Calculation of Response Characteristics of Various Hydrocarbon Gas Sensors

Junhee Lee and Hyeri Jang*
Director, *Senior Researcher / R&D Center
Worldi Co., Ltd.
Seoul, South Korea
videoman720@worldi.kr, **jhr3675@ worldi.kr*

G. T. Park*, Sangho Shin, Daehwan Kwon, Inkyum Kim
*Corresponding Author, Researchers
Safety Research Division, K. G. S
Chungbuk-do, South Korea
**gtparkgs@kgs.or.kr*

***Abstract*—**Technologies for detecting leaks of gases and measuring gaseous concentrations have been widely developed with every sensor type. To manufacture excellent gas leak detector, an excellent gas sensors are necessary parts. In this research, the design of a system to simultaneously measure performances of five gas sensors is introduced. That system need the components of measuring appliances, sensing circuits, control firmware, and PC software to be operated. Also the performances to test gas sensors need response characteristics, accuracy, and repeatability according to output signals for injecting gas amounts into gas sensors. The firmware is implemented to operate sensors and to acquire output data against for input of sensors in real time. Acquired data were stored in the text file according to every sensor during a pre-set measurement interval. Software is coded to draw graphs of the voltage values measured by each sensor in real time. Using proposed a testing system we showed how to test response characteristics and induce better calibration equations of five sensors. This paper compared experimental data of five sensors and verified which gas sensor is the best.

Keywords- *gas sensor, leak detector, concentration, response characteristics*

*****

I. INTRODUCTION

Amounts of gas of LPG, LNG, and CO in a variety of gas facilities have been growing according to the gaseous industry and factories were expanded. Preventing risks from gas leaks and explosions in the industry fields, gas safety management is essential [1]. On Sept 14, 2018, thousands of miles of natural gas pipeline in Massachusetts are leak-prone and need repair, utilities have told state regulators, highlighting aging energy infrastructure risks after explosions ripped through three towns outside of Boston, USA [2]. By the Risk yearbook 2017 from KGS, 574 gas risks have occurred for 5 years. As those results, 61 people were died and 524 people had major injuries [3].

Protection and safe management against gas risks are very momentous at facilities using toxic or combustible gases. To prevent a variety of gas risks and risks, Korea Gas Safety Corporation has been achieving the completion inspection and a regular check using a gas leak detector in the gas facilities such as gas valves, joints, gauges and pipelines [4].

To fully perform the gas safety management and inspections, excellent gas sensors and detectors with good monitoring algorithms using least squares by swarm by intelligence techniques are inevitably needed [5]. The required functions of gas detectors are high sensitivity at low concentration range, fast response time, high measuring accuracy and enhanced durability [6]. Before gas sensor is applied to a detector, response characteristics of gas sensor verified by a sampling module to inject standard gases under controlled gas flow rate [8]. In this paper we proposed a system to measure and test sensitivity, accuracy and initial response time for gas sensors. Thus proposed system will be used to inspect gas leakages and prevent gas risks at various industry facilities and gas plants.

II. SELECTION OF TARGET SENSORS

A. Conditions of Selected gas sensors

It is very significant to use a superior gas sensor to manufacture the superb gas leak detector. An outstanding gas sensor has great calibration between input and output [9]. So, we searched, analyzed, and selected several sensors being used at industry fields for practically manufacture flammable gas leak detectors. There are various types to manufacture sensors. Their manufacturing methods are semiconductor, hot-wire, or catalytic combustion, electric chemical, and non-dispersive IR etc. The characteristics and specifications are different ever sensor. Gas leak manufactures need to conclude and select which sensor is best. Because it is affected to performance of a gas leak detector and equipment, selecting better gas sensors is very important. Performances of gas leak detectors are usually influenced by fast response time, detecting range and accuracy.

There are advantage and disadvantage according to sensor ’ s manufacturing types. Compared catalytic combustion sensors to optical sensors, optical sensors are long for lifetime, higher for accuracy, and low for power consumption. But in low concentration range, an optical gas sensor has slow response time because of measured by scanning small gas particles in an optical path. Because the optical detector absorbs intensity of the infrared source if it is same wavelength of the target gas, the detecting performance can be very weak if other than wavelengths of target gas are not filtered.

