Method and device for measuring dielectric properties of a fluidum using dipole antenna and / or wave guide cavity technology

The present invention relates to a method and device for measuring the dielectric properties of a fluidum containing at least 10 percent by volume of a fluid, characterized by a function generator and a spectrum analyzer or rectifier, both connected to at least two dipole elements working as a dipole antenna and / or a wave guide cavity, whereby said dipole elements are at least partly separated by the fluidum under investigation. An amplitude versus frequency plot (A-f plot) is made and the shape of the A-f plot relects the complex dielectric properties of the fluidum under investigation. More specifically, the present invention relates to the use of industrial piping systems and printed circuit board constructions for inline measurement of the dielectric properties of a fluidum in a reproducible and cost effective way.

Introduction

The present invention relates to a method and device for inline measurement of the properties of a fluidum, without the use of chemicals, using the physical principles of dipole antenna and transmission line technology. More specifically, the present invention relates to a method and device to measure the dielectric properties of fluids, fluid - solid suspensions, fluid – gas suspensions and solid – gas suspensions. Even more specifically, the present invention relates to a method and device to assess the properties of water, such as drinking water, waste water and industrial process water.

Many prior art methods to determine the quality of drinking water, process water and industrial water are labor intensive, require the use of chemicals for chemical and / or biological analysis and are offline. As a result, many prior art water analysis techniques are expensive and introduce a time delay before measurement information is available.

A promising technique to track changes in the quality of a water stream is to asses its dielectric properties. Existing prior art methods to measure the dielectric properties of a solution are based on classic capacitance measurements in discrete elements such as a plate capacitor. These methods are offline and suffer from relatively large parasitic capacitance and / or parasitic inductance, thereby limiting the sensitivity of the measurements, and / or require a relatively complex measurement set-up, involving relatively high investment cost. A recently developed technique for inline measurement of the dielectric properties of fluids is based on transmission line technologie. A fluid sample is applied as dielectric in a transmission line resonator, such as a coaxial stub resonator or a stripline resonator. Subsequently, the electric properties of the transmission line resonator, further on referred to as stub resonator, are characterized by an amplitude versus frequency plot, further on referred to as A-f plot. The shape of the A-f plot is determined by the dielectric properties of the fluid under investigation. By the use of transmission line theory i.e., by solving the telegrapher's equations, the dielectric properties of a fluid i.e, its dielectric permittivity and loss tangent as a function of frequency, can be derived directly from the A-f plot. More qualitatively, an A-f plot provides a fingerprint of the fluid and can be used to track changes of the fluid composition and to use these changes in an early warning system.

The technology according to the present invention deals with a unique combination of dipole antenna technology and wave guide technology, resulting in a very sensitive and specific sensor system operating in a broad frequency range. The sensor technology according to the present invention is feasible for application on large scale i.e., for inline measurement of dielectric properties of a fluidum in piping systems in process industry as well as for application on very small scale i.e., for inline analysis of small fluid samples using printed circuit board (PCB) technology.

Description of the technology according to the present invention

According to a first aspect, the present invention relates to a function generator FG. This function generator preferably produces a sinus or square wave electrical signal with a frequency that can be adjusted in the range between 1 Hz and 50 GHz.

According to a second aspect, the present invention relates to a spectrum analyzer or a hf (high frequency) rectifier SA, preferably able to measure the amplitude of a sinus or square wave electrical signal with a frequency in the range between 1 Hz and 50 GHz.

According to a third aspect, the present invention relates to a first dipole element connected to the first electrical connection point of both the function generator and the spectrum analyzer or rectifier.

According to a fourth aspect, the present invention relates to a second dipole element connected to the second electrical connection point of both the function generator and the spectrum analyzer or rectifier.

According to a fifth aspect, the present invention relates to a volume, at least partly filled with the dielectric under investigation, that is placed between the first dipole element and the second dipole element.

According to a sixth aspect, the present invention relates to at least a microcontroller that is connected to the function generator and / or the spectrum analyzer or rectifier and that is equipped with software for automatic measurement of an amplitude versus frequency plot.

Now that the main aspects of the technology according to the present invention have been explained, a number of embodiments of the technology according to the present invention will be explained.

