fast and efficient pore size determination that, compared to conventional methods, offers clear advantages, most of all in terms of time required. But numerical support of the bubble point test also facilitates unprecedented precision in the determination of pore size through this measurement method. Each different mesh type requires only a single computation to calculate the appropriate correction factor. The comparative experiments with the previously used method for empirical determination of the capillary pressure constant revealed something of particular interest. Due to the large number of measurements required to attain a reliable empirical value, in this conventional method the constant for a particular weave type was stipulated as an average value. Our evaluation of identical weave types with different pore sizes using the newly developed simulation revealed that the value for the capillary pressure constant within a particular weave type can in fact vary by up to as much as 100%. In other words, due to the linear characteristic of Eq. 4, pore size determined using the old, averaged correction factor could also, in the worst case, deviate by 100% from the opening that actually exists. The logical conclusion is that, if a correct statement about the actual pore sizes is to be made, an individual capillary pressure constant needs to be calculated for each single mesh type. Another conclusion from these findings is that pore size distribution – or pore portion (see ASTM E1294) – as measured with a fluid porometer like the PSM 165 requires optimisation. Woven wire meshes are extremely regular structures with defined pores. Nevertheless, in reality smaller fluctuations in pores size do occur due to production tolerances in the wire manufacturing and in the weaving process. To detect these fluctuations, the pore portion can be measured. Figure 6 shows the pore portion measured with standard settings of the porometer for a mesh type with a pore size of 20 µm.

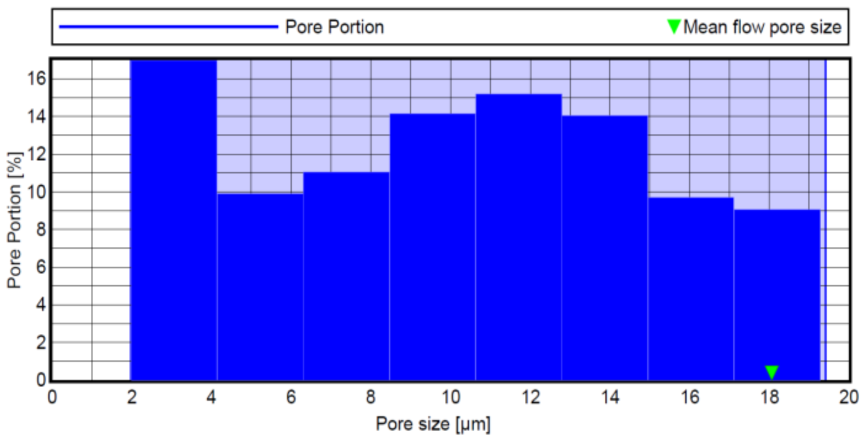


Fig. 6: Measurement of pore portion using standard settings

It is immediately obvious that the measurement is not physically plausible, as a mesh like this could never have pores with sizes of 16 µm or less. Instead, one would expect a tight distribution of the pores close to the nominal pore size of 20 µm. After helpful telephone conversations with the company Topas GmbH and thanks to the physical understanding gained through the simulation of the bubble point, this measurement method was promptly optimised and conducted again with a newly calculated capillary pressure constant. The result of this measurement is shown in Figure 7.

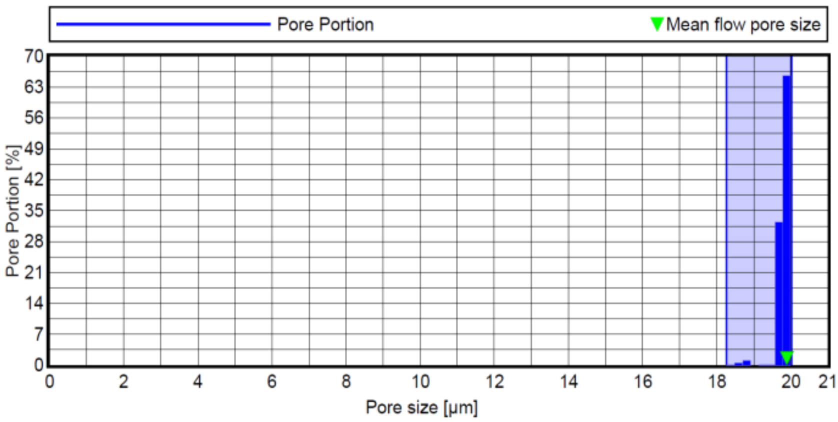


Fig. 7: Measurement of pore portion using improved method and adjusted capillary pressure constant

The measured pore size distribution now corresponds to the expected result. The majority of the pores are distributed tightly around the nominal pore size of 20 µm. The falsely detected pores from the previous measurement no longer appear in this measurement. The adjustments made were then transposed to the other mesh types, making it possible to demonstrate that the optimised measurement method can be applied to all mesh types, and that it supplies reliable results.

Outlook and further action

The knowledge acquired is already being applied at GKD in development processes. For example, the development process of the new, optimised dutch weave mesh type OT 6 was substantially supported by the simulation and the improved measurement methods. This made it possible during development to quickly and reliably identify problems as they occurred and to immediately eradicate them in the subsequent stage. Furthermore, the improved measurement methods have already been integrated into quality control at GKD to ensure faster and more efficient testing to the highest quality standards. Finally, product developments being custom designed for individual customers can now be tested for their bubble point before a single metre of mesh has been woven. Because the model works independently of the imported geometry, correction factors for all standard GKD weave types have been calculated that facilitate fast and, most importantly, precise pore size determination.

Nomenclature

Symbols

Symbol	Unit	Definition
C	-	Capillary pressure constant
d	m	Diameter
g	m/s²	Gravity
h	m	Height of meniscus
p	Pa	Pressure
r	m	Radius
θ	rad	Wetting angle of contact
ρ	kg/m³	Density
σ	N/m	Surface tension

Indices, subscript

Index	Definition
A	Atmospheric
K	Capillary
S	Surface

Abbreviations

Abbreviation	Meaning
KT	Twilled dutch weave
OT	Optimised dutch weave
QM	Square mesh

15.975 characters incl. spaces

GKD – GEBR. KUFFERATH AG

The owner-run technical weaver GKD – GEBR. KUFFERATH AG is the global market leader for metal and plastic woven solutions as well as transparent media facades. Under the umbrella of GKD the company combines four independent business units: Industrial meshes, Process belt meshes, Architectural meshes and Transparent media façades. With its six plants – including the headquarters in Germany and other facilities in the US, South Africa, China, India and Chile – as well as its branches in France, Great Britain, Spain, Dubai, Qatar and worldwide representatives, GKD is never far from its customers.

For more information:
GKD – GEBR. KUFFERATH AG
Metallweberstraße 46
D-52353 Düren
Tel.: +49 (0) 2421 / 803-0
Fax: +49 (0) 2421 / 803-233
E-mail: solidweave@gkd.de
www.gkd.de

Please send a reprint to:
impetus.PR
Ursula Herrling-Tusch
Charlottenburger Allee 27-29
D-52068 Aachen
Tel.: +49 (0) 241 / 189 25-10
Fax: +49 (0) 241 / 189 25-29
E-mail: herrling-tusch@impetus-pr.de