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Research on Development and Accuracy Improvement of an Explosion Proof Combustible Gas Leak Detector Using an IR Sensor

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Abstract**—**In this paper, we presented not only development technology of an explosion proof type and portable combustible gas leak detector but also algorithm to improve accuracy for measuring gas concentrations. The presented techniques are to apply the flame-proof enclosure and intrinsic safe explosion proof to an infrared gas leak detector at first in Korea and to improve accuracy using linearization recursion equation and Lagrange interpolation polynomial. Together, we tested sensor characteristics and calibrated suitable input gases and output voltages. Then, we advanced the performances of combustible gaseous detectors through reflecting demands of gas safety management fields. To check performances of two company's detectors, we achieved the measurement tests with eight standard gases made by Korea Gas Safety Corporation. We demonstrated our instruments 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.

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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 years
Explosion proof	0

As described in Table I, we found two sensors to detect combustible gases Fig. 1 shows their sensors. Before 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

Fig. 1 Gas sensor modules

Two sensors have similar specifications. But, the N.E.T's sensor has more accurate than Dynament sensor's manufacturer at 0% to 50% FS. But over than 50% FS, the Dynament's sensor has more accurate than the N.E.T.'s sensor. Moreover, the Dynament's sensor is lighter than N.E.T. sensor's manufacturer, and N.E.T.'s sensor is cheaper than Dynament's sensor.

B. Performance Test of Infrared Sensors

To verify the performances of sensors, we measured and analyzed the sensor's output voltages according to the variations of methane concentration. In general, better sensor means 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 measured output values from sensors Dynament and NET companies. The results of these sensors are shown in Table III and Fig. 3.

TABLE II
SPECIFICATION OF SENSOR MODULES

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

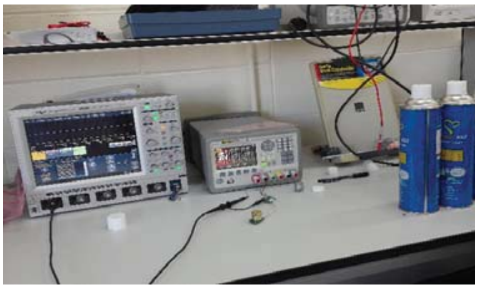

Fig. 2 Performance Test of gas sensor modules

TABLE III
RESULT OF SENSOR MODULES

Standard Gas		Dynament (mV)			N.E.T.(mV)		
%LEL	%Vol	max	min	mean	max	min	mean
0	0	438	428	432.3	438	416	425.6
15	0.75	807	797	802.1	739	717	726.8
20	1	919	907	912.8	751	729	740.3
25	1.25	1100	1099	1104.7	869	845	859
30	1.5	1152	1142	1146.4	883	860	872.2
35	1.75	1236	1224	1230.3	997	974	988
40	2	1348	1338	1343.1	1048	1039	1043.5
45	2.25	1468	1460	1464.4	1144	1135	1138.6

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.

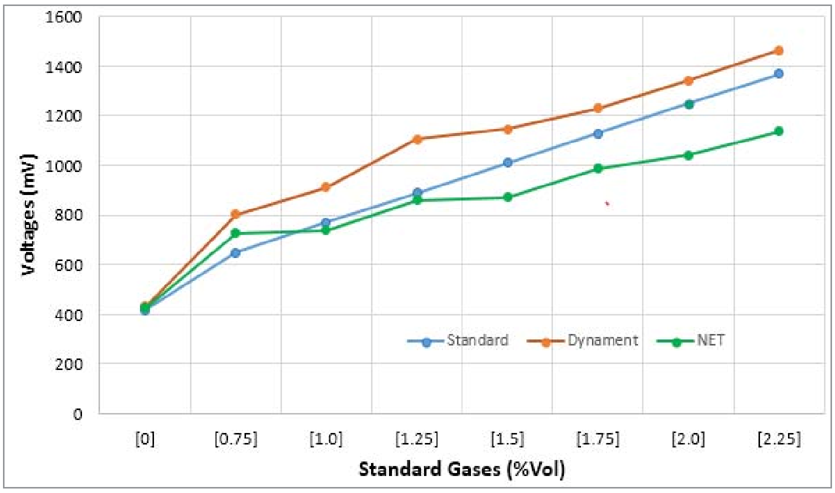

Fig. 3 Result of output voltages of sensors

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

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, (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) are in Table IV.

