

## A STUDY ON pH ANALYZER USING ARTIFICIAL INTELLIGENCE IN WATER MANAGEMENT OF THERMAL POWER GENERATION PLANT

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### Abstract

*pH is a very important factor that critically affects the efficiency of desulfurization facilities as well as in the generation of boiler tube scales in power plants as an indicator of hydrogen ion concentration of the aqueous solution. It is also a major item in the quality management of pure water and wastewater treatment facilities. However, it has been difficult to manage the accurate pH measurement frequently. If it is neglected, the maintenance cost is inevitably increased due to shortened life of boiler tubes while also damaging the them as well as lowering the efficiency of the desulfurization equipment and generating a hard scale. The pH meter applied to the plant is calibrated periodically by the operator using the buffer (standard solution), but when the calibration is impossible, all the pH electrodes are replaced. Therefore, it is required to develop an electrode pH meter with a self-correcting function to ensure the quality of the boiler tube with accurate pH control and improved efficiency of the whole desulfurization system. This study derives its purpose to introduce the world's first pH-based analysis system ever created using the artificial intelligence to perform "bufferless" automatic calibration and technology operated with higher efficiency. For pH analysis, this is an essential tool for water management in domestic and overseas thermal power plants.*

**Keywords:** electrode, electrolyte, buffer, glass, reference electrode, junction, pH analysis, reference potential, cell, artificial intelligence

### Introduction

The pH measurement is a measure of activity, not hydrogen ion concentration. Modern pH electrodes form an electromotive force proportional to H<sup>+</sup> ion activity. [1] The electromotive force formed by the glass electrode is compared with the junction potential generated constantly at the reference electrode through the internal electrolyte. Basically, the pH measurement is to measure the electromotive force between the glass electrode and the reference electrode (potential difference measurement).

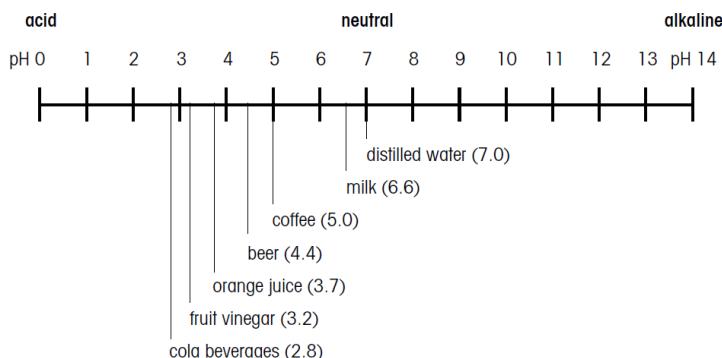
If the calibration of the glass electrode through the buffer solution is not appropriate, or if the reference electrode potential which should be constant is shaken, the accuracy of the measurement becomes poor. Food product quality pH analysis is probably the oldest method in the world, and all food products are taste organs checked for anomalies. It is recognized that some are acidic and some are alkaline, and modern pH electrodes can produce these tastes accurately (See Fig. 1).

The acidity and alkalinity of the target substance depend on the concentration of hydrogen ion (H<sup>+</sup>) in solution, and the pH value is defined as the logarithm of the reciprocal of the H<sup>+</sup> ion concentration of the given solution according to the Sørensen equation (See Table 1).

When accurate pH management is possible, it:

- Enhanced completeness of products
- Reduced production costs
- Prevented damages for environment, human nature and material resources

- Satisfied regulations of management authorities
- Derived a high level knowledge from the entire research

**Fig. 1.** pH values of various food products**Table 1.** pH scale

range	pH	H <sup>+</sup> concentration (mol/L)	OH <sup>-</sup> concentration (mol/L)
acid	0	1	0,00000000000001
	1	0,1	0,00000000000001
	2	0,01	0,00000000000001
	3	0,001	0,00000000000001
	4	0,0001	0,00000000000001
	5	0,00001	0,00000000000001
	6	0,000001	0,00000000000001
neutral	7	0,0000001	0,0000001
	8	0,00000001	0,0000001
	9	0,000000001	0,0000001
	10	0,0000000001	0,0000001
alkaline	11	0,00000000001	0,001
	12	0,000000000001	0,01
	13	0,0000000000001	0,1
	14	0,00000000000001	1

