# Low Cost Sensor to Measure Solid Concentrations in Wastewater

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***Abstract*— The use of sensors has increased in the last years. They allow the real-time monitoring and reduce the processing cost because most of wireless sensor networks (WSNs) do not require the intervention of people to perform the measurement. Sensors are useful for industrial processes that can imply some danger for workers. These devices also make easy the development of some tasks as the ones carried out in Wastewater Treatment Plant (WWTP). This paper presents the design, deployment and calibration of a low cost sensor able to detect the concentration of solids in some phases of the water treatment. The sensor is based on 2 coils and a microprocessor module.. Several models and combination of coils have been testes. The results show that our sensor is capable of measuring concentrations form 0% to 20% (0 mg/l to 200,000 mg/l) with an error lower than the 3.5%.**

***Keywords—Solid Concentration, low cost sensor, inductive sensor, wastewater, condition monitoring, industrial processes.***

## I. INTRODUCTION

The use of sensors is currently very common in most of our daily tasks. The application field of sensor is extremely wide and we can find many sensors-based applications in agriculture, industry processes environmental monitoring our e-health, among others [1]. The wireless sensor networks (WSNs) allow us to follow the real-time evolution of some parameters. With this information, we can take the corrective measures that are necessary or check that everything works correctly.

Nevertheless, the maintenance cost of the sensors can difficult their use in some areas, i.e., if the manufacturing cost of these devices is too high, the monitoring of large areas can be very expensive. For this reason, there is an increase tendency on developing low cost and low maintenance sensors. Some low cost and physical sensors have been developed for monitoring turbidity [2], conductivity [3], and others . In this sense, chemical sensors are not recommended to implement this kind of systems since they require a continuous maintenance. Thus, the use of physical sensors is the best option for long-term monitoring.

One of the most important industrial processes in the operation of a city is the treatment of urban wastewater. This treatment is developed in Wastewater Treatment Plant (WWTP). The treatment of water is important so as not to cause serious environmental damage in the points of spillage of water used by cities. Also the sludge and water obtained after treating the wastewater can be used in applications such as irrigation and crops fertilizer. At the exit of the mud thickener (see Fig. 1), it is obtained a mixture of water that contains different concentrations of solids and thus, it is important to quantify this amount. The monitoring of solids is very important in the industrial process of separating water and solids because the concentration of solids in the two effluents (water effluent and solids effluent) is an important indicative of the correct operation of the WWTP. Currently, the monitoring of solid concentration in water can be performed by direct techniques, although this process requires too much time and does not permit a real-time monitoring. The indirect methods are the most used and it is related with the water turbidity. This technique is not accurate enough for high solid concentrations.

This paper presents the design of a low cost sensor for monitoring solids concentrations in water. This sensor is based on two coils where a coil is powered by an alternating current. The electromagnetic (EM) field generated by the powered coil induces a current in the second coil. This current is modified due to the interaction of solids present in the water and thus we take profit of this fact to monitor the solids concentration. This sensor can be used for monitoring the sewage sludge which presents solids concentrations from 12% to 40 % [4] [5]. These values can slightly change depending on the type of water, processes in the WWTP, the chemical substances used in the processes, and other variable. However, our sensor can be used in these plants while the concentration of solids is lower than 40%.

The rest of the paper is structured as follows. Section 2 summarizes some interesting previous works where the solids concentration in water is measured. The basic operation of a WWTP and the principles of operation of our sensor is explained in Section 3. Section 4, show the test bench, the calibration and verification process carried out to characterize our sensor. Finally, Section 5 presents the conclusion and future work.

## II. RELATED WORK

In this section, we show the current techniques used for determining the concentration of solids. Moreover, we present some sensor deployments based on coils.

The standard method to determine the concentration of solids in the water is the ebullition of the sample. The sample is maintained at 103-105 ºC until the difference between the previous and the current weight is equal to or less than 0.5 mg or 4%. At that time it is considered that the sample is dry and the initial weight is compared with the final weight to obtain the evaporated water. This calculates the solids that existed in the sample[6].

