# High-performance Ceramic in Electromagnetic Flowmeters for Applications in the Chemical Industry

**The chemical industry relies on tried and true measuring technology to measure the volume flow of electrically conductive media: well over 3 million electromagnetic flowmeters (EMF) are in use all over the world. The demands placed on devices are extremly stringent in this field of application.**


*Fig. 1*
*OPTIFLUX 5300 electromagnetic flowmeter with measuring tube made of oxide ceramic (flange version)*

### Introduction

The demands placed on flowmeters used in chemical plants are much more stringent than those in the water industry, for example. In addition to the electronics, the design and measuring tube material are crucial when it comes to determining whether the EMF is suitable for use in chemical processes. The following properties of the measuring tube material are particularly relevant:

- Corrosion resistance to aggressive media
- Form stability
- High resistance to thermal shock
- Vacuum resistance, form stability with under/over pressure
- Resistance to abrasion
- Diffusion tight
- Leakage immunity.

Even if not normally the case, sometimes with certain tasks such as measuring nitric acid, several of these properties are required at the same time. The PFA and PTFE linings typically used for EMFs are not adequate in this case as they are not acceptably resistant to diffusion. For this reason, EMFs with measuring tubes and measuring tube liners made out of ceramic materials have been available for decades for this type of application. *KROHNE Messtechnik* was a pioneer in this area, introducing the first ceramic device as early as 1982. Since then, and in close cooperation with Mannheim-based *FRIATEC AG*/DE, KROHNE has been constantly perfecting the ceramic measuring tubes for the various fields of application. KROHNE currently offers a variety of different device types featuring ceramic measuring tubes: in addition to their use with acids and bases in chemistry, the flowmeters used in bottling machines in the beverage industry are almost exclusively equipped with ceramic measuring tubes. This is where another of the ceramic properties comes into play: extraordinary low surface roughness means good hygienic suitability.

### Flowmeter design

The OPTIFLUX process measuring devices used in the chemical industry (Fig. 1) feature measuring tubes made of oxide ceramics with a base of aluminia or zirconia. The electrodes are mainly platinum but depending on the application, other materials (hastelloy, titanium, tantalum) are also used. Variants without wetted metal electrodes, so-called capacitive EMFs, are also available.

To understand the special properties of ceramic measuring tubes, you must first understand their design: a measuring tube is a single rotation-symmetric piece from

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*Fig. 2*
*Oxide ceramic powder is poured into a mold*

*Fig. 3*
*The powder is placed under high pressure and compressed into a cylinder*

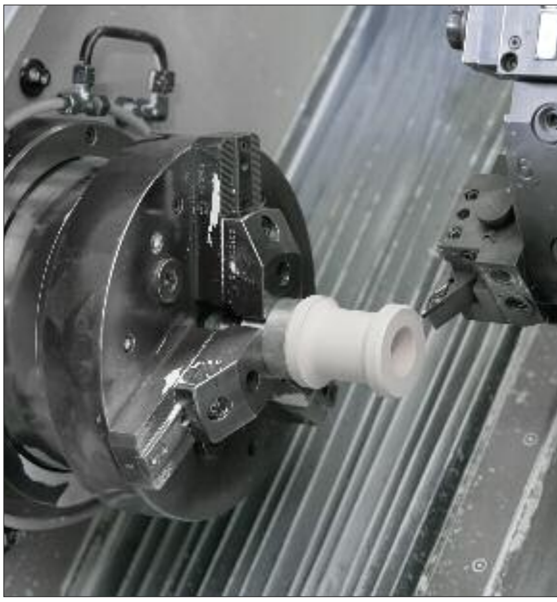

*Fig. 4*
*The shape of the measuring tube is mechanically carved out by green machining*

face to face. It is manufactured as if it were a cast piece. This holds true for nominal sizes up to DN 300, sizes above that are lined with ceramic plates.

**Production of ceramic components**

The starting material for the measuring tubes is an aluminia or zirconia powder featuring special mineral quality (Fig. 2) which is pressed into a cylindrical shape (Fig. 3) under pressures >1000 bar. The cylinder is then machined into the shape of the measuring tube (Fig. 4). It is sintered above 1700 °C in an elaborated process (Fig. 5), during which the ceramic shrinks to the pre-calculated size. The hardened measuring tube is now the desired basic size and any continued processing such as machining the outside diameter, end faces and inlet taper is only possible with a diamond-tipped tool (Fig. 6). Following quality control (Fig. 7), it is ready to be installed into the EMF.