Semiconductor sensors usually use SnO2 basis and are excellently sensitive, but stabilizing time is long. If gas sensors are used in risk regions where leaks of flammable gases are frequently occurred, sensitivity is good but stabilizing time is bad. It is required for sensor with explosion proof structure in risk zone. Accuracy rate of gas sensors should be less error than plus and minus 3% if it is a good sensor. Lifetime should be more than 5 years. To enable manufacturing the best gas leak detector we should recommend best gas sensors to

ISSN: 2454-4248
57 – 61

manufacturers. It is preventing risk from gas leaks and explosions in gas industrial fields.

B. Specifications of gas sensors

After that, we selected five gas sensors frequently used through investigating their several performances of sensors of four manufacturers in Korea and international countries. Their specifications of selected sensors are shown in Table 1.

TABLE I. SPECIFICATIONS OF TARGET GAS SENSORS

Items	CH4-D3-3V	KNC801	INP20-CH45	MSH-P	MSH-DS
Picture					
Manufacturer	E	K	N	D2	D1
Target gas(Vol%)	CH4 (0~5%)	CH4 (0~5%)	CH4 0~4.4%	CH4 (0~5%) C3H8	CH4 (0~5%)
Current	25mA	76mA	45mA	15mA	80mA
Explosion Proof Structure	None	Ex d	Ex d	Ex d	Ex d
Power(V)	5.0	3.0	3~5.5	3~5	3~5
Temperature(℃)	-20~+50	-20~+50	-40~+60	-20~+50	-20~+50
Response time(T90)	100sec	10sec	≤30 sec	≤30 sec	≤30 sec
Accuracy	±3%	±3%	±2% (≤50%)	±2% (≤50%)	±2%

III. DESIGN OF THE TEST SYSTEM OF GAS SENSORS

A. Concept to test gas sensors

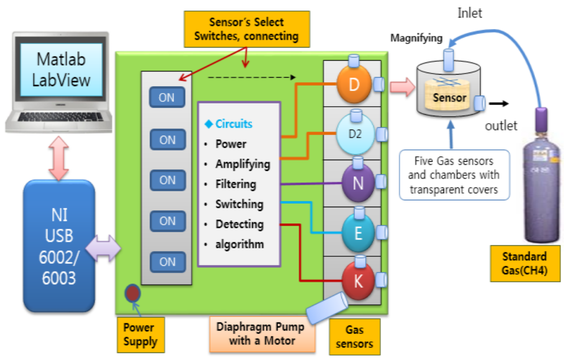


Figure 1. Concept of a system for testing various sensors

We designed concept of a system for testing performance of 5 gas sensors as shown in figure 1. It shows concept and all layouts of a test board with five gas sensors, connecting and signal streams, interfaces, and real CH_4 gases. Every gas sensor is covered with a small chamber consisted of transparent acryl materials. The suction pump serves injecting standard gases from a pressure vessel into the sensors and emitting gases to the outlet. A suction pump is configured with a diaphragm pump and a motor. The reason for this is operated for fast flowing and measurement. Switches are used to select sensors to be targets for testing. The power is supplied with DC 12V and 5A. And then we configured hardware circuits, which are power, sensing and amplifying, filtering, switching, and detecting circuits. When gas sensors are tested, temperature and humidity are very important components [10]. In this test environment, room temperature is about 25℃ and humidity is about 85%.

B. Design of circuits for measuring gas sensors

In here, we selected five sensors to check and test characteristics of operation. Operation method of each sensor is different each other. So, every sensor, we designed power operating, filtering, and amplifying circuit. Figure 2 shows operating and sensing circuit for a MSH-DS sensor. It uses a MCU and RS485 communication method by connecting of RX and TX ports. Figure 3 shows the operating circuit for a MSH-P sensor. Figure 4 shows the circuit for operating an INP20-CH45 sensor. Figure 5 is the circuit for operating a KGS 801 sensor. Figure 6 shows the circuit for operating a CH4-03-3V sensor an advanced ICs.