Pavanelli and Bigi [7] used an Imhoff cone to determine the concentration of solids in an indirect way. They compared the use of the cone with the nephelometer and concluded that use of an Imhoff cone has a good correlation with the total solids. They determined that use of a cone is better of nephelometer, especially in cases with high concentration of solids, because it does not need dilutions. The problem of this technique is that it is not instantaneous. Thus, this technique cannot be used for a continuous monitoring.

Another technique to determine the solids concentration of water is measuring the turbidity [8]. There are different methods to quantify the turbidity. For example, Parra et al. [9] developed a low cost turbidity sensor, which is capable to differentiate between sediment matter, and two species of algae (green algae and brown algae). This sensor is based on infrared and red LEDs and two photoresitances to difference the different types of turbidity. Depending on the light absorption of the sample, the value of resistance changes and it is related to the turbidity.

Oliveira et al. [10] showed a turbidity sensor based on 4 LEDs (blue, green, red and infrared) and a polymer optical fiber (POF). The LEDs are sequentially powered by the emitter fiber using a coupler. The light was guided to a measurement cell. Authors used two receiving fibers for measurement at 180º and 80º. The authors used sediments collected in Mira beach, Portugal. The results showed that the POF sensor had a high dynamic range. The maximum concentration of solids that can be measured with this sensor is 100 g/l solids (10% of solids)

Acoustic methods can also be used for measuring the turbidity [11]. Chanson, et al. [12] used the acoustic Doppler backscattering to measure the turbidity. They used water and mud samples collected in an estuary of Eastern Australia. The authors checked that there was a linear relationship between suspended sediment concentration and turbidity.

The use of turbidity to determine the concentration of solid has two gaps. The first one is the fact that the turbidity does not only depends on the suspended solids. The presence of dissolved substances can increase the value of turbidity. The second problem is the working range. For our application, we need to measure solid concentration in several orders of magnitude above that the working range of the current sensors. In the already mentioned article, the highest concentration of solids they could detect was of 100 g/l, However, this turbidity cannot be used for determining the concentration of solids[10].

Finally, the sensors based on coils were used for sensing other parameters. Parra et al.[13] used sensors based on coils in for monitoring the conductivity level in estuaries. The sensors were based on two coils and it was integrated in a WSN to monitor the changes of fauna and flora in these environments.

As far we know, there is not current proposal of low cost systems to monitor the solids concentration in wastewater. Our proposed sensor is based on coils and can be used for monitoring the solids concentration in our desired working range.

## III. LOW COST SENSOR FOR DETECTING SOLIDS IN WATER

This section summarizes the operation of a sewage treatment plant and presents our proposed low cost sensor for detecting the amount of solids in water.

### *A. Basic operation of a Wastewater Treatment Plant (WWTP)*

An important industrial process in cities and our daily lives is the treatment of urban wastewater in plants. The wastewater that reaches the WWTPs remains in these facilities between 24 and 48 hours. To take advantage of and recover these waters, they must receive a series of treatments.

When the treatment plant receives the wastewater, first the larger waste and the floating fats, as well as the sands and solids with greater thickness are eliminated. The resulting mixture is rested in large tanks called decanters. On the surface, there are floating debris accumulated and the heaviest (sludge) located in the bottom which will automatically be removed.

Later, the water passes to large rafts populated by millions of different types of bacteria which are feed on the organic remains that are still present in the wastewater. During this process, the water is constantly mixed so that the bacteria have as much oxygen as possible.

Then the water passes to other decanter ponds where the remaining mud is removed. Finally, the water is returned back to its natural course, to a river, or it is channeled for other uses, as agriculture. On the other hand, all the sludge extracted from the decanters goes to another facility (digester) where are treated before being stored or destined to other uses, such as the manufacturing of fertilizers for agriculture. In this phase, combustible gas is also produced. This gas is used as fuel in the installation itself (for the heating of buildings or to produce electricity).

