Design of Dual Light Source Photoelectric Sludge Concentration Sensor

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Abstract. Provided a scheme of activated sludge sensor using dual AC modulation light source. This technique can overcome interferences under nature condition and do not need to clean frequently and lower the maintenance costs. Proved the feasibility by Lambert-Beer law and also designed a series of experiments to demonstrate the requirements have been reached.

Introduction
Activated sludge treatment of sewage is the main way the world's industrial organic wastewater treatment and secondary treatment of urban sewage. To ensure the normal operation of the sewage treatment process and quality of sewage treatment. In the sewage treatment process real-time detection aeration tank, secondary sedimentation tank, return sludge, excess sludge concentration is very important because it is decided sludge discharge, measure the sludge concentration and reflect the effect of Aeration status an important indicator [1]. At present, domestic online testing sludge concentration mainly photoelectric, ultrasonic and microwave method. Since the photodetector technology is very mature, good quality of optoelectronic devices. In this paper, the use of photoelectric detection method to study a dual light source photoelectric sludge concentration sludge concentration sensor for continuous accurate measurement, effectively overcome the shortcomings of current devices suffer interference under natural conditions, as well as sensors need to be cleaned frequently [2].

The Theoretical Basis of the Photodetector Concentration Sensor

Lambert-Beer's Law
When light is absorbed through a homogeneous medium, the light intensity by using Lambert-Beer's law is expressed as:

$$\Phi = \Phi_0 e^{-\alpha \ell}$$  \hspace{1cm} (1)

Wherein, $\Phi_0$ is the incident light intensity; $\alpha$ is the absorption coefficient of the medium; $\ell$ is the thickness of the medium.

It is proportional to the concentration of the absorption coefficient $\alpha$ and the medium liquid or gaseous medium. Thus, when a certain thickness of the material to be detected, received on the photodetector flux density measured only about media. Formula 1 may also be expressed as:

$$\Phi = \Phi_0 e^{-kd}$$  \hspace{1cm} (2)

Wherein, $k$ is the constant coefficient, $d$ is the thickness of the object to be detected, $s$ is the concentration of the liquid.

Conventional transmission type detection method is the use of a single current source, through the medium to be detected flux change is detected by the photodetector [3]. Taking into account the characteristics of the sludge, and the field conditions, there are a variety of complex interference sources, such as natural light, stray light, the color of mud, water, bubbles, etc., plus
the sludge is a suspension of a precipitate inevitable sensor it will be stained with mud, all of which are on the sensor design challenges. This single-source method cannot be applied to DC sludge concentration measurement [4].

Pairs of Light Sludge Concentration Sensor Structure

Dual-source technology designed sensor structure shown in Figure 1, the figure description of each parameter is as follows: \( L_1, L_2 \) is a light emitting tube, \( S_1, S_2 \) is receiving pipe, \( \eta_{L1}, \eta_{L2} \) is Stained glass LED after mud transmittance, \( \eta_{S1}, \eta_{S2} \) is transmittance after receiving tube glass stick mud, \( \Phi_1, \Phi_2, \Phi_1', \Phi_2' \) is the intensity of the LED; \( r_1, r_1', r_2, r_2' \) is the receiver to control light intensity, \( d_1, d_2, D_1, D_2 \) is the optical path.

Figure 1. Sensor Structure Diagram.

Figures 1 and formula (2) can be obtained the following relationship:

\[
\begin{align*}
&\begin{cases}
 r_1 = \eta_{L1}q_1 \\
 q_1 = p_1e^{-Kd_1S} \\
 p_1 = \eta_{L1}\Phi_1 \\
 \beta_1r_1 = I_1 \\
\end{cases} \\
&\begin{cases}
 r_1' = \eta_{L2}q_1' \\
 q_1' = p_1'e^{-Kd_1'S} \\
 p_1' = \eta_{L2}\Phi_1' \\
 \beta_1'r_1 = I_1' \\
\end{cases} \\
&\begin{cases}
 r_2 = \eta_{L2}q_2 \\
 q_2 = p_2e^{-Kd_2S} \\
 p_2 = \eta_{L2}\Phi_2 \\
 \beta_2r_2 = I_2 \\
\end{cases} \\
&\begin{cases}
 r_2' = \eta_{L2}q_2' \\
 q_2' = p_2'e^{-Kd_2'S} \\
 p_2' = \eta_{L2}\Phi_2' \\
 \beta_2'r_2 = I_2' \\
\end{cases}
\]