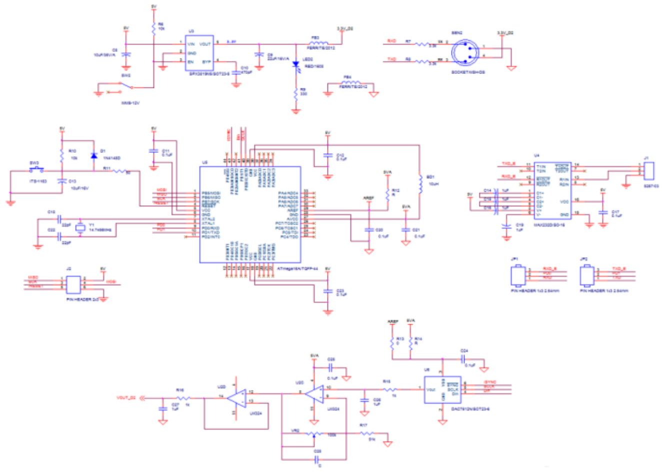


Figure 2. The operating circuits for a MSH-DS sensor.

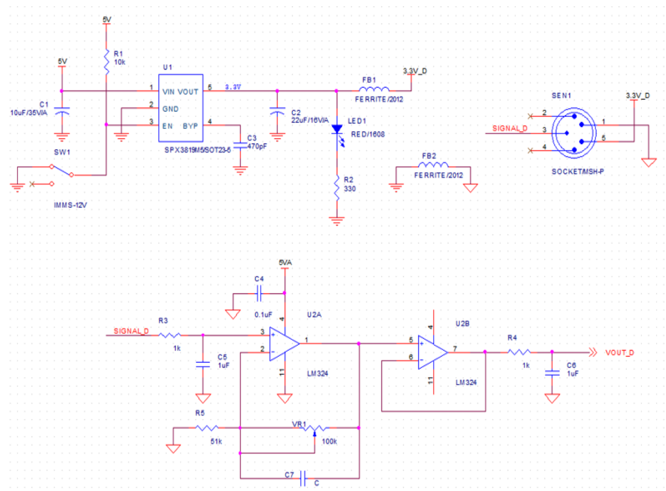


Figure 3. The operating circuit for a MSH-P sensor.

ISSN: 2454-4248
57 – 61

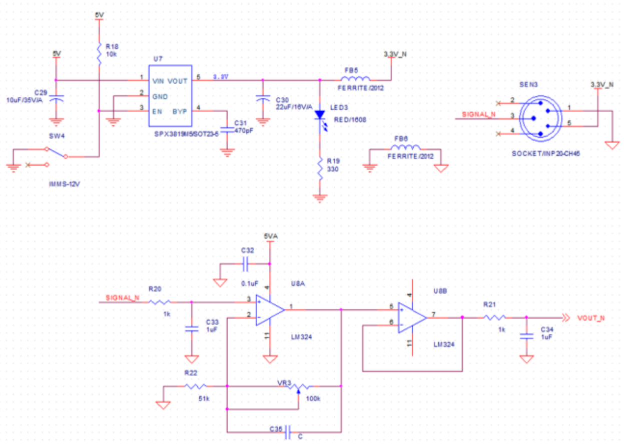


Figure 4. An operating circuits for an INP20-CH45 sensor.

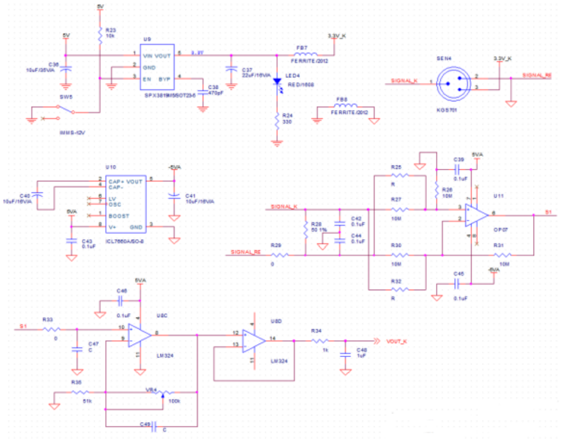


Figure 5. The circuits for operating a KGS 801 sensor.

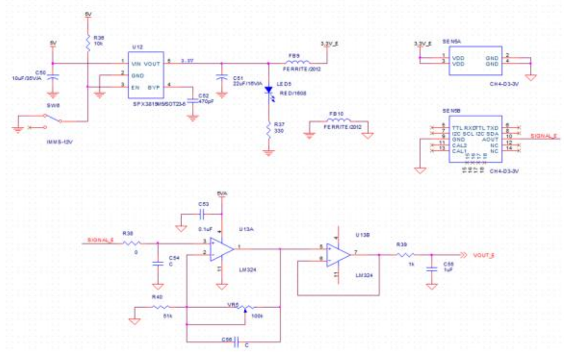


Figure 6. The circuit for operating a CH4-03-3V sensor.