Within the last phase of sludge treatment, this sludge is biologically stabilized and then mechanically dehydrated (except in small WWTPs). Our sensor is just located before the sludge dehydrator and will be responsible of measuring the amount of solids present in the water and the process conditions. Fig. 1 shows the operating circuit of a WWTP that receives the wastewater from the cities.

Fig. 1. Sewage treatment plant and position of our sensor

### B. Principles of operation of the proposed low cost sensor for detecting solids in water

In order to measure the amount of solids present in water, we propose the use of a set of coils. The amount of solids is related to the induced current measures in one of these coils (See Fig. 2).

We foresee that the installation of the sensor be done in two points of the WWTP. These points will be in the output currents from the mud thickener and the sludge dehydration. At these points the solids concentrations are too high for the use of optical methods, but too low for the use of capacitive sensors such as those used to calculate soil moisture.

To measure the amount of solids in water, we use 2 different coils. One of them is powered with an alternating signal. The polarity changes of this signal make that the coil alternates between the charge and discharge phases. When an alternating current goes through a coil, an electromagnetic field is created. Because the second coil is very near, this electromagnetic field induces a current in this coil. The magnitude of the induced current is related to the disturbances that the solids present in the water contains. This value also gives us information regarding to the process condition and can help us to monitor the resulting wastes (see Fig. 2).

To protect the rest of elements and control the process of charge and discharge, it is recommended to add a resistor of low resistance in the powered coil side and a capacitor in parallel with the induced coil (See Fig. 3).

Because, there are very few references regarding to this method, we have to check different kind of coils and different combinations. Table 1 shows the different combinations of coils used in this study. We used four different combinations of coils.

### C. Design of node

After designing our transducer, we have to integrate it in a node capable of generating the signal and gather the data. To do it, we need a micro-processor (a NodeMCU module [14]) and some discrete components to implement a voltage amplifier (See Fig. 4). The NodeMCU is an open source platform specially designed to deploy Internet of Things (IoT) solutions to solve most of the requirements the society is currently demanding. The main features of this device are the following:

- It incorporates a 32-bit MCU of low consumption (Tensilica L106)
- IEEE 802.11 b/g/n Wifi interface
- 128 kB of RAM memory
- 1 10-bit analog input (ADC)
- 17 GPIO input and output pins (general purpose).

The power consumption of this device is typically 140 mA when transmitting with IEEE 802.11 g standard. However, it requires up to 320 mA during the start phase. Using the power save mode DTIM3 it is possible to reduce the power consumption lower than 1mA. To power it, we can use batteries with alternative energy sources or connecting it to the electrical network. Because this module can only generate 4.5v output signals and our coils need at least 9v signals, we have implemented an universal polarization network based on a bipolar junction transistor.

The NodeMCU generates an alternating signal (a square or sinus signals are appropriate). This signal is amplified by the universal polarization network which is calculated to offer a voltage gain of 2.5. The output signal is driven to the powered coil. After that, the induced current is gathered by the NodeMCU which in charge of processing and storing the measured results. These values can be sent to a computer that acts as server. Table 2 shows the detailed cost of the electronic part of our proposed low cost sensor.

The use of this kind of modules able to be integrated to a network permits the real-time and remote monitoring of a place or parameter since the sampling period time can be programmed according to our requirements.

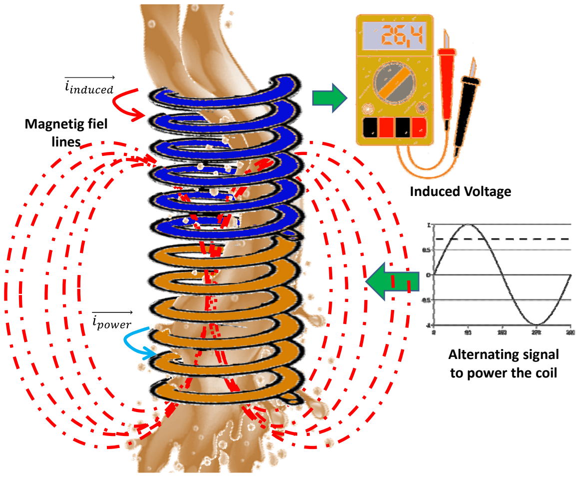



Fig. 2. Operation Diagram of our low cost sensor.

