

# **Real-time non-distractive microwave sensor for nutrient monitoring in wastewater treatment.**

**Nisreen Al-Dasoqi, Alex Mason, Rafid Alkhaddar, Ahmed Al-Shamma'a.**

School of Built Environment, Built Environment and Sustainable Technologies  
Research Institute (BEST), Liverpool John Moores University, Liverpool, L3 3AF.

E-mail: n.al-dasoqi@2009.ljmu.ac.uk

**Abstract.** A real-time non intrusive microwave sensor system able to monitor the nutrients found in wastewater has been designed, simulated and implemented. These liquids are continuously flowing through a PTFE pipe and the properties of these liquids gradually degraded in time. Microwaves have the ability to give real-time changes in any material permittivity by means of changing the velocity of the signal, attenuating or reflecting it. The primarily measurements show promising results for future sensor developments which lead to a novel system that can be used in wastewater treatment plants.

## **1. Introduction**

Urban wastewater contains domestic and industrial wastewater with or without rain runoff [1]. In order to maintain a healthy environment and to control diseases this wastewater has to be collected and treated, protecting the environment from the adverse effect of wastewater. The main issue that wastewater treatment works face is how to detect the low concentrations of nutrients before discharging the treated wastewater. In recent years the wastewater treatment industry has suffered from a lack of reliable and efficient tools which support on line measurement of a number of important parameters such as pH, Chemical Oxygen Demand (COD), Biochemical Oxygen Demand (BOD), Chlorine (Cl), Ammonium and phosphorus. All of these parameters give a general idea of the quality of the treated water to be discharged to a water course. This paper presents a novel sensor design that has been used to detect Phosphorous (P). P is one of the key elements necessary for growth of plants and animals; in lake ecosystems it tends to be the growth limiting nutrient and is a backbone of the Kerbs' Cycle (a set of biochemical reactions that occur in the mitochondria) and DNA [2]. The presence of P is often scarce in the well-oxygenated lake waters, unlike nitrogen; phosphate is retained in the soil by a complex system of biological uptake, absorption, and mineralisation. Phosphates are not toxic to people or animals unless they are present in very high levels. Digestive problems could occur from extremely high levels of phosphate [2].

## **2. The use of microwaves for nutrient detection**

Microwaves are electromagnetic waves (EM waves) with wavelengths in the range of (1mm-0.3m) or equivalently, with frequencies between 1 and 300 GHz. The EM waves have been successfully used as a sensing element for various industrial applications including water level measurements [3] and material moisture [4].

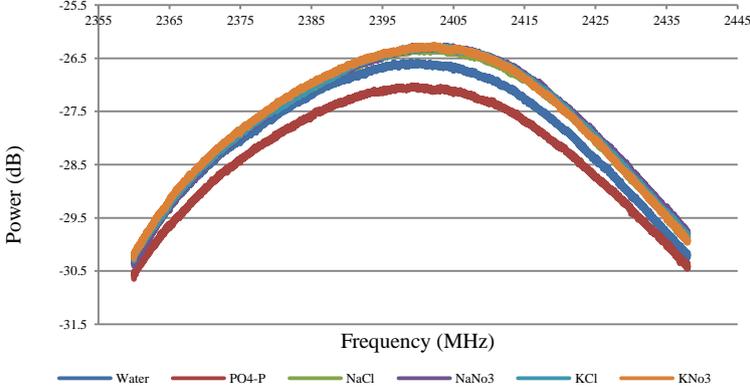
A microwave resonator can be defined as a section of transmission line with open or shorted ends (ports). Depending on the type of transmission line, the resonators are called, for example, coaxial, microstrip, stripline, slotline, or cavity resonators. When an EM wave signal is incident to one end (or port) of a microwave resonator, some fraction of the signal may be reflected back to that port whilst the remainder exits the other port, therefore being transmitted [5]. Microwave sensors in the form of cavity resonators operate based upon the interaction of the EM waves and the material or object under test. The object changes the velocity of the signal, attenuates or reflects it. The object under test will be placed inside or near to the microwave resonator to determine the transmitted ( $S_{21}$ ) and reflected ( $S_{11}$ ) microwave power at discrete frequency intervals. By considering how these parameters vary with the object under test one can accurately determine the composition of the object under test.