### **Method of Measuring pH Value**

The pH measurement is a potentiometric measurement (electrical difference is measured). The potential of the glass (measuring electrode) for example, pH electrode relative to the reference electrode is the measured value. [2]

Two or more metal conductors interconnected by one or more electrolytes form a galvanic circuit. By connecting the two conductors (electrodes) to the instrument with the highest possible input resistance, the circuit potential E can be measured. [3] This pseudo-non-electrical measurement does not add any change to the chemical composition of the test solution. When the charge exchange is performed between the phases of the galvanic circuit electrodes, galvanic potentials are generated. Since they are composed of at least two phases, it is not possible to measure them individually.

The circuit potential E consists of several components.

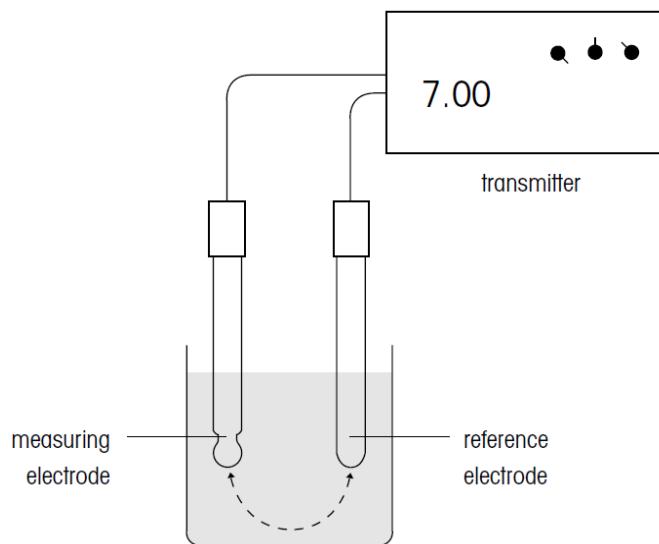
$$\frac{E}{E} = \frac{E'}{E'} + \frac{E''}{E''} + \frac{E'''}{E'''}$$

Metal A / Electrolyte 1 // Electrolyte 2 / Metal B

(1)

From here:

- $E'$ : indicating electrode potential
- $E''$ : diffusion potential
- $E'''$ : reference electrode potential



**Fig. 2.** Potentiometric Measurement Principle

$E$  is the concentration ( $C$ ) or activity ( $a$ ) dependent variable of the targeted ion. The mathematical correlation between activity level and galvanic potential is defined by the Nernst equation.

$$E_{Ag^+} = E_{0Ag} + \frac{2.3 RT}{nF} \cdot \log a_{Ag^+} \quad (2)$$

From here:

- $E_{Ag^+}$ = Galvanic Potential of Electrode
- $E_{0Ag}$ = Galvanic Potential in the StandardState
- $(a_{Ag^+}=1.0)$
- $R$  = Gas Constant
- $T$  = Absolute Temperature (Calvin)
- $F$  = Faraday Constant
- $n$  = Charge (Electrode:  $n = 1$ )
- $a_{Ag^+}$ =Activity Level of Ion

Variable  $2.3 RT/F$  is defined as the Nernst potential  $EN$  and is the same as the potential change due to a 10-fold change in activity. The galvanic potential of the indicating electrode  $E'$  can be obtained by taking all other variables of the circuit potential  $E$  as a constant.