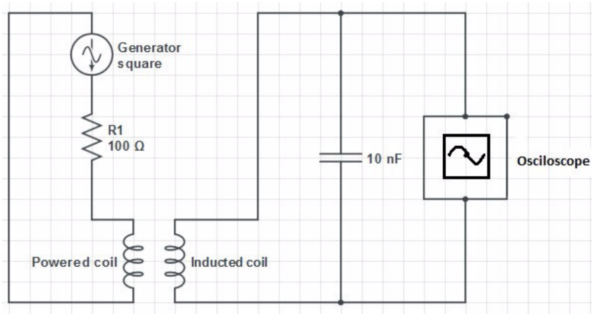
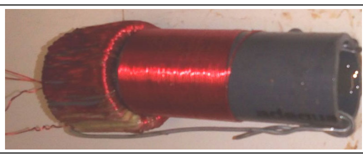
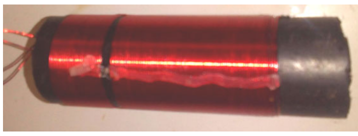



Fig. 3. Circuit coil used in the laboratory

TABLE I. CHARACTERISTICS OF THE DIFFERENT COILS

| **Coils** | **Characteristics of the different coils** | | |
|---|---|---|---|
| | ***Picture*** | ***Powered Coil*** | ***Induced Coil*** |
| m1 |  | Type: Solenoid,Nº Spires:70 High: 34 mm,Diam: 25 mm | Type: Toroid,Nº Spires: 220 High: 28 mm,Inner Coil Diam:25 mm,Outer Coil Diam:34 mm |
| m2 | | Type: Toroid,Nº Spires: 220 High: 28 mm,Inner Coil Diam:25 mm,Outer Coil Diam:34 mm | Type: Solenoid,Nº Spires:70 High: 34 mm,Diam: 25 mm |
| m3 |  | Type: Solenoid,Nº Spires:90 High: 42 mm,Diam: 25 mm | Type: Solenoid,Nº Spires:30 High: 14 mm,Diam: 25 mm |
| m4 | | Type: Solenoid,Nº Spires:30 High: 14 mm,Diam: 25 mm | Type: Solenoid,Nº Spires:90 High: 42 mm, Diam: 25 mm |
| m5 |  | Type: Toroid,Nº Spires: 220 High: 28 mm,Inner Coil Diam:25 mm,Outer Coil Diam:34 mm | Type: Toroid,Nº Spires: 70 High: 28 mm,Inner Coil Diam:25 mm,Outer Coil Diam:34 mm |
| m6 | | Type: Toroid,Nº Spires: 70 High: 28 mm,Inner Coil Diam:25 mm,Outer Coil Diam:34 mm | Type: Toroid,Nº Spires: 220 High: 28 mm,Inner Coil Diam:25 mm,Outer Coil Diam:34 mm |
| m7 |  | Type: Toroid,Nº Spires: 300 High: 25 mm, Inner Coil Diam:43 mm,Outer Coil Diam:52 mm | Type: Toroid,Nº Spires: 220 High: 28 mm, Inner Coil Diam:25 mm, Outer Coil Diam:34 mm |