This brief description does not come close to reflecting the extreme amount of effort and long years of experience and expertise necessary to manufacture high-performance ceramic. One example of the numerous innovations resulting from the cooperation of FRIATEC and KROHNE is the fused-in-place cermet electrode: when inserting the electrode containing precious metal into the ceramic measuring tube, the goal is to unite two different materials with as little gap as possible and in such a way as to ensure that temperature shocks cannot cause any damage. A leak at this position could mean a safety concern and increased costs, depending on the measured product. To begin with, two holes are made in the ceramic raw form and the electrode is inserted like a massive pin, the

*Fig. 5*
*The ceramic components are sintered in the kiln*

*Fig. 6*
*Final finishing touches to the measuring tube*

*Fig. 7*
*Quality control of the finished measuring tube (pictured: helium leak test)*

ceramic then shrinks during sintering. The result is a leak-free compound of two materials.

Due to the technical complexity of inserting the pins properly, both companies joined together to look for a solution, finding it in the form of the cermet electrode. A cermet electrode is a composite component made up of ceramic and metal, in this case platinum. Two of these electrodes are already integrated into each green body. During the fusing process, the ceramic portion of the electrode bonds to the surrounding ceramic while the platinum is optimally embedded as regards thermal and electrical properties. The result is a homogenous ceramic fusion zone with no potential gap (i.e. no leakage point) between the measuring tube and the electrode (Fig. 8–9).

**Properties of flowmeters with ceramic components**

This type of manufacturing justifies many of the features of the OPTIFLUX ceramic EMF, which are so valued in the chemical industry. The combination of accuracy, repeatability, robustness, long-term stability and process reliability is unsurpassed amongst process measuring devices.

The long-term stability (i.e. accuracy over many measuring cycles) of the measuring tube is achieved thanks to the extraordinary form stability of the ceramic. Plastic coatings, on the other hand, are malleable, exhibit vacuum sensitivity and are by far not as resistant to wear.

The extremely high long-term stability of the ceramic devices was scientifically investigated during cooperative research between KROHNE and the *PTB (National Metrology Institute)*. During the tests, the devices tested for the food and beverage industry were subjected to a total of 600 simulated Cleaning-In-Process cleaning cycles, one after the other, followed by another 60 sterilisations with hot steam (SIP) (extreme temperature change). That corresponds to a device life of approximately 4–5 years in average operation. The tests showed that the ceramic devices had an average deviation of only 0,05 % compared to the tests in new condition and also featured stable repeatability at various flow rates (Fig. 10). The average deviation compared to the new condition was 8 times higher with measuring tubes with plastic liners.

The high geometric stability is one of the main reasons the OPTIFLUX 5300 is so widely used as a reference device/Master-Meter in flow measurement plants in national institutions, measurement offices, nationally recognised testing bodies and notified bodies. Sterilisation with hot steam (SIP) exceeds the temperature changes of over 100 K commonly found in processes in the chemical industry. Thanks to the skilful adaptation of the thermal expansion properties of the measuring tube and cermet electrode, the material bond easily withstands this stress.

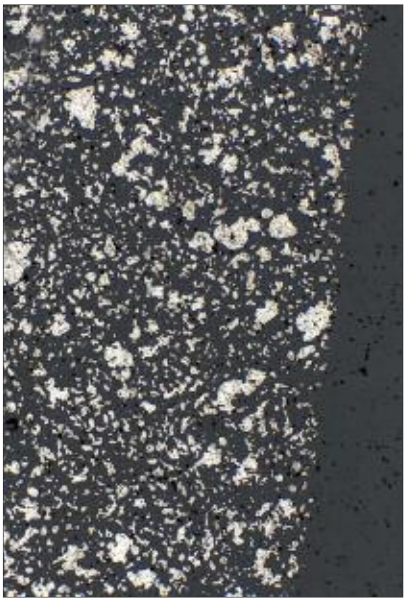

*Fig. 8*
*SEM image of fused-in-place cermet electrode: the light points (platinum) are the only way to recognise that there are two different materials (left)*

*Fig. 9*
*Finished ceramic measuring tube prior to installation into the EMF. The black dot represents the fused-in-place cermet electrode*