TABLE IV
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, by 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>

Fig. 4 Comparison Test of combustible gas detectors

Two combustible gas detectors using IR sensors which are shown Fig. 4 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 V.

TABLE V
ENVIRONMENT OF EXPERIMENT

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

Table VI and Fig. 5 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 VI
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 VII shows the results of concentration experiments for an international gas detector (RaeSystems co., Ltd), and the graphs are shown in Fig. 6. Errors of this detector are very small except 25%LEL section on the max and T90 values as shown in Table VIII and Fig. 7. Results of testing methane detectors, output curve of an international detector is more linear than a Korean detector.

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TABLE VII
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

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. 7, we can know that our proposed method, output of a detector using prediction (9) are more elaborate than those of a Korean realistic detector.

TABLE VIII
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

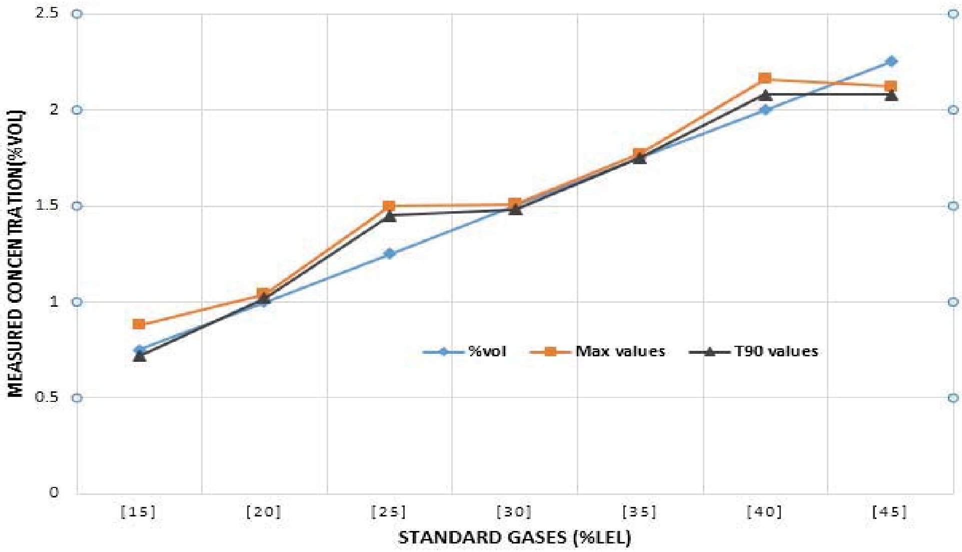

Fig. 5 Results of gas concentration density (domestic)

