Porous ceramic and its application as filtering material  
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This article provides an overview of the design and structure of filter elements made of porous ceramic. Using the example of some select filter elements, the difference between varying types of filter elements are described in more detail and examples for application in gas and liquid filtration are presented.

1. Introduction
The use of porous ceramic as filter material has a long history. Since the 1920s, ceramic filter elements have been used in industrial gas and liquid filtration. At the beginning, porous ceramic was applied in the shape of filter disks or stones, later on in the shape of filter candles, a true innovation at that time. Today, filigree ceramic honeycomb or foam elements as well as ceramic hollow fibre and multi-channel structures are also being applied as filter elements. Due to their advantages, above all the excellent temperature and chemical resistance, high degree of durability as well as their outstanding filtration performance, ceramic has maintained its place in filtration to this day.

2. Ceramic filter elements
There are a large number of different ceramic filter elements that differ with respect to design, structure, material and geometry. Filter ceramic may consist of grain ceramic, fibre ceramic or compound ceramic – a fibre compound embedded in a grain matrix. The porosity ranges from approx. 40% with pure grain ceramic up to approx. 90% with pure fibre ceramic. Due to the fibre structure, fibre elements have a very larger inner surface besides their high porosity as well as a low flow resistance. Fig. 1 shows as an example the structure of a fibre ceramic consisting of aluminium silicate fibres providing a high dirt holding capacity inside. They have good fracture toughness as a result of their loose structure, but their mechanical strength is relatively low. When using these for gas cleaning with backpulsing for cleaning off dust, the process has to be performed in such a way that no fibres become detached from the structure.

Grain ceramic has a mechanically stable and strong structure. The pore size and distribution is defined by the selection of the structure grain. Depending on the applied structure grain and binding phase, it is possible to produce structures with smooth, very permeable pore channels, which are suited as membrane support, for example, or a rather labyrinth-like pore structure with a rough surface that promotes the separation of fine particle or drops inside the structure. The scanning electron microscope images in Fig. 2 and 3 show examples of such structures. There are filter elements with symmetric or asymmetric structures. With a symmetric structure, the pore size is distributed evenly throughout the entire material. Contrary to this, one or several layers with small pore sizes are applied to the basic material with asymmetric structures (see Fig. 4). With their finer pore size, these layers separate smaller particles. At the same time, an as thin as possible layer structure on the basic element reduces the total pressure drop. A thin layer thickness that just about allows the defect-free coating of the basic element is optimal. Asymmetric structures allow higher throughputs at low pressure drop and higher filtration grade and high mechanical stability at the same time.

The filter materials mainly used consist of aluminium oxide, siliccon carbide silicate, cordierite, mullite, chamotte and technically pure carbon. The geometry of the ceramic filter elements ranges from cylinders, candles, sleeves, plates, cassettes, disks, mono and multi-channel pipes up to honeycomb or foam structures.

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Characterised according to the respective application, we distinguish between surface, precoat and depth filter elements as well as coalescers and ceramic membrane filter elements for cross flow filtration. The design and structure of the ceramic is selected according to the application. For example: a depth filter has a more open and coarser pore structure on the surface to allow particles to penetrate in depth. A surface filter on the other hand preferably has a tighter pore size distribution and fine pores on the surface to only separate the particles on the surface and prevent in depth penetration.

The filtration properties of the filter elements depend on the fineness of the applied material and the structure formed with this as well as on the applied material itself. With specially designed membrane filter elements, it is possible to achieve filtration grades in the nanofiltration range of less than 5 nm in liquid filtration. Ceramic ultrafiltration (UF) and microfiltration membranes (MF membranes) achieve filtration grades from 0.005 to 2 μm. With correspondingly coarser structures, the filtration grade in liquid filtration ranges to some 10 μm or even higher. In gas filtration, the typical filtration grades extend to the submicron range.

The range of temperature resistance of ceramic filter elements varies depending on the material. Temperature resistance up to 1000 ºC and above are possible. The chemical resistance covers the entire pH spectrum from 0 to 14 depending on the material. Each application case requires the right selection with respect to material durability, mechanical stability and filtration properties among the different ceramic filter elements available.

3. Application fields

In general, ceramic filter elements are used for all applications where high temperatures and/or chemically aggressive conditions are. Resistance to chemicals with respect to the application of cleaning agents and the attainable service life of the filter elements also make ceramic the material of choice.

Hot gas filtration is a prime example for the use of ceramic filter elements in gas filtration. For decades now, grain ceramic as well as fibre ceramic elements have been preferred in this field. The only alternative at such high temperatures are metal filter media. Due to the fact that the hot gas flows often contain sulphurous or chlorine components, chemical resistance is the decisive advantage of ceramic over metal filter elements.

Further application fields for ceramic filter elements in gas filtration are, amongst others, filtration of process gases, e.g. steam and other vapours, as well as of oxygen and hydrogen. Ceramic filter elements are also applied in mixed gas filtration for producing nitric acid. Other application fields for ceramic filter elements are: recycling of catalysts in chemicals production processes, filtration in digester gas production and filtration of compressed air. Ceramic filter elements are also successfully used as coalescers for separating aerosols from gas flows at higher gas temperatures or with more aggressive gas media.