### **Conventional pH Measurement Methodology**

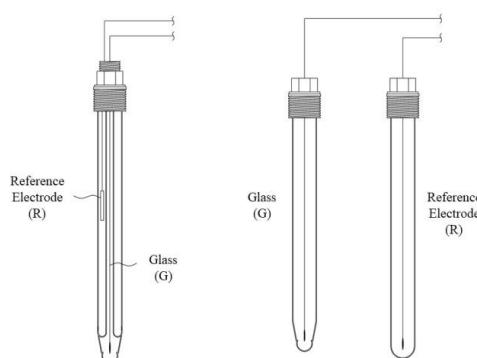
As shown in Figure 1, a conventional pH measuring system is generally composed of glass (G) and reference electrode (R), which is a half-cell or composite electrode. [4] Here, the output of the electric cell can be simply defined as follows:

$$(PH - PC1) = G \text{ (or E1)} - R \text{ (or E2)} \quad (3)$$

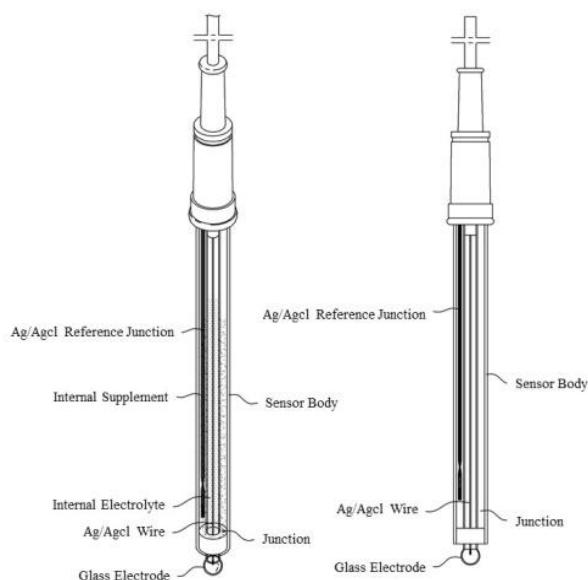
The PH and PC1 components are the logarithm of hydrogen and chloride ion concentrations. Here, if PC1 is constant, it can be expressed as follows:

$$pH = K(G - R) \quad (4)$$

Where K is a constant,



**Fig. 3.** A sketch of composite electrode (left) and half-cell (right) of the conventional pH measurement system



**Fig. 4.** Composite electrode type detail of the conventional pH measurement system

### ***Disadvantages of Conventional pH System***

The conventional pH measurement systems have several disadvantages. First, the contamination of the internal electrolyte filled in the reference electrode and the dependency of the chloride ion concentration may cause buffering of the electrode.

The second disadvantage of conventional pH measurement systems is that the concentration cannot be kept constant because of the chloride ion, and the practical need to provide a solution is sometimes to replenish the internal electrolyte, which is either gel or liquid replacement form and is preferred to use a reference electrode of the replaceable type.

The third disadvantage is that all the electrodes must be of a closed type, but the reference potential changes due to contamination of the reference electrode because contaminants flow back through the junction, often leading to the need to calibrate or replace the electrodes.

The fourth disadvantage is that all precipitates are coated on some reference electrodes, creating a resistance in the ground loop current path which, according to Ohm's law, causes a voltage drop across the glass and reference electrodes.

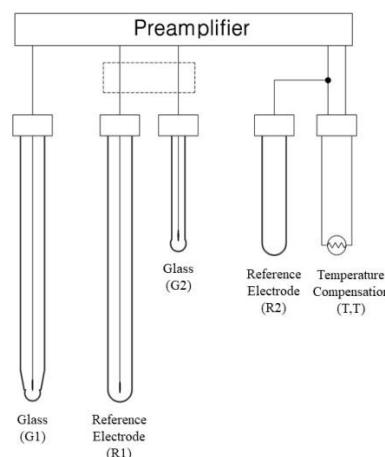
Accordingly, the common problem is that the process ion enters the reference electrode. Likewise, when a well-travelable ion meets and forms an overcharge, the movement of a fast ion is delayed.

As a result, if the buffer is calibrated critically, the ion balance of the reference electrode is disturbed and the maintenance cost of the buffer used each time is considerable.

The pH analysis of the current power plant is as described above. In fact, the drift caused by the solution pH fluctuation in the process analysis is actually difficult to distinguish and requires a lot of unnecessary maintenance to reduce the waste of manpower and lower the overall cost. [5]

### ***Four-Electrode Type pH Electrode***

A four-electrode type pH electrode has been developed to overcome the disadvantages of the conventional system. The four electrode type pH electrode has a glass G1 as the general composite electrode system and another glass G2 and a reference electrode R2 on the reference electrode R1.



