Operating & design

Improved accuracy in bubble point measurement

The bubble point test is widely used in filter media quality control. However, the correlation between pressure and pore size is only valid for cylindrical pores. To determine pore size with other shapes, correction factors need to be applied.

Up to now, the pore size has been determined empirically or simply, by estimation. This paper describes a method which uses CFD simulations to determine a more accurate correction factor and thus a more precise pore size.

Introduction

The bubble point test is a standard test for the 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. Because of the numerous assumptions involved, the correction factor is very imprecise. To enable a truly precise statement on real pore size, the company GKD - Gebr. Kufferath AG used numerical methods. These multiphase models made it possible to establish reliable values for the required correction factors.

Theoretical fundamentals

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

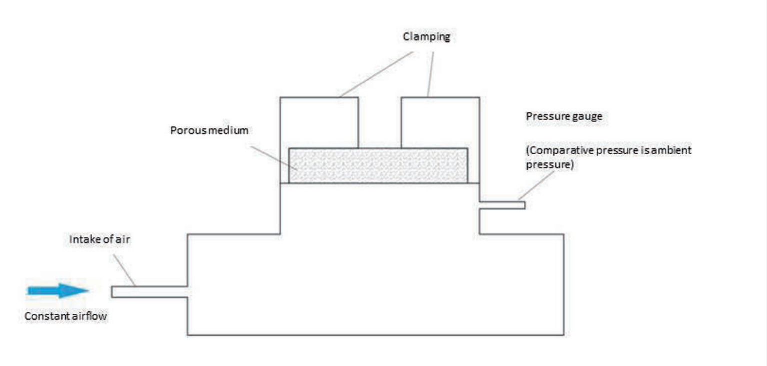

Figure 1: Schematic diagram of the bubble point test.

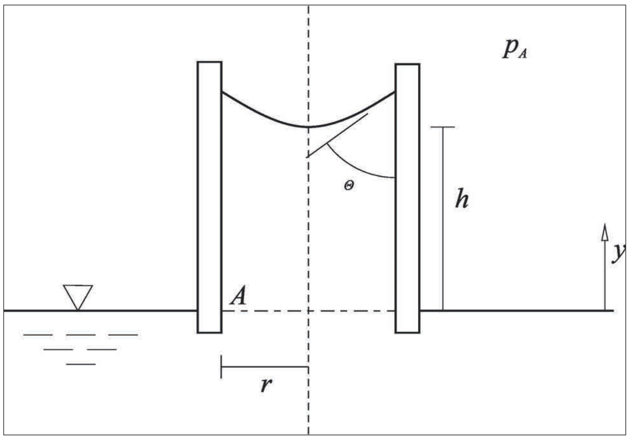

Figure 2: Capillary action in the cylindrical pores.

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 as 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).

We assumed a balance of forces in this construction and got the following equation:

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

When we transposed this equation for the radius of the pore, we got:

$$r=\frac{2\sigma_s\cos\theta}{\rho g h}$$

We then replaced the radius with the diameter to be found and assumed a completely wetting fluid (θ=0). In addition, we acknowledged that the expression in the denominator in Eq. 2 is a pressure. So Eq. 2 becomes:

$$d=\frac{4\sigma_s}{pK}$$

We know from the derivation of Eq. 3 that this formula only applies to 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:

$$d=C\bullet\frac{\sigma_s}{\Delta p}$$

The dimensionless correction factor C is also known as the capillary pressure constant. The ASTM F316 standard, for example, stipulates the constant for membranes as 2860, for Δp in Pa and 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 had to be recalculated for each different pore shape. This procedure was 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 which consisted 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 certain.

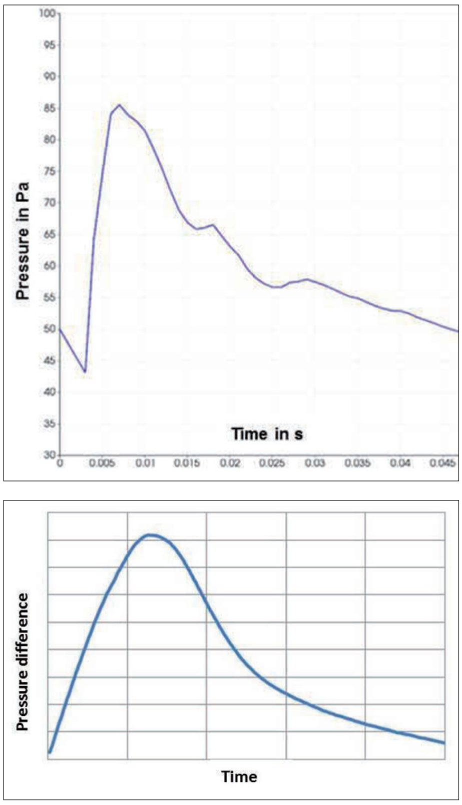

Figure 3: Comparison of pressure curves for test simulation (top) and analytical solution (bottom).

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 (ODW), because the geometries occurring in these mesh types are still relatively simple, and also because lots of measurement data on them is 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