Wherein, \( \beta_1, \beta_1', \beta_2, \beta_2' \) is the \( S_1, S_2 \) relative relative sensitivity of \( r_1, r_1', r_2, r_2', I_1, I_1', I_2, I_2' \) is the receiver tube relative to the current generated by the incident light different, \( S \) is the measured concentration of the sludge. To be launched, the relationship between photocurrent generated between the receiver tube:
\[
\frac{I_1}{I_1} = \frac{\beta_1, \eta_1, \Phi_1 e^{-K_{1S}}}{\beta_1, \eta_1, \Phi_1 e^{-K_{1S}}} \cdot \frac{I_2}{I_2} = \frac{\beta_2, \eta_2, \Phi_2 e^{-K_{2S}}}{\beta_2, \eta_2, \Phi_2 e^{-K_{2S}}} \cdot V = \frac{I_1 I_2}{I_1 I_2} = \frac{\beta_1, \eta_1, \Phi_1, \beta_2, \eta_2, \Phi_2 e^{\epsilon(K_{1S} + d_1 - d_1 - d_2)}}{(7)}
\]

Let: \( A = \frac{\beta_1 \Phi_1}{\beta_2 \Phi_2} \), \( B = d_1 + d_2 - d_1 - d_2 \), then equation (7) can be expressed as:

\[
V = Ae^{KB} \tag{8}
\]

\[
S = \frac{\ln(V / A)}{KB} \tag{9}
\]

After the sensor calibration is, A, KB are constants, S is a function of V, using this principle enables sludge concentration on line.

**Experimental Study of Dual Light Source Photo sensor**

In order to verify the correctness of theoretical analysis sensor, design of experimental apparatus, as shown in Figure 2.

In Figure 2, on the left is an infrared light-emitting diode, in the middle of transparent glass tank filled with water samples, the right side of the photodiode. Due to limitations of the experimental conditions, between the sink and the light emitting tube and receiving tube, with a homogeneous thin plastic sheet to simulate sensor stained with mud, when the thickness of the plastic sheet is not and can simulate different thicknesses of sludge. Tank of sensor is a rectangular parallelepiped container from the open side of 2mm in thickness of ordinary glass, length 17cm, width 14cm, thickness of about 1.3cm, volume of about 300ml. The distance between received diodes and the light-emitting diodes is 1.7cm, the distance between the two light-emitting tube 1cm, the distance between the receiver tube and recevier tube is 1cm. Gallium arsenide L, infrared light emission peak wavelength at about 940nm [5]. The photodetector element selected silicon photodiodes, the light intensity of radiation into an electrical signal output. A photodiode having a high light sensitivity, good linearity and broad spectral response in the wavelength of 0.3-1.2μm, the peak wavelength is about 900nm. It is very close match that Peak wavelength of silicon and gallium arsenide, help to improve transfer efficiency and anti-jamming capability [6]. GaAs emission intensity decreases as the temperature rises, the photodiode current temperature coefficient of + 78μA, with increasing temperature, so when using the combination of the two, can be compensated with each other, more conducive to stable.

To verify the performance of the sensor, we designed two tests: (1) to verify compliance with a light transmitting L-B sludge Law; (2) Verify that when the sensor sticky mud desert does not affect the measured concentration values.

Test 1: Program in a single tube test, namely LED L1 and receiving tube S2, there have been provided with the sludge tank, useless plastic paper. Different concentrations of the active sludge in the sink. Its concentration in the range of 0 to 12000ppm, experiments carried out entirely in the black box, in order to rule out natural light, stray light interference, the experiment has been repeated 7 group. In the repeated experiment to try to ensure that each tank water level constant, the relative positions of the same tank, to ensure a different set of experiments, the same experimental conditions. Then measure the voltage of S1 is worth to 7 sets of data. Drawing concentration and voltage curves 7 sets of data, the first set of data shown in Figure 3, the other six sets of data are shown in Table 1.