Preliminary testing using other microwave cavities has been completed to investigate if this method can be applied to detect P solutions. Initially phosphate ( $PO_4$ ) was considered using a microwave Vector Network Analyser (VNA) and a cylindrical microwave cavity (see figure 1). The detectable phosphate concentration was high however in this case since 500ppm of Potassium Phosphate ( $KPO_4$ ) in Deionised Water (DW) was used. Also 500 ppm of four other solutions were introduced which were NaCl,  $NaNO_3$ , KCl, and  $KNO_3$  to test if the microwave sensor is more sensitive to P solution other than others. The DW response was taken as a reference reading for any amplitude shifts (AS) or frequency shifts (FS) that may occur when any of the solutions were introduced to the cavity.



**Figure 1. Preliminary cylindrical microwave cavity setup**

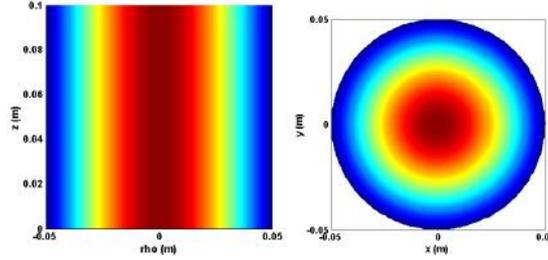
The transmitted power  $S_{21}$  was measured for the six solutions that been introduced to the cavity one after the other. Results in figure 2 show that the power of the phosphate is 0.7dB less than the other six solutions which have nearly the same power values.



**Figure 2. Transmitted power response for the cylindrical cavity**

### 3. Microwave sensor design and simulation.

The microwave sensor cavity was designed to work at the  $TM_{010}$  (Transverse Magnetic) mode shown in figure 3. This geometry has been used for material permittivity measurements since 1946 [6].



**Figure 3.** Electric field for  $TM_{010}$  mode in Cylindrical Resonant cavity [7]

#### 3.1 Cavity design

The  $TM_{010}$  mode is the lowest resonant frequency for a short cylindrical cavity, some of its advantages are that the electric field is maximum in the axes of the cavity, and the resonant frequency is independent of the cavity height (reduction of errors depending on measuring dimensions) [7]; for these reasons a cavity with a PTFE pipe inserted in the middle has been designed as follows:

From a given cylinder radius  $a = 37.5\text{mm}$ , the resonant frequency  $f_{010}$  was calculated from (1) as follows:

$$fnml = \frac{c}{2\pi\sqrt{\mu r \epsilon r}} \sqrt{\left(\frac{P'nm}{a}\right)^2 + \left(\frac{l\pi}{d}\right)^2} \quad (1)$$

$$d < 0.9348 \cdot a \quad (2)$$

$$b < \frac{a}{\sqrt{\epsilon r}} \quad (3)$$

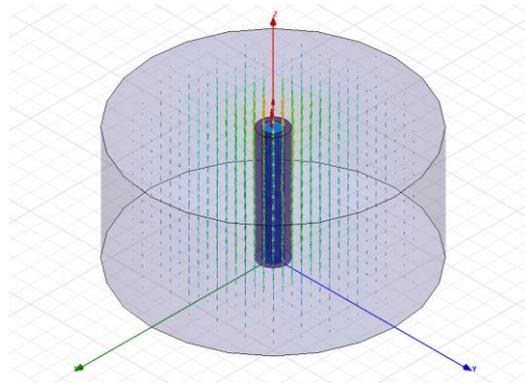
Where  $fnml$  is  $f_{010}$ ,  $P'nm$  can be determined from [8],  $d$  is the height of the cavity and independent of the resonant frequency as  $l = 0$ , but to get a maximum bandwidth for the next resonant mode the condition in (2) must be applied [7], in this case the next resonant mode is  $TM_{110}$ , which is also independent from  $d$ . The last measurement to be considered was the maximum radius of a hole  $b$  to be made in the resonant cavity for the insertion of the PTFE pipe; this hole must be under the cut off frequency, see equation (3) in order to avoid leakage of the microwave energy outside the cavity, where  $\epsilon r = 81$  for water. Figure 4 shows the cavity design model.