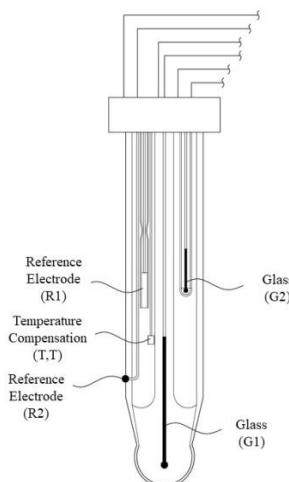
**Fig. 5.** Four-electrode type pH electrode structure

Theoretically, the potential of the reference electrode is 0mV, but its potential is actually changed when it is used. In the conventional system, when the reference potential is changed, the potential difference at the glass will also change, and the indication value will be different.

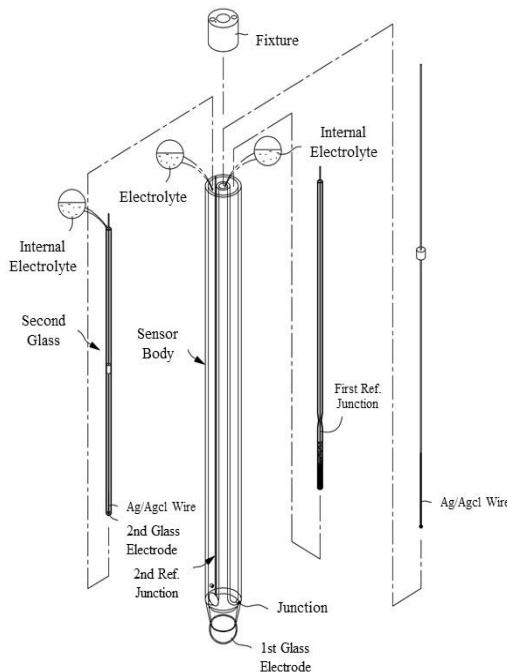
However, in the four-electrode type system, the reference electrode R1 is sensed by the interaction between the other measurement electrode G2 and the absolute reference electrode R2. [6]

That is, when the potential of the reference electrode R1 changes with respect to the contamination or the interference ion, the glass G2 senses it, and it is then possible to know how many mV is changed. Basically, it can be expressed as follows. The glass G2 senses the reference electrode R1 and outputs the signal separately.

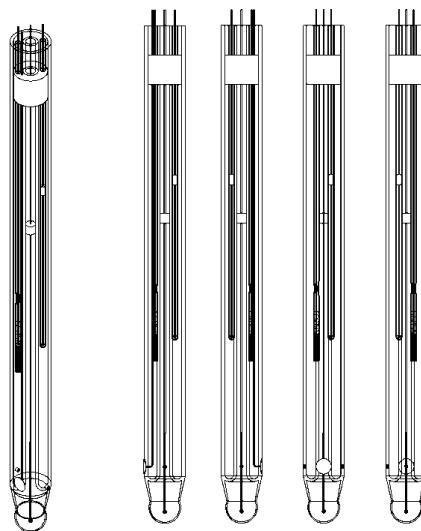
$$\text{pH} = K [(G1 - R2) - (R1 - R2)] = K [G1 - R1] \quad (5)$$



**Fig. 6.** An example of 4-electrode type pH composite electrode



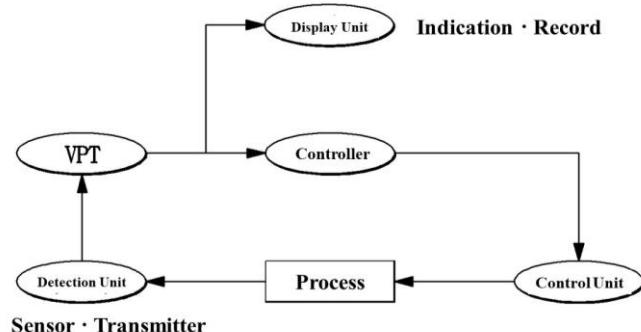
**Fig. 7.** Disassembled view of 4-electrode type pH composite electrode