![Figure 2. Schematic Experimental Setup.](image-url)
Error Analysis: Φ₀ and -kd fluctuate to some extent, the main cause of volatility is due to an error experimental device. In making repeated experiment, we cannot ensure that the same sludge concentration. Each time you change the sludge concentration, it must open the black box, replace the water samples to remove the tank, the same cannot be re-placed and the last position, the measurement results will change the location of the sink impact. With the increase of sludge concentration, suspended solids will precipitate, after a time lag of water samples to be stirred, which will have an impact on the measurement results [7]. Even the presence of the above factors affect the results, the measurement results are relatively satisfactory, seven sets of curves are very close correlation of each set of data in more than 0.99, so L-B's law is fully applicable to sludge concentration measurement.

Test 2: adding a certain concentration of sludge in the sink, by layer added to a homogeneous thin plastic paper, Using reverse pulse drive.

The test procedure is as follows: (1) sink into a concentration of the sludge, put a layer of plastic paper, when the bright lights L1, L2 when the lamp is off, measure S1, S2 voltage value V1, V1'. When the lamp is lit L2, L1 is off when the lamp is measured S1, S2 voltage value V2, V2'; calculations \( V = \frac{V_1 \times V_2}{V_1' \times V_2} \). (2) before receiving tube add a layer of plastic sheets, according to the same method step 1 is calculated by formula 7 in V0.(3) repeat steps 1 and 2 until the launch tube head tube and receiver each have six layers of plastic sheet.(4) Holding tank sludge concentration constant, repeat the experimental procedure, for a total of seven sets of experiments, plotted in Fig. 4, Linear regression equation of the data shown in Table 2.

Error Analysis: (1) tank volume is too small, sludge suspended solids precipitation soon, in order to accurately measure must sludge container for mixing, but stirring sludge suspended solids particles are unevenly distributed, with different concentrations at different times along the path of light through the suspension, so the output voltage readings vary widely, it is difficult to accurately measure. Since the output is unstable, the proportion accounted for reading error is larger than the system error. (2)even if the water sample was stirred suspension there will be some precipitation, resulting in a voltage value with the passage of time becomes large, resulting in a fitting line appears greater than zero slope [8]. (3) When adding plastic paper, plastic paper moves past, we cannot rule out errors caused by different light transmittance plastic sheets caused. Although the experimental data and theoretical occurred some errors, but errors are within the allowable range, the AC modulation dual light source photoelectric sensor technology can overcome the effects of stained mud.

<table>
<thead>
<tr>
<th>No.</th>
<th>Fitting equation</th>
<th>( R^2 )</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>( y = 0.6966e^{-0.7702x} )</td>
<td>0.99</td>
</tr>
<tr>
<td>2</td>
<td>( y = 0.6825e^{-0.0655x} )</td>
<td>0.9923</td>
</tr>
<tr>
<td>3</td>
<td>( y = 0.7087e^{-0.0715x} )</td>
<td>0.9986</td>
</tr>
<tr>
<td>4</td>
<td>( y = 0.6859e^{-0.0655x} )</td>
<td>0.9949</td>
</tr>
<tr>
<td>5</td>
<td>( y = 0.7019e^{-0.0742x} )</td>
<td>0.9948</td>
</tr>
<tr>
<td>6</td>
<td>( y = 0.7084e^{-0.0495x} )</td>
<td>0.9982</td>
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<table>
<thead>
<tr>
<th>No.</th>
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<tbody>
<tr>
<td>1</td>
<td>( y = 0.0352x + 4.0178 )</td>
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<tr>
<td>2</td>
<td>( y = 0.0594x + 3.965 )</td>
</tr>
<tr>
<td>3</td>
<td>( y = 0.0488x + 4.0137 )</td>
</tr>
<tr>
<td>4</td>
<td>( y = -0.0441x + 4.4036 )</td>
</tr>
<tr>
<td>5</td>
<td>( y = 0.0489x + 4.0436 )</td>
</tr>
<tr>
<td>6</td>
<td>( y = 0.0376x + 4.4972 )</td>
</tr>
<tr>
<td>7</td>
<td>( y = 0.0167x + 4.3881 )</td>
</tr>
</tbody>
</table>
Conclusion

This paper presents a sludge concentration sensor design, AC dual light source modulation technique can effectively overcome the interference of natural light and stray light, the photovoltaic device parameters to overcome the dispersion of interference, to overcome the impact of the sensor stick mud, through a series of tests It proved the feasibility of the program.

References