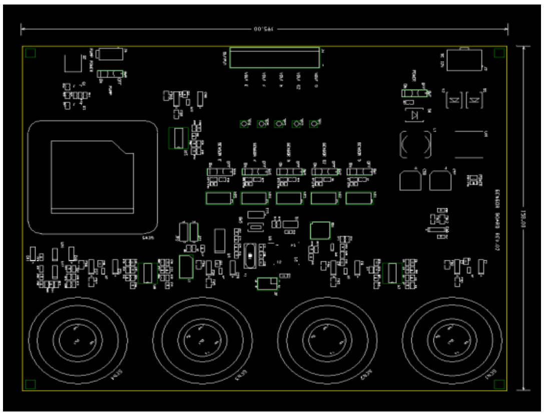


Figure 7. Appearance of a manufactured PCB

To manufacture a sensor testing system, the printed circuit board is made according to circuit designs as shown in figure 7. Figure 8 shows the manufactured testing system to measure performances of five sensors. The designed and manufactured test board is operated according as a procedure and a sequence to test performances of gas sensors as shown in figure 9 after the power is on. In addition, Matlab/Simulink program codes are implemented for acquiring data via the test board from each sensor and for displaying real data on screen of PC as shown in figure 10. The sources of implemented codes are effectively to measure sensors and those algorithms are ported to memory on the test circuit board. Which are crossly compiled by a firmware tool on PC. The operating order is as followings. First, after the power is on, the system is on and the pump is operated. Second, standard gases of methane are injected to small chambers of all gas sensors. Third, five sensing circuits measure output signals of voltages. Fourth, after receiving those output signals of voltages using a DAQ kit, the Lab-view program with the calibration algorithm calculates gas concentration against input and displays those data on PC screen. Continuously, Matlab/Simulink can be executed to acquire signals of sensors and displayed concentration data from sensors in real time.

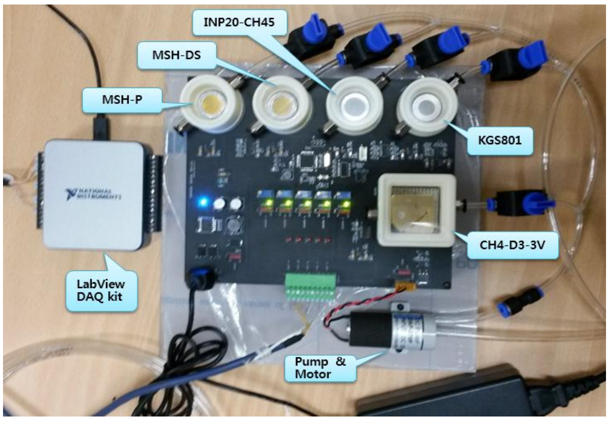


Figure 8. A Circuit system board for testing sensors

The output voltages measured from the sensors are transformed. Their data are graphed on the PC screen in real time. Also, the calculated data by each sensor are stored as electronic files of output (0).txt ~ output (4).txt at the same time. Those data can be opened and displayed as a graph. All data can be easily compared and analysed simultaneously on one screen. In here, we implemented an algorithm to accurately measure output voltage from every sensor. The measuring algorithm is made by inducing an interpolation polynomial function after generating a look-up table through input-output experimenting using seven types of gas concentration. That interpolation function is used by 6-order Lagrange interpolation.