In a first preferred embodiment, the technology according to the present invention relates to a first conductive metal or metal coated cilinder, that can be filled with a fluidum and that is used as a first dipole element. The first conductive cilinder is on one end connected to a second non conductive cilinder. The other end of the second non conductive cilinder is connected to a third conductive cilinder which has preferably the same length as the first conductive cilinder. Subsequently, the fluidum under investigation is pumped through the series of the first conductive cilinder, the second non conductive cilinder and the third conductive cilinder. Figure 1 gives a schematic overview of the construction according to this first preferred embodiment. For the first preferred embodiment, the numbers 1 and 2 in figure 1 should be ignored. Number 3 relates to the fluidum under investigation that is pumped through the series of cilinders. Number 4 stands for one of the connection points that are to be connected with the function generator and the spectrum analyzer. For the sake of completeness, it is mentioned that the function generator, the spectrum analyzer or rectifier and the dipole construction according to figure 1, are preferably electrically connected in parallel. By the use of at least a microcontroller and software, an A-f plot is automatically produced. Since the properties of the dipole antenna depend on the dielectric between the first conductive cilinder and the second conductive cilinder, the shape of the A-f plot reflects the dielectric properties of the fluid under investigation. It is noted that below at critical length of the second non conductive cilinder, the series of the first, second and third cilinder not only perform as a dipole antenna but also as a wave guide cavity whereby the cavity is supplied with energy through the function generator. Since the resonant frequency of the wave guide cavity is different from that of the dipole antenna, the system will have a large number of resonant frequencies. This results in a sensor that is very feasible for impedance spectroscopy and determination of the complex dielectric properties of the fluidum under investigation, resulting in a much more detailed fingerprint of the fluidum under investigation than a separate dipole or a separate cavity. Finally, it is noted that the wave guide cavity, as a resonator according to the first preferred embodiment, has very interesting properties towards conductive or slightly conductive media. On one hand, the conductivity of the fluidum under investigation will result in an improved performance of the cavity resonator since the second non conductive cilinder (the middle section in figure 1) will behave more like a wave guide since it has "conductive walls due to the conductivity". On the other hand, the quality factor of the cavity resonator will decrease as a result of dielectric losses in the resonator. This at first sight unexpected behavior, appears to make the system according to the first preferred embodiment very reponsive to different conductive dielectrics in a broad conductivity range. A second effect is that the response of the dipole antenna to conductivity is different from that of the cavity resonator and that the differences in response between dipole antenna and cavity resonator are also frequency dependent. As a result, the A-f plots obtained with the system according to the present invention provide very specific fingerprints of a dielectric. Finally, it is noted that the efficiency of the cavity resonator is determined by wave reflections at the end of the cilindrical ends of the cavity. Placing a conductive wall at both ends of the cilindrical cavity, such that its ends are at least partly covered with a conductive surface, will drastically increase the quality factor of the cavity resonator. Placing any kind of conductive wall at one end of the cavity resonator or at both ends of the cavity resonator such that its surface is perpendicular to the axial length coordinate of the cavity cilinder, expressly is part of the technology according to the present invention. A practical way to realize a conductive wall for reflection of electromagnetic waves in the cavity is to mount a perforated metal plate at either one end or both ends of the cavity resonator. In this case, the fluidum can flow through the perforated holes so that the sensor can still be used as an inline flow through sensor. Also bending or narrowing of the cilinder near its ends may result in the desired reflections. It is noted that both the design with reflection layer and without reclection layer are part of the technology according to the present invention.

In a second preferred embodiment the cilinders in the system according to the first embodiment are filled with particles, see also figure 2 in which number 5 stands for particles. These particles preferably consist of glass beads, polymer particles or ion exchange resin. In case of glass beads, the sensor can be used as a biofilm monitor for fluid flowing through the sensor. In case a biofilm is formed on the glass beads, the sensor will detect a change in dielectric properties of the dielectric in the cilinders. Since the biofilm contains organic components, a capacitive cell membrane and adds frequency dependent conductivity to the fluidum in the cilinders, the sensor system according to the present invention will produce a detailed and unique fingerprint (A-f) plot of the system with biofilm. An additional advantage of using glass beads is that samples of the glass beads can be taken. The glass beads can be analyzed on the presence of biomass on the surface using a light microscope or by analyzing the concentration of ATP on the glass surface. By relating different ATP concentrations to the corresponding A-f plots, the biofilm mass on the glass beads can be determined quantitatively as a function of time from automatically measured A-f plots. Analogously, the cilinders in the system according to the first embodiment can be filled with ion exchange resin, so that the load degree of ion exchanges resin can be determined quantitatively as a function of time from automatically measured A-f plots. In case the cilinders in the system according to first embodiment are filled with polymer particles, such as macroporous polypropylene polymers, chemical compounds can be absorbed by the particles or can adsorp onto the particle surface. As a result, it is possible to detect traces of pollutants in water and to measure the concentration of these pollutants in water as a function of time. It is noted that also a coaxial stub resonator can be filled with glass beads or polymer particles or ion exchange resin. In case a coaxial stub resonator is filled with glass beads, it can be used as a biofilm monitor as well. By taking samples of the glass beads as described above, a quantitative relation can be determined between the biofilm mass in the coaxial stub resonator and the shape of the A-f plot, obtained when the coaxial stub resonator is connected to a function generator and a spectrum analyzer or rectifier. Application of a coaxial stub resonator filled with glass particles as a biofilm monitor with sampling possibilities, expressly makes part of the technology of the present invention.