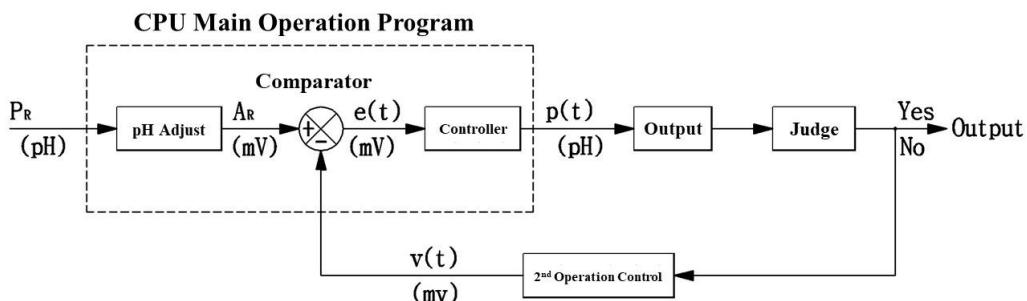
**Fig. 8.** Detailed view of 4-electrode type pH composite electrode (example of glass body)

#### *Operation with 4-Electrode Type pH Electrode*

As shown in Figure 9 below, the basic system structure consists of a process of calculating and displaying numerical values in the process through a converter, a controller, and a manipulator.



**Fig. 9.** Basic system structure (here, VPT is the transforming unit)

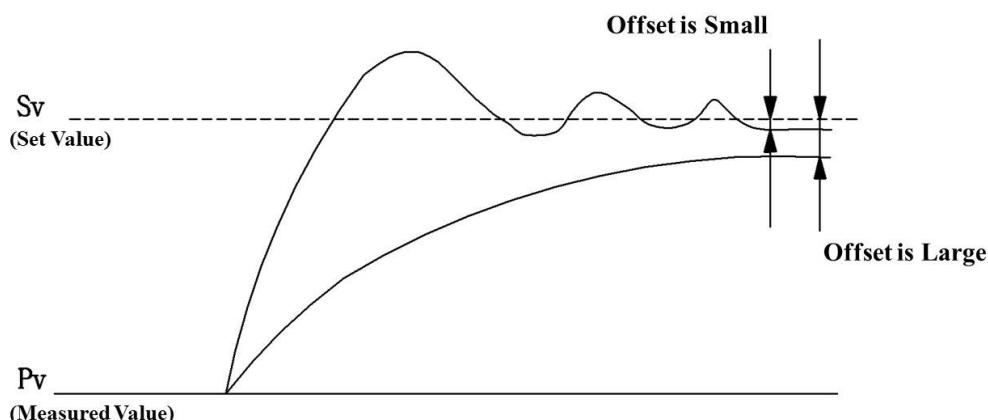


**Fig. 10.** Basic Operation Block System

As shown in Fig. 10 above, the basic operation block diagram shows that when the pH calibration is performed during the initial fabrication, all the signal data is calculated by the controller through the comparator. This is the general pH analyzer thus far, and the artificial intelligence type pH analyzer has a built-in output transmitter and indicating function. It is determined whether the signal output from the controller is "normal" or "bad", and if it is a "normal" signal, it is sent out, and if it is "bad", it is sent out as a second operation.

In the second arithmetic control, it is checked whether the signal judged bad is actually a bad signal. If the signal is sent again to the comparator, the controller will perform the arithmetic operation. This process displays optimized values, repeating the process of reading once a second, reading it out, and then exporting it as the final number.

In other words, the CPU main operation program can be said as the most basic pH control and is the general method as shown in Figure 10. It is possible to judge whether the primary output is actually the hydrogen ion concentration or the signal interference, and output the output. However, if there is a defect/decoy still detected in the result of the evaluation, the CPU comparator is then operated again to perform the second operation control. Eventually, the analyzer automatically repeats all of these operations with the pH electrode signal for the optimal pH control.