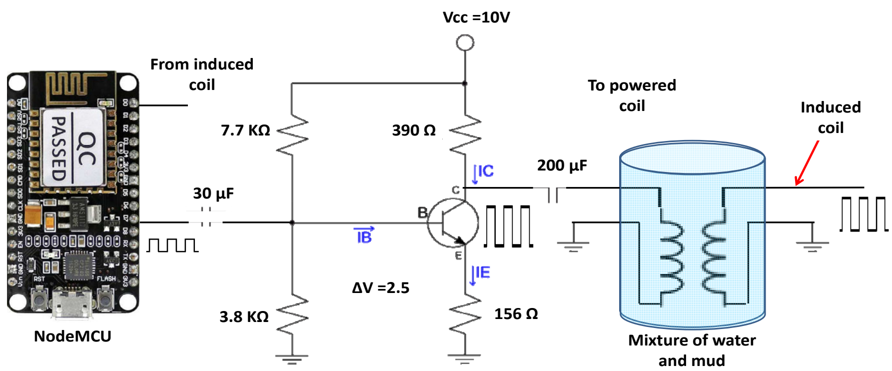



Fig. 4. Complete circuit of our Low cost sensor

TABLE II. PRICES OF ELECTRONIC COMPOMENTS OF OUR SENSOR

| Component | Table Column Head |
|---|---|
| | ***Price*** |
| Discrete components (Resistors, Cpacitors, Transsistors) | 1.90 € |
| NodeMCU Module | 19.82€ |
| Coils | 1.83€ |
| Total | 23.55€ |

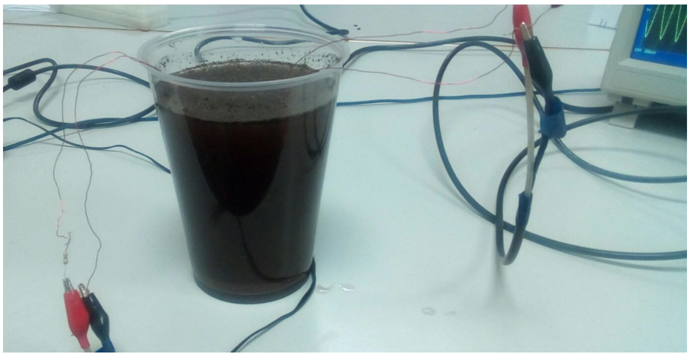


Fig. 5. Example of a sample

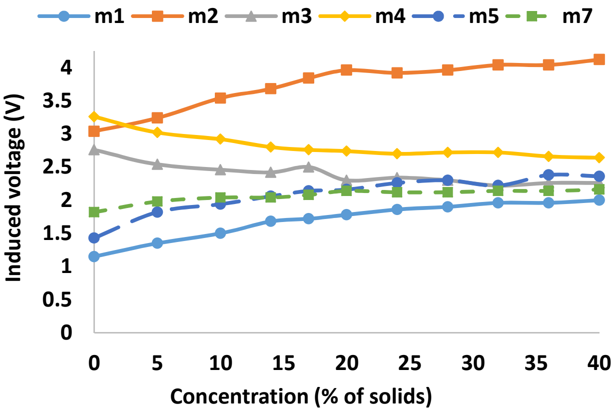



Fig. 6. Induced voltage results

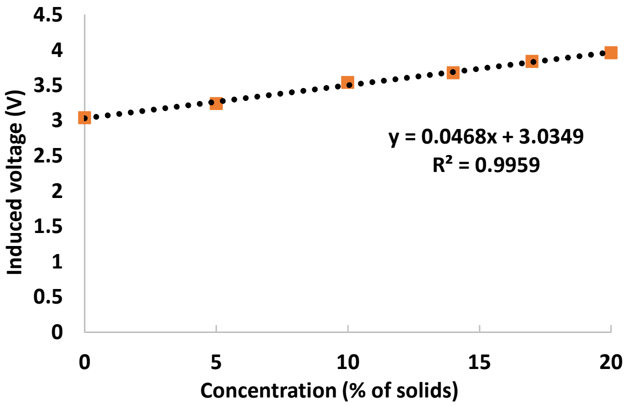



Fig. 7. Results of model m2

## IV. TEST BENCH AND MEASUREMENT RESULTS

This section describes the test bench, the calibration process and the verifications performed with our sensors in order to determine the correct operation.