In a third preferred embodiment of the present invention the fluidum under investigation is not pumped through the series of the first conductive cilinder, the second non conductive cilinder and the third conductive cilinder. Instead, the second non conductive cilinder is left out of the system, see also figure 3. The dielectric under investigation is pumped between the first conductive cilinder and the second conductive cilinder, see fluid flow number 3 in figure 3. Both cilinders in figure 3 refer to the the dipole conductors. Number 5 in figure 3 stand for the connection points of both dipole conductors.

In a fourth preferred embodiment of the present invention, a suspension of particles is pumped between both dipole conductors, see also figure 4. Number 6 in figure 4 stands for a particle.

In a fifth preferred embodiment of the present invention, the system in figure 3 is immobilized in a cube by adding a resin, such as a polyurethane resin to it. Subsequently, a hole indicated as number 4 in figure 3 is drilled into the cube such that fluid flow number 3 becomes possible.

In a sixth preferred embodiment of the present invention, the system in figure 1 is realized by stacking printed circuit boards. For this purpose metal plated cavities are made in a series of PCBs. Each PCB has the metal plated cavities at exactly the same coordinates. Around each metal plated cavity, a first metal connection point is present, whereby said first metal connection point is galvanically connected to the first metal plated cavity, and located on the PCB surface and around the metal plated cavity. By stacking the PCBs, a cilinder such as indicated with number 2 in figure 1 is obtained. Subsequently, a number of PCBs with cavities that are not metal plated and that are positioned on the PCB at exactly the same coordinates as the metal plated cavities are added to the stack. After this, a number of PCBs with metal plated cavities is added to the stack. The result is a series of a first metal plated dipole cilinder, a second non metal plated dipole cilinder and a third metal plated dipole cilinder as shown in figure 1. It is noted that also this system can be used as a dipole antenna system and as a cavity at the same time, resulting in a very sensitive sensor system. The wire connections such as indicated by number 4 in figure 1, can, for example, be a wire in the last PCB of the stack PCBs forming the first metal plated dipole cilinder and a wire in the last PCB of the stack of PCBs forming the third metal plated dipole cilinder. An important advantage of applying PCB technology to realize a sensor with the technology according to the present invention is the high reproducibility an cost effectiveness at which a sensor can be produced. The high reproducibility at which the sensor can be produced opens possibilities for miniaturization of the system. Since smaller sensor dimensions result in higher resonant frequencies, the measurements can be performed at relatively high frequencies providing extra information on the dielectric properties of the fluidum under investigation.

Now the technology according to the present invention has been explained in detail, a number of preferred application conditions is mentioned.

Preferably, the dipole is operated at a frequencies between 1 MHz and 10 GHz. Preferably, the wave guide cavity resonators are operated at a frequency between 10 MHz and 100 GHz. Preferably, all PCB connections are gold plated.

Non limiting examples of a fluidum feasible to be investigated with the technology according to the present invention are drinking water, waste water, food. The technology according tot the present invention is feasible for application in pharmaceutical industry, veterinary industry and biotechnological industry.

Clauses

1. Sensor for measuring the dielectric properties of a fluidum consisting for more than 10 percent by volume of a fluid characterized by
    - a function generator and
    - a spectrum analyzer or rectifier both connected with a first connection point to
    - a first dipole element consisting of a conductive metal or metal coated cilinder that is placed in series with
    - a second non conductive cilinder placed in serie with
    - a second dipole element consisting of a conductive metal or metal coated cilinder that is connected with a second connection point to the function generator and spectrum analyzer or rectifier
    - a fluidum under investigation that is present in or pumped through the series of the first dipole element, the non conductive cilinder and the second dipole element
    - at least one microcontroller connected to the function generator and the spectrum analyzer or rectifier equipped with software for automated measurement of amplitude versus frequency plots (A-f plots).
2. Biofilm monitor according to clause 1 whereby the series of the first dipole element, the non conductive cilinder and the second dipole element are filled with glass beads
3. Sensor according to clause 1 for measuring the load of an ion exchange resin whereby the non conductive cilinder and the second dipole element are filled with ion exchange resin.
4. Sensor according to clause 1 for fingerprinting of water whereby the non conductive cilinder and the second dipole element are filled with macroporous polymer.
5. Sensor according to any of the previous clauses 1 to 3 whereby the series of the first dipole element, the non conductive cilinder and the second dipole element are realized by stacking subsequently PCBs with metal plated cavities, PCBs with non conductive cavities and PCBs with metal plated cavities.
6. Method for measuring the dielectric properties of a fluidum consisting for more than 10 percent by volume of a fluid characterized by a sensor according to one of the previous clauses 1-5.