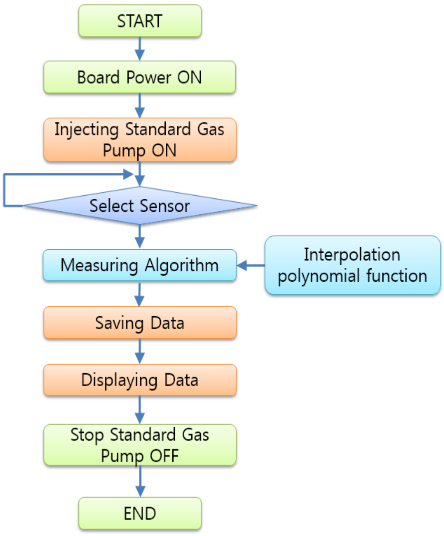
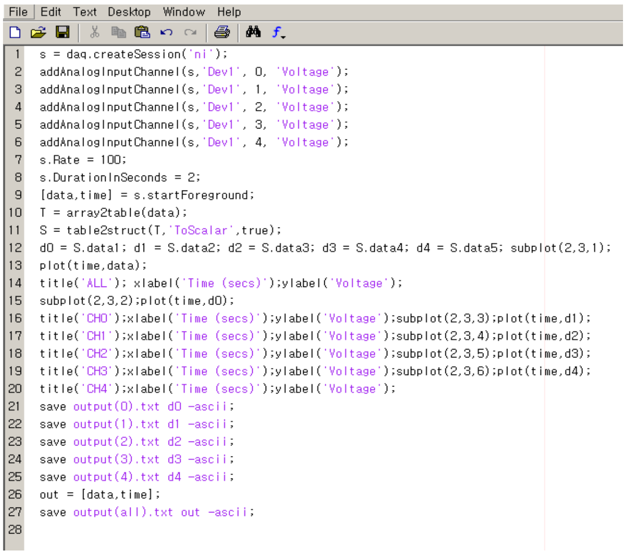


Figure 9. The procedure to operate a test board.



```
s = daq.createSession('ni');
addAnalogInputChannel(s,'Dev1', 0, 'Voltage');
addAnalogInputChannel(s,'Dev1', 1, 'Voltage');
addAnalogInputChannel(s,'Dev1', 2, 'Voltage');
addAnalogInputChannel(s,'Dev1', 3, 'Voltage');
addAnalogInputChannel(s,'Dev1', 4, 'Voltage');
s.Rate = 100;
s.DurationInSeconds = 2;
[data,time] = s.startForeground;
T = array2table(data);
S = table2struct(T,'ToScalar',true);
d0 = S.data1; d1 = S.data2; d2 = S.data3; d3 = S.data4; d4 = S.data5; subplot(2,3,1);
plot(time,data);
title('ALL'); xlabel('Time (secs)');ylabel('Voltage');
subplot(2,3,2);plot(time,d0);
title('CH0');xlabel('Time (secs)');ylabel('Voltage');subplot(2,3,3);plot(time,d1);
title('CH1');xlabel('Time (secs)');ylabel('Voltage');subplot(2,3,4);plot(time,d2);
title('CH2');xlabel('Time (secs)');ylabel('Voltage');subplot(2,3,5);plot(time,d3);
title('CH3');xlabel('Time (secs)');ylabel('Voltage');subplot(2,3,6);plot(time,d4);
title('CH4');xlabel('Time (secs)');ylabel('Voltage');
save output(0).txt d0 -ascii;
save output(1).txt d1 -ascii;
save output(2).txt d2 -ascii;
save output(3).txt d3 -ascii;
save output(4).txt d4 -ascii;
out = [data,time];
save output(all).txt out -ascii;
```

Figure 10. The program codes to draw sensor's data

IV. EXPERIMENTS AND RESULTS

To achieve experiments of gas sensors, fives gas sensors 4 manufacturers were mounted on the test circuit board. Standard gases of methane with seven types of concentration with (0.5%, 1.25%, 2%, 2.75%, 3.5%, 4.25%, and 4.5%). The output voltages were measured and recorded in real time by connecting between a NI USB-6002 device and the test board with sensors. The experimental temperature was 22.6℃ and the humidity was 65%. The standard gases had error ranges of plus and minus 2%, but their error ranges were not applied at performance test. Figures 11, 12, and 13 show results of stabilization state test of five gas sensors. Stabilization times of them, T90, are measured under 30 seconds.

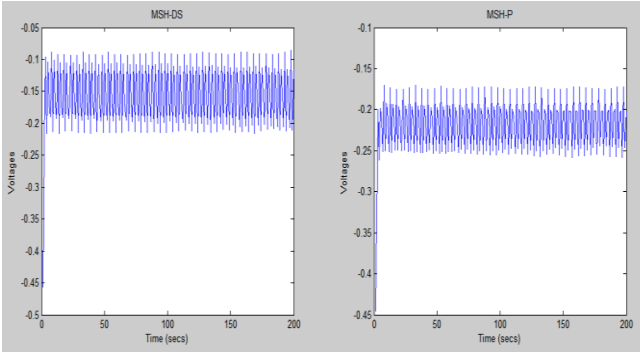


Figure 11. Stabilization of sensors of MSH-DS and MSH-P

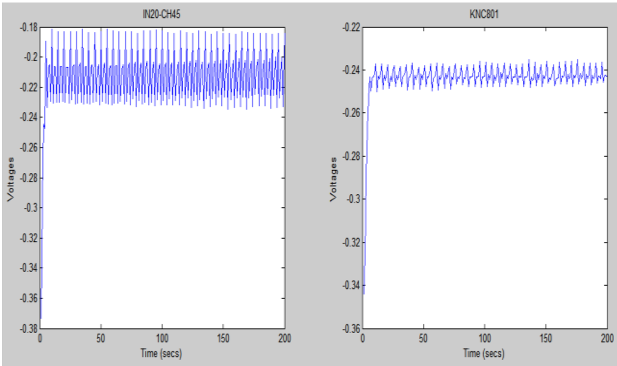


Figure 12. Stabilization of sensors of IN20-CH45 and KNC801

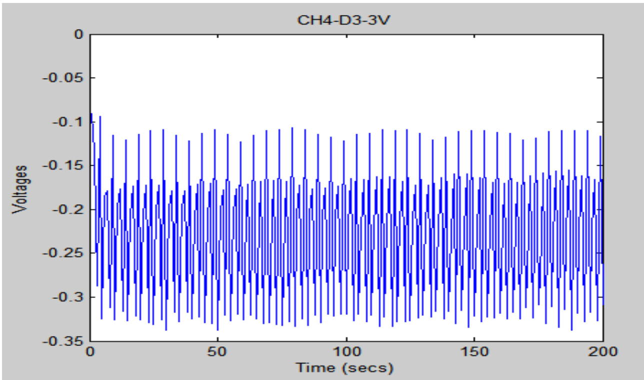


Figure 13. Stabilization of a sensor of CH4-D3-3V

In this Table 2, the normalized averages of measured output voltages from sensors are shown by seven classified values while standard methane gases of seven concentration are injected into the sensor's chambers for 5 minutes. The averages of normalized concentration data five times are graphed as shown in figure 14. Accuracy and response time can be compared and verified by displaying measured concentrations. We verified performances and characteristics for five gas sensors. Linearity of five gas sensors is good. Of all, the best sensor is second, KNC-801. If engineers control gradient (m) and offset of output equation, line equations of second and fifth gases are similar to a line of standard gases. And then accuracy of other sensors as well as second and fifth can be improved by numerical analysis such as Lagrange's and Neville's interpolation formula. Every sensor can be used at gas industry fields if sensitivity and offset are adjusted.

TABLE II. AVERAGES OF NORMALIZED OUTPUT VOLTAGES MEASURED FROM FIVE SENSORS

Standard CH4 (%Vol)	Sensor 1 (CH4-D3-3V)	Sensor 2 (KNC-801)	Sensor 3 (INP20-CH45)	Sensor 4 (MSH-P)	Sensor 5 (MSH-DS)
0	0.412	0.005	0.073	0.02	0.189
0.5	0.904	0.555	0.248	0.412	0.502
1.25	1.396	1.105	0.528	0.904	1.007
2.0	1.888	1.655	0.798	1.396	1.456
2.75	2.380	2.205	1.108	1.888	1.893
3.5	2.873	2.755	1.360	2.380	2.328
4.25	3.365	3.305	1.723	2.873	2.892
5.0	3.857	3.855	2.138	3.365	3.480

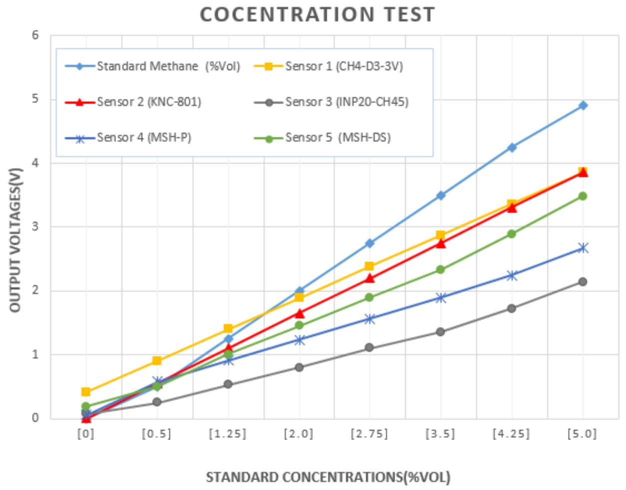


Figure 14. The graph of output voltages from five sensors.

V. CONCLUSIONS

In spite of uncountable efforts against gas risks, they are occurring in industrial fields until now. It is necessary to effectively prevent those gas risks and reduce damages from risks. To cope effectively with gas leak and explosion risks, human's effort as well as superb gas leak detectors are needful in industry fields. Better a senor, better a gas leak detector. So, we, here, proposed and designed a circuit system for testing various gas sensors to widely distribute them to gas inspectors and managers. Also, we demonstrated a result acquiring data from sensors and displayed their data on screen by using a Labview device and Matlab codes. Through this research, we proposed a method to test gas sensors and to improve performance of gas sensors with Lagrange Interpolation polynomial. We realized that excellent gas sensor is important to achieve high accuracy and fast initial response time. From experimental results by using the developed a test board, we could be decide which sensor is best. Each sensor is not perfect, but each it is an advantage. The five gas sensors can be widely utilized at manufacturing portable gas leak detectors and static gas detectors. A sensor of them can be needed to adjust gradient and offset. A sensor can be necessary to induce an interpolation polynomial equation for improving measurement accuracy. On the other hand, the proposed gas testing system will be utilized at 4th industry with related gas safety and management. Also, it will be used at test of many other gas sensors, such as, monoxide (CO), hydrogen (H_2O), exhausted fume, and toxic gases.

ACKNOWLEDGMENT

This research was supported by the Ministry of Trade Industry and Energy under the theme of "Commercialized Development of the IoT Sensor Basis Remote Monitoring System for Lager Gas Tanks and Plants (20172220100450)" and "Development of Concept Design on Integration System of Knowledge Basis Framework for Generation Plant Operation & Maintenance (10082562)"

REFERENCES

[1] Incident Investigation & Safety Checkup Division, Gas Incident Statistics, Korea Gas Safety Corporation, 2017
[2] https://www.cnbc.com/2018/09/14/reuters-america-massachusetts-gas-explosions-shine-spotlight-on-century-old-pipelines.html
[3] Incident Investigation & Safety Checkup Division, Gas accident yearbook, Korea Gas Safety Corporation, 2017
[4] Gyoutae Park, Geunjun Lyu, Youngdo Jo, Jaheon Gu, Jongbu Eun, and Hiesik Kim, "Development of Gas Safety Management System for Smart-Home Services," International Journal of Distributed Sensor Networks, vol. 9, issue 591027, 2013
[5] Peng Chen, Yonghong Xie and et al., "A wireless sensor data-based coal mine gas monitoring algorithm with least squares support vector machines optimized by swarm intelligence techniques," International Journal of Distributed Sensor Networks vol. 14, pp. 1-21, 2018
[6] Gyou-tae Park, Geun-jun Lyu, Young-do Jo, Jeong-rock Kwon, Sang-guk Ahn and Hiesik Kim, "A Study of the Development and Accuracy Improvement of an IR Combustible Gas Leak Detector with Explosion Proof," KIGAS, vol. 18, pp. 1-12, 2014
[7] I. V. Sadkovskya, A, I. Eikhval'd, and T. A. Eikhval'd, "Measurement of the Compressibility of Working Liquid of a Laser Interferometric Oil Manometer with the help of a low-pressure Interferometric Piezometer," Measurement Techniques, vol. 61, pp. 481-485, 2018
[8] Grzegorz Jasinski, Anna Strzelczyk and Piotr Koscinsk, "Gas sampling system for matrix of semiconductor gas sensors," Mater. Sci. Eng. Vol. 104, no. 012033, 2015
[9] L Dewi and Y Somantri, "Wireless Sensor Network on LPG Gas Leak Detectin and Automatic Gas Regulator System Using Arduino." Mater. Sci. Eng. vol. 384, no. 012064, 2018
[10] P Suchorska-Wozniak, W Nawrot, O Rac, M Fiedot and H Teterycz, "Improving the sensitivity of the ZnO gas sensor to dimethylsulfide," Mater. Sci. Eng. no. 104, no. 012030, 2015