### *A. Test bench preparation*

In this subsection we are going to explain the process followed for obtained the results.

Before starting the calibration process, we have to determine which combination of coils is more suitable to develop our low cost sensor. To do it, we have introduced each model in a sample of tap water. The powered coil has been powered by a sinus wave with different frequencies (from 1Hz to 500 KHz) and the induced signal has been measured with an oscilloscope. The results shows that the optimal working frequency for each model are m1=150 KHz, m2=175 KHz, m3=150 KHz, m4=325 KHz, m5= 400 KHz and m7=250 KHz. Model m6 was discarded because no optimal frequency was detected. The optimal working frequency is the one that registers the highest induced signal. In addition, different solutions with different solid concentration have been prepared. The concentration solutions are 0%, 5%, 10%, 14%, 17%, 20%, 24%, 28%, 32%, 36% and 40% of solids. In all cases, we prepared 750 ml of solutions and placed them in glasses with the volume of 1 l. We introduced the coil in the glasses and we removed the solutions to ensure the homogeneity of the sample. Fig. 5 shows an example of a sample.

### *B. Obtained results*

In this subsection we are going to analyzed the values obtained for the different prototypes.

In Fig. 6 shows the results of detecting different concentrations of solids in water for each model. We can observe in all prototypes there is a difference in the magnitude of induced voltage between the value of 0% and 40% of solids.

On the one hand, we observe that prototype 1, 2 and 5 have the biggest difference of induced voltage between 0% to 40% of solids. These differences are 0.85 V in prototype 1, 1.08V in prototype 2 and 0.93V in prototype 5. These prototypes have in common the presence of a toroid with 220 spires. So, we should initially consider one of these models to implement our sensor. On the other hand, if we compare the differences in the induced voltage for concentrations higher than 20%, the differences are small. So we decided to select the model m2 which is the one that presents the biggest difference between 0% and 20%. The voltage difference between 0% and 20% of concentration of solids is 0.92 V (See Fig. 7). Finally, we can model the behaviour our system by a lineal equation showed in Fig.6. This equation has a correlation coefficient of R2= 0.9959 which can be considered quite good.

### *C. Verification*

This subsection shows the verification tests to determine the accuracy of the proposed sensor. That is, we need to ensure that after calibrating the developed sensor, it is possible to detect unknown samples and tag it accordingly to our previous analysis. To carry out this verification, we have prepared 5 unknown samples which have been monitored by our sensor to obtain the resulting induced voltage. The results are introduced in our mathematical model (See Fig. 7) to estimate the concentration of solids. Finally, we compare the actual value of solids with the values calculated by our mathematical model. The results are shown in Table 3. The maximum error obtained is 3.2 %, and minimum error is 0.6%

If we compare our result with the existing sensors, we observe that our proposed sensor can operate in a larger range than turbidity sensors which presents a detection limit at 10% of solids concentration. Our sensor can measure in a range from 0% to 20%.

## V. Conclusions

In this paper, we have presented a new sensor based on two coils for monitoring the concentration of solids in water. The working range of our sensor goes from 0 % to 20% of solids with a maximum error of 3.2 %. We determined that best combination of coils is the one composed by a toroid and a solenoid. Regarding to the obtained results, our sensor is able to measure higher concentrations than a turbidity sensors. Moreover, it can measure lower concentrations than some commercial sensors which imply that it can be used for different applications. A possible application is the condition monitoring of industrial processes as the treatments of sludge in water in WWTP. Finally, the electronic to implement a sensor with these features has an approximate cost of 23.55€.

We think this sensor can be used in many applications in industrial processes. So, as future works, we will work on modifying the characteristics of coils so they can be used in a higher concentration of solids. Furthermore, we will combine this coil with other coils to determine the water flow and the conductivity of the water.

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