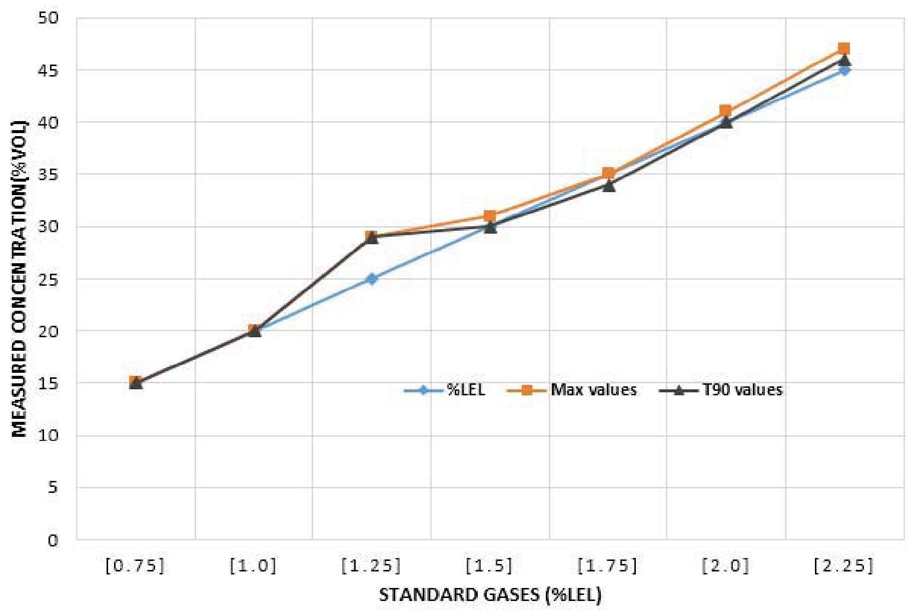

Fig. 6 Results of gas concentration density (international)

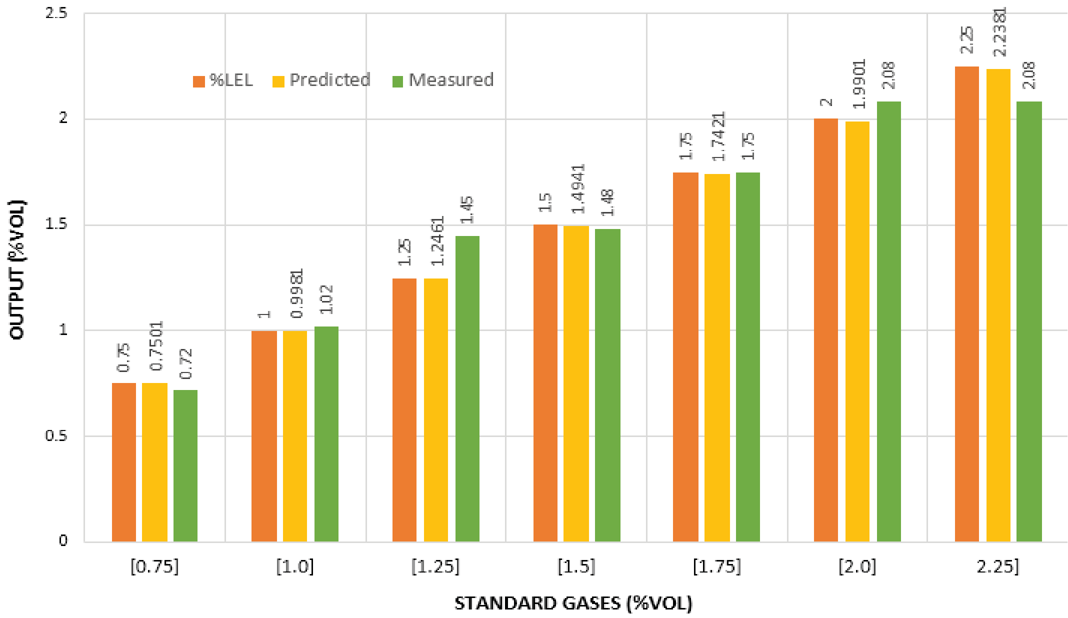

Fig. 7 Results of predicted and measured values

III. Conclusion

In this paper, we tested and analyzed the performance of infrared gas sensors and combustible gas detectors, and we suggested a method to improve accuracy using linear regression equation, linear piecewise approximation, and Lagrange interpolation polynomial. We, also, proposed applying techniques of flame proof enclosure and intrinsic safe explosion proof to an infrared gas leak detector at first in Korea. Also, to advance detector's performances, we added easy functions such as colorful LCD and protection structure of measuring pipe after investigating field demands. 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 than detectors through gaseous concentration experiments.

Besides, our combustible gas detectors can transfer the measured concentration data to the smart appliances. Hopefully, we will prevent the dangerous gas and fire incidents by using our developed instruments in the gas safety management fields.

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