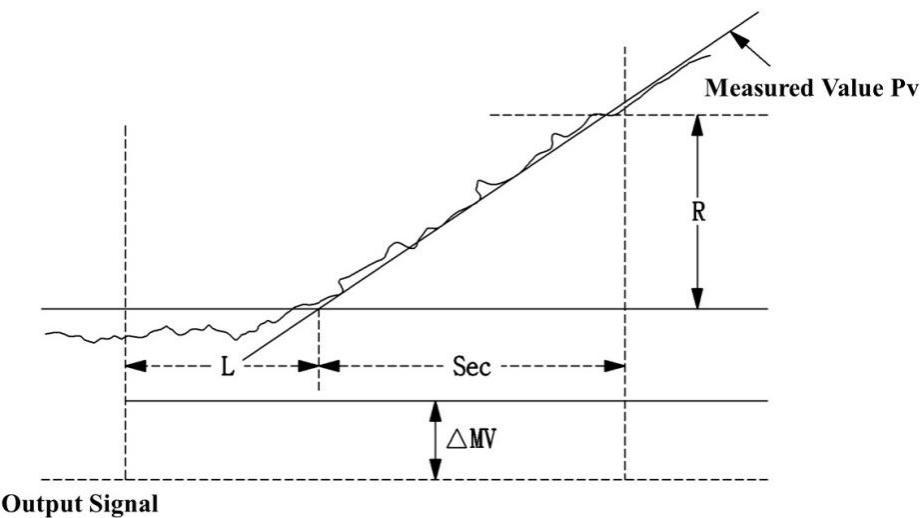
**Fig. 11.** Fuzzy Proportional Control Operation

As shown in Figure 11, the set values that require optimization operation in the field are actually different from the measured values. This is because the offset according to the set value and the offset according to the measured value are different from each other.

For example, let's assume that the optimal operating condition at the site is pH9.3 and that the actual measured value is pH9.0 with a large offset. Further assume that pH9.0 is counted in the CPU per second, and that the reference potential (0mV) of the reference electrode R1 does not change at least eight times in ten times. In this case, the current measurement is actually pH9.0. However, if pH9.2 with a small offset is 6 times out of 10 and pH9.0 is 4 times, the actual reading should be pH9.2.

Next, let's assume that all of these conditions are the same and that only the reference potential (0mV) has changed.

The reference electrode (R1) is theoretically 0mV but it changes due to various factors such as interference and contamination. However, the conventional analyzers have no ways to detect this. The reason is because it only detects the changed potential difference between the glass and the reference potential, but does not know how much the reference potential has changed.



**Fig. 12.** Automatic Balance Response

Suppose that the second glass (G2) senses the reference potential of the reference electrode (R1). For example, assume that 5mV has moved from the first 0mV. If the allowable range is  $0\text{mV}\pm 15\text{mV}$ , it will be recognized as "normal" value if the same number is repeated more than 8 of 10 times.

If 15mV is exceeded, it is recognized as a "bad" signal, and the calibration is automatically set to the original setting value of 0mV. In this case, the reference potential of the glass (G1) is set to 0mV without a buffer, and automatic calibration is performed.

As shown in Fig. 12, the measured value ( $P_v$ ) is always compared with the set value, and the "normal" and "bad" are judged and the output is transmitted.

## Conclusion

One of the reasons for measuring pH is that if the pH value is acidic, corrosion of the tank and pipe will occur if the conductivity of the boiler feedwater is very low. Periodic pH management is needed to minimize the burden of large-scale repair and maintenance costs. In some cases, the pH value is raised to 9 when necessary using an appropriate additive such as ammonia solution. By monitoring the pH index, you can instantly see the acid base flow through the ion exchanger.

This technology can improve the world's advanced power generating operation technology by possessing the core technology such as signal processing system that automatically resolves quick solution through the artificially intelligent self-diagnosis function in case of any system failures or troubles caused.

It allows reduction of unnecessary maintenance costs and enables early notification of replacement season of consumables. In addition, the stability of the facility operation and the accuracy of checking system are improved. Thus, it is possible to confirm and prevent these problems in the field in advance which is very effective for the overall operation of power generation facilities.

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