#### 3.2 Cavity simulation

A simulation program called High Frequency Structure Simulator (HFSS) has been used; figure 4 shows the electric field distribution inside the cavity for the first mode ( $TM_{010}$ ). Where all the design parameters shown in table 1 were used.

**Table 1.** Cylindrical cavity design parameters.

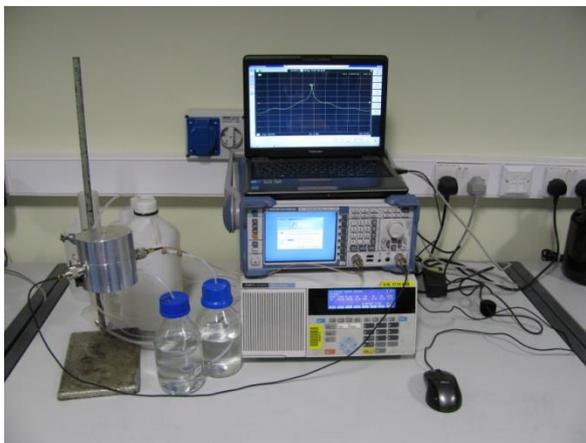
Parameter	Value
$a$	37.5 mm
$b$	8mm
$d$	30mm
$f_{010}$	1.6326 GHz.



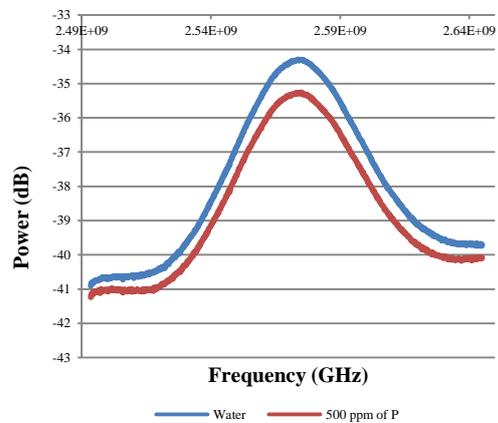
**Figure 4.** HFSS simulation for the cavity design

#### 4. Microwave sensor cavity system insulation

The designed cavity has been installed within a system contains: 1. HPLC Pump which controls the flow rate in the pipe and pumps up the deionised water then the Phosphate solution, 2. VNA which supply the microwave signal to be introduced in the cavity and measure the transmitted power  $S_{21}$ , 3. Microwave cavity sensor where all the interaction of the electromagnetic waves and the solution to be measured takes place, 4. Laptop to grab data for more measurements and analysis to be done and 5. Deionised and Phosphate solution bottles, Figure 5.a shows the system setup, and figure 5.b shows the primarily results obtained from the designed cavity.



**a**



**b**

**Figure 5.** System setup and the primarily results

#### 5. Conclusion and future work

The prototype has been successfully designed, simulated and insulated within a system, the primarily measurements showed promising results which would have a significant sensitivity to phosphate as the transmitted power decreases when the phosphate solution introduced into the cavity. This means that the cavity can be used to detect lower concentration of phosphate if more improvements of some parameters (i.e. antenna design) done, Further measurements should be done and more external factors to be controlled such as solution temperatures as the permittivity of water is highly temperature dependent.

## References

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