In liquid filtration, ceramic filter elements are also used in many different processes. Main criteria for the selection of ceramic filter elements are above all resistance to chemicals and cleanability. Application fields are, amongst others, filtration of the most varied chemicals as well as of process water, wastewater and water. Furthermore, ceramic filter elements are used to separate and recycle catalysts from liquid chemical products production processes. One main application field for ceramic membranes is oil/water separation. For example, ceramic precoat filters are used for the polishing filtration of brine in chlorine-alkali electrolysis.
4. Examples of ceramic filter elements

Using some select filter elements that differ with respect to the ceramic material, their structure and design as well as their filtration properties and application fields, an impression of various ceramic filter element types shall be provide.

4.1 Grain ceramic hot gas filter element

The ‘Dia-Schumalith’ hot gas filter element by Pall Corporation has an asymmetric structure consisting of ceramic grains. A fine-filtering membrane consisting of fine mullite grains is sintered on to the flow side of the coarsely porous carrier element consisting of silicon carbide grains. Membranes with different degrees of fineness are available. These are selected according to application case and required separation capacity. The combination of carrier element and membrane ensures a low differential pressure at high filtration grades and very good cleaning behaviour. The cleaning behaviour is of great importance for permanent and reliable operation, especially with respect to long-term stability of the filter elements. The average pore size of the carrier element is 50 μm. The membrane is applied with a thickness from 150 to 200 μm. The filter elements are available as cylinders or candles. They are preferably applied as candles with lengths between 1.5 and 2.5 m (see Fig. 5). The standard outer diameter of the elements is 60 mm, the inner one 40 mm. Dia-Schumalith filter elements are preferably used in hot gas filtration, especially because of their outstanding thermal shock resistance. As a result of continuous improvement and further development of the filter elements, these have a high mechanical strength, which is still outstanding at high temperatures. Due to the homogeneous structure of the fine-filtering membrane, it is possible to efficiently separate particles with sizes ranging down to 0.3 μm. It is possible to achieve clean gas concentrations of typically less than 1 mg/m³. The membrane achieves surface filtration. Once a corresponding pressure loss is reached due to the continuously growing filter cake, this is cleaned off and the filtration cycle starts anew. In gas filtration, the filter cake is cleaned off with a pressure pulse in the opposite direction of filtration. Cleanable surface filters are used in continuous processes with higher particle concentrations. Dia-Schumalith filter elements have proven to be successful worldwide over many years now in the most varied hot gas filtration applications. One example especially worth mentioning is their application in coal gasification /1/.

4.2 Carbon filter elements

One example of a filter element consisting of high-quality carbon is the Carbo filter element by Pall Corporation (see Fig. 6). The ‘Pall’ Carbo filter elements consist of different grain fractions, depending on the type. These are joined with each other via carbon bridges created through sintering at high temperatures. Due to the binder-free carbon structure, the filter medium has an outstanding chemical resistance and can be applied across the entire pH spectrum from 0 to 14. Carbo filter elements cover a broad application spectrum. Fine-pored Carbo filter elements with very smooth surfaces are especially suited for fine filtration with backwashing. The coarser types have a slightly rough surface to which filter aids adhere well. They are preferably used for precoat filtration with cellulose. One application focus here is on polishing filtration of brine in chloralkali electrolysis. The fully automatic backwashable precoat filters with Carbo filter elements are operated directly upstream from the ion exchanger and the membrane cell. Besides the good adhesion of the filter aid to the filter elements, the Carbo elements also guarantee even perfusion of the elements and thus even build-up of the precoat layer across the entire length of the filter elements. The rigid structure of the ceramic elements rules out a shape change of the precoat layer at rising differential pressure during the filtration cycle and thus the formation of cracks in the layer. Particles larger than 0.3 μm are separated up to a concentration of less than 0.5 ppm in the brine. Carbo filter elements are in successful application throughout the world in over 300 precoat filtering plants for brine polishing filtration.

4.3 Ceramic membrane filter elements

Ceramic membrane filter elements preferably consist of a carrier element made of pure α-Al2O3, the chemically stable form of alumina. The membranes consist of Al2O3, ZrO2 or TiO2, depending on the pore size. With a finely tiered, multi-layer membrane design (see Fig. 7), it is possible to produce ceramic membrane filter elements with pore sizes that cover the entire range of micro and ultrafiltration. The mostly tubular single and multi-channel filter elements are suited for cross flow filtration applications under abrasive or chemically aggressive conditions. The range of pH stability normally covers 1 through 14. The filter elements are above all distinguished by their high selectivity. The high temperature resistance compared to polymer membranes open up additional interesting application possibilities. The filter elements are available with different channel diameters of e.g. 2.8 to 16 mm. Newer developments aim at increasing the packing density of the channels and thus the filtration surface density. For example: tubular multi-channel elements are available with an outer diameter of 41 mm and 61 single channels (hydraulic channel diameter: 3.1 mm) and a filtration surface of 0.75m²/element at a length of 1.2 m (‘Schumasiv’ 1 61/3.1 filter element produced by Pall Corporation).

Schumasiv ceramic membrane filter elements by Pall Corporation (see Fig. 8) have been in successful application for years, amongst other things in the most varied processes for oil/water separation. Examples for this are: processing of compressor condensate and cooling lubricants, cleaning of oily rinsing baths and wastewater, as well as increasing the service life of cleaning and degreasing baths. Further application focuses can be found in water treatment, filtration of enamels, paints and lacquers, recycling of catalysts as well as filtration of acids and alkalis. Furthermore, they are also applied in the food, beverage and pharmaceutical industry.

Literature: