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Development of Board for Testing IR Combustible Gas Sensors and Their Performance Test

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Abstract - In this paper, we developed a board to test IR combustible gas sensors and achieved their performance test. For the first of all, we verified characteristics of sensors through testing from input of gases to output of voltages. Second, we induced a suitable calibration line to represent characteristics of sensors using linearization regression equation. Third, we improved measuring algorithm using recursion equation and Lagrange interpolation polynomial. Then, we proposed the best calibration line using by our algorithm to inspect gas leaks of safety management fields. To check performances of several sensors, we achieved the measurement tests with six standard gases made by Korea Gas Safety Corporation. We demonstrated instruments applied by our algorithm better in detecting accuracy other than detectors through experimental results.

Keywords - *Gas sensor, leak, detector, accuracy, interpolation*

I. Introduction

In May 2015, a gas explosion accident happened while removing residual gas in processing internal pressure test in the Chung-ju city at the LP gas professional inspection company, Korea [1]. In this accident one person killed, two people injured and over than 10 million won damaged in property. Usually gaseous accidents happened to critical damages against human and property resources [2]. In Korea, an inspector, completing courses on gas leak detection, has been to check and monitor gaseous facilities for preventing accidents. Nevertheless, a gas inspector wears protection equipment against toxic gases such as ammonia, carbon monoxide, they were poisoned. In these accidents, an inspector suffered sudden death. It found that combustible gases such as methane, hydrogen, can be exploded by very small sparks. So it is very important to usually effort the safety management when treating gases or in their facilities and pipelines.

In this paper, we developed an emerging gas leak detector using an IR gas sensor, which can be safely measured in explosion danger areas. We tested the performance of gas sensors and combustible gas detectors through comparing international good model and improved its performance such as accuracy, response time, range, and design.

II. Method

A. Combustible of Infrared Gas Sensor

Our criterion for selecting a compatible sensor is based on Table Ⅰ.

TABLE I. Criteria of a Sensor Module

Item	Content
Accuracy	≤±3% Full Scale %Vol.
MTBF	≥ 5 year
Explosion proof	0

As described in Table I, we found two type sensors to detect combustible gases. Fig. 1 shows their appearances of sensors. Before manufacturing gas leak detection instruments, we have to test and compare a variety of sensors based on specifications provided by manufacturers. Table II shows some parts of sensor's specifications [3], [4].

(a) Dynament (b) N.E.T

Figure 1. Gas sensor modules

Two type sensors have similar specifications. But, the N.E.T's sensor has more accurate than Dynament sensor's manufacturer at from 0% to 50% FS in methane. But over than 50% FS in methane, the Dynament's sensor has more accurate than the N.E.T.'s sensors. Moreover, the Dynament's sensor is lighter than N.E.T's sensor, otherwise N.E.T.'s sensor is cheaper than Dynament's sensor. . The results of these sensors are shown in Fig.3 and Fig. 4.

B. Performance Test of Infrared Sensors

To verify performances of sensors, we measured and analyzed sensor's output voltages according to variations of methane concentration. In general, better sensor, less error between ideal and measured values [5]. To verify performance of methane gaseous sensors, we measured the output voltages from sensors and compared their specifications and real measuring voltages. First of all, we installed the experiment instrumentations for performance of sensors as shown in Fig. 2. Then, we developed testing board of sensors from input of gases to output of voltages for the sensors made by N.E.T. Company. Fig. 2 shows a designed sensor testing board and scene of performance testing using standard gases with six kinds of concentrations.

TABLE II. SPECIFICATION OF SENSOR MODULES

<table>
<tr><td colspan="4">General</td></tr>
<tr><td colspan="2">Specification</td><td>Dynament</td><td>N.E.T.</td></tr>
<tr><td colspan="2">Operating Voltage Range</td><td>3.0-5.0 DCV</td><td>3.0-5.5 DCV</td></tr>
<tr><td colspan="2">MTBF</td><td colspan="2">≥5 years</td></tr>
<tr><td colspan="2">Weight</td><td>15g</td><td>22g</td></tr>
<tr><td colspan="2">Price</td><td>$275</td><td>$240</td></tr>
<tr><td rowspan="2">Ex Proof</td><td>ATEX</td><td colspan="2">II 2G Ex d IIC Gb</td></tr>
<tr><td>IECEx</td><td colspan="2">Ex d I and/or Ex d IIC</td></tr>
<tr><td colspan="4">Hydrocarbon</td></tr>
<tr><td colspan="2">Item</td><td>Dynament</td><td>N.E.T.</td></tr>
<tr><td rowspan="2">Measuring Range</td><td>Methane</td><td>0-5%,
0-100%vol.</td><td>0-5%,
0-100%vol.</td></tr>
<tr><td>HC</td><td colspan="2">0-100%LEL.</td></tr>
<tr><td colspan="2">Accuracy</td><td>±10%
(reading)</td><td>±1%FS(≤25%)
±2%FS(≤50%)
±5%FS(>50%)</td></tr>
<tr><td colspan="2">Response Time T90</td><td colspan="2">≤30 seconds</td></tr>
</table>

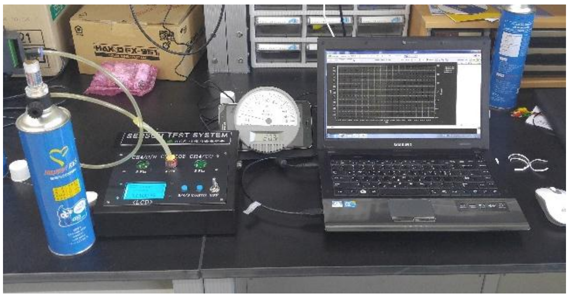

Figure 2. Testing board and performance test of gas sensors

Fig. 3 and Fig. 4 displays results of concentration measuring five tests of the 1st sensor at 30%LEL and 25%LEL in methane respectively. In here, peak voltages are uniformed at 3rd to 4th tests. Final concentration is used by average of five test results at Fig. 3 and Fig. 4. Fig. 5 shows average values of output voltages of three sensors made by N.E.T. and comparably good linear characteristics.

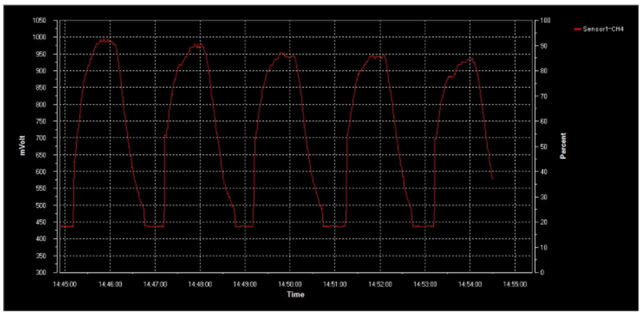

Figure 3. Test result of the 1st sensor at CH_4 30%LEL

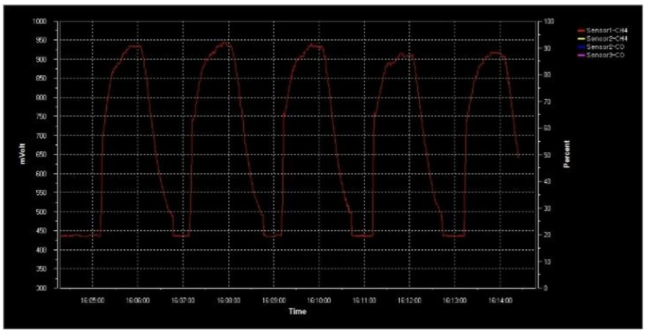

Figure 4. Test result of the 2nd sensor at CH_4 25%LEL

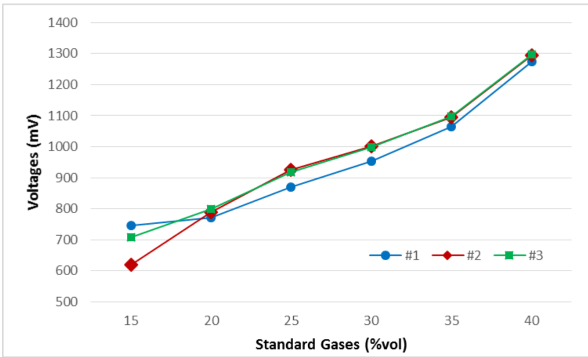

Figure 5. Output average voltages of test sensors

C. Analysis of Characteristic of IR Sensors

We utilized the method of least squares, one of the linear regression function, for analyzing the output voltages and improving accuracy of gas leak detectors. The method of least squares is getting the most approximate function from the data. In the other words, this method makes less error between the approximation function and data.

$$y = ax + b \qquad (1)$$

If the approximation function is (1), then the error equation is defined by using (2), number of n data ((p_1, q_1), (p_2, q_2), …, (p_n, q_n)), and (1).

$$e_i = q_i - y_i = q_i - (ap_i + b) \quad (2)$$

A goal of the method of least squares minimizes the sum of the squares of the error. So, the (3) expresses this goal:

$$S = \sum_{i=1}^{n} (e_i)^2 = \sum_{i=1}^{n} (q_i - y_i)^2 = \sum_{i=1}^{n} (q_i - (ap_i + b))^2 \quad (3)$$

Equations (4) and (5) are derived from (3) as a result of partial differential by gradient *(a)* and intercept *(b)* for minimizing sum of the squares of the error.

$$\frac{\partial S}{\partial a} = 2\sum_{i=1}^{n} (q_i - (ap_i + b)(-p_i) = 0 \quad (4)$$

$$\frac{\partial S}{\partial b} = 2\sum_{i=1}^{n} (q_i - (ap_i + b)(-1) = 0 \quad (5)$$

Based on (4) and (5), we calculated (6) and (7), which are approximation functions of the sensor output voltages.

$$y_d = 22.542\, x_d + 462.77 \quad (6)$$

$$y_n = 15.169\, x_n + 451.07 \quad (7)$$

The x is %LEL (Lower Explosion Limit) concentration of the gas, and the y is approximated output voltage of sensors. We can calculate sum of the squares of the errors using (3), and results are (8).

$$S_d = 0.12, S_n = 0.05 \quad (8)$$

Equation (8) means that the approximation for two sensors is very elaborate, and we can also check that absolute values of sum of error are close to zero. This fact means that the response is very excellent. So based on (6) and (7) that are calculated by the linear regression using the method of least squares, we can calculate the formula for %LEL concentrations of the real concentrations.

$$y_d = 0.0496 x_d - 0.0061 \quad (9)$$

$$y_n = 0.0501 x_n \quad (10)$$

Results of (9) and (10) follow Table III.

TABLE III. RESULT VALUES OF PREDICTION

Standard gas (%LEL)	Prediction(%Vol)	
	Dynament	N.E.T
15	0.7501	0.7515
20	0.9981	1.002
25	1.2461	1.2525
30	1.4941	1.503
35	1.7421	1.7535
40	1.9901	2.004
45	2.2381	2.2545

D. Development and Test of IR Combustible Gas Detector

Output values of the sensor can be changed from its unique characteristics, using frequency, temperature and humidity conditions and so on [6]. So we have to apply some calibration like interpolation, mapping, and learning and so on [7]. Therefore, we developed combustible gas (CH_4, C_3H_8) detector using IR sensors and accuracy improvement algorithm using Lagrange interpolation and linear piecewise approximation. Then, we tested their performance through measuring and analyzing output from gas detectors when injecting variety of standard gases made in Korea Gas Safety Corporation.

<Domestic> <International>

Figure 6. Comparison Test of combustible gas detectors

Two combustible gas detectors using IR sensors which are shown Fig. 6 are manufactured by using the Dynament's sensor. A domestic detector applies the linear regression using eight kinds of standard gases, and an international product is guaranteed performance by the Research Institute of Standard for Environmental Testing. Experiment environment follows Table IV.

TABLE IV. ENVIRONMENT OF EXPERIMENT

Item	Domestic	International
Temperature	18.6 ℃	23.7 ℃
Humidity	22%	42%

Table V, Fig. 7 and Fig. 8 show concentration experiment results of a domestic gas detector. A domestic detector has some errors at 15%LEL, 25%LEL and 45%LEL section about max values. About T90 values, this has some error at 25%LEL, 40%LEL and 45%LEL section.

TABLE V. RESULT VALUES OF A GAS DETECTOR (DOMESTIC)

Standard gas		Max values (%Vol)	T90 values (%Vol)
%LEL	%Vol		
15	0.75	0.88	0.72
20	1	1.04	1.02
25	1.25	1.5	1.45
30	1.5	1.51	1.48
35	1.75	1.77	1.75
40	2	2.16	2.08
45	2.25	2.12	2.08

TABLE VI. RESULTS OF A COMBUSTIBLE GAS DETECTOR (INTERNATIONAL)

Standard gas		Max values (%Vol)	T90 values (%Vol)
%LEL	%Vol		
15	0.75	15	15
20	1	20	20
25	1.25	29	29
30	1.5	31	30
35	1.75	35	34
40	2	41	40
45	2.25	47	46

TABLE VII. COMPARISON OF PREDICTION AND MEASUREMENT VALUES

Standard gas		Predicted		Measured	
%LEL	%Vol	output	errors	output	Errors
15	0.75	0.7501	0.0001	0.72	-0.03
20	1	0.9981	-0.0019	1.02	0.02
25	1.25	1.2461	-0.0039	1.45	0.2
30	1.5	1.4941	-0.0059	1.48	-0.02
35	1.75	1.7421	-0.0079	1.75	0
40	2	1.9901	-0.0099	2.08	0.08
45	2.25	2.2381	-0.0119	2.08	-0.17
Sum of errors			-0.0413		0.08

Table VII shows the results of concentration experiments for an international gas detector (RaeSystems co., Ltd), and the graphs are shown in Fig. 7 and Fig. 8. Errors of this detector are very small except 25%LEL section on the max and T90 values as shown in Table VIII and Fig. 9. Results of testing methane detectors, output curve of an international detector is more linear other than a Korean detector.

Here, we proposed a method to approximate output of a gas leak detector using T90 values and calculation result of (9). In Table VIII and Fig. 9, we can know that our proposed method, output of a detector using prediction (9) are more elaborate than those of a Korean realistic detector.

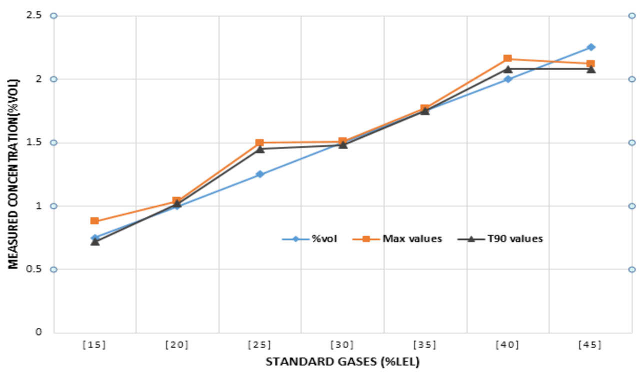

Figure 7. Results of gas concentration density (domestic)

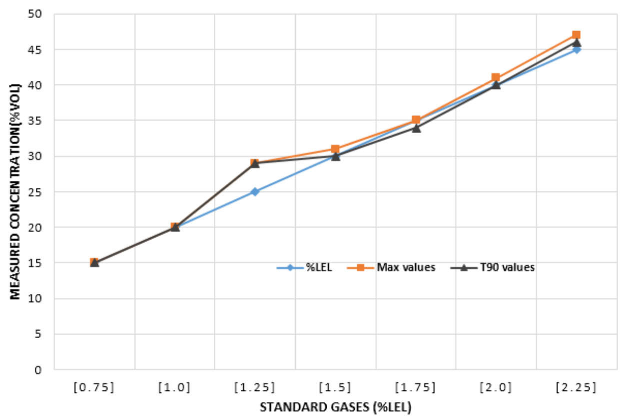

Figure 8. Results of gas concentration density (international)

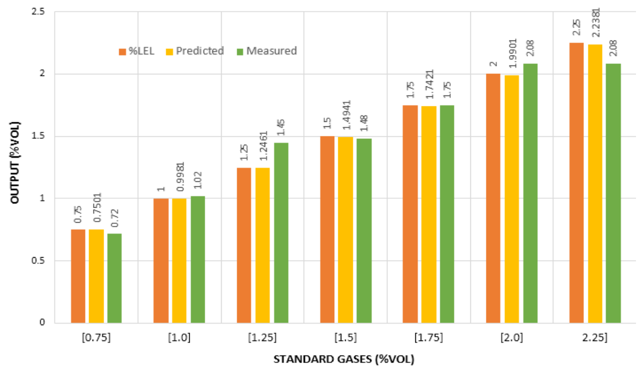

Figure 9. Results of predicted and measured values

III. CONCLUSION

In this paper, we developed a board to test IR combustible gas sensors and performed their test. Then, we induced the best calibration line to represent characteristics of sensors using linearization regression equation and Lagrange interpolation polynomial. We tested and analyzed the performance of infrared gas sensors and applied a gas detector manufacture. To analyze our and other company's detectors, we performed measurement tests with eight standard gases made by Korea Gas Safety Corporation. We demonstrated that the gas leak detector is better in measuring accuracy other than detectors through gaseous concentration experiments.

Hopefully we'll prevent the dangerous gas and fire incidents as using our developed instruments in the gas safety management fields.

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