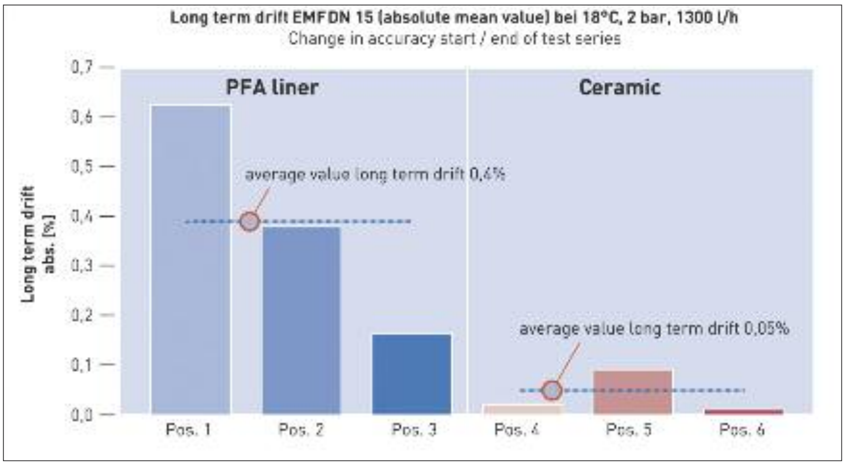


*Fig. 10*
*Test series regarding accuracy changes, average deviation from new condition*

with flanges available on the market. Thanks to the shorter screws (less expansion upon heating), the flange version offers a high degree of fire resistance as dangerous products do not leak out at connection points if a fire occurs. The flange version of the OPTIFLUX 5300 is the only measuring device with ceramic measuring tube to feature a Pressure Equipment Directive 97/23/EC with individual approval for zirconium oxide (FRIALIT FZM) and on top of that has design approval for DN 15 to DN 300 from *TÜV Rheinland*/DE. For the first time, this enables the chemical operator to use a ceramic EMF as per the Pressure Equipment Directive. This means, the operator does not have to run his own test and can reduce costs.


*Fig. 11*
*OPTIFLUX 5300 measures highly abrasive magnesium hydroxide sludge*

Burst tests proved that the measuring tubes with just 2 mm wall thickness could withstand over 600 bar, and those with 4 mm more than 1000 bar internal pressure – a result of the consistent application of the finite element method (FEM). Checking the break lines after the break tests showed that there was no specific nucleation site for the formation of cracks, neither near the fused-in-place electrodes nor in the rest of the measuring tube.

Additional material testing procedures included tensile and compression as well as corrosion tests. The strength when it comes to tensile loads was close to the value of steel. The high compression strength is one of the outstanding properties of this ceramic. That is why the measuring tubes are robust when it comes to withstanding the mechanical loads placed on them during installation and operation in chemical plants.

An application example illustrates the abrasion resistance of the virtually diamond hard ceramic: the Dutch company *NEDMAG Industries Mining and Manufacturing B.V.* is Europe's leading manufacturer of ultrapure synthetic magnesite (DBM: dead burned magnesia). DBM is mainly used in refractory applications such as liners in blast furnaces. When producing DBM, magnesium hydroxide sludge with 53 % solid content is also created. To further process this extremely abrasive sludge, its flow rate must first be measured. Since a PFA or PTFE liner would fail in a short time in this case, an OPTIFLUX 5300 with ceramic measuring tube was used (Fig. 11).

And when it comes to corrosion resistance, the requirements of the chemical industry are extremely high: to equip standard processes and new production routes, we rely on ceramic because other materials are not sufficiently durable or require expensive special materials. KROHNE offers a comprehensive list of corrosion resistance for its EMFs with ceramic measuring tubes.

To further increase process reliability, EMFs with ceramic measuring tubes are available in both sandwich (DN25…100) and flange versions (DN15…300). The OPTIFLUX 5300 is the only ceramic EMF

**Conclusion**

Electromagnetic flowmeters with ceramic measuring tubes boast unrivalled high performance, particularly in the chemical industry. Thanks to the unique combination of material properties such as surface hardness and finish, mechanical strength, resistance to corrosion and temperature change, the operator benefits from the extreme accuracy and long-term stability as well as vacuum and diffusion resistance. The chemical industry's own requirements concerning process reliability, longevity and durability are met perfectly.