Microcontroller based Ammonia Leak Detection using NH4-NH3 Electrochemical Sensor

Vijaysinha V. Wankhede[1] Prof. V. M. Joshi[2]
[1,2]Department of Electronics & Telecommunications Engineering
[1,2]TSSM's PVPIT, Pune, India

Abstract— The paper consists of Ammonia leak detection algorithm which is an application. It based on PIC microcontroller using electrochemical sensor. Running a large scale industry, safety of worker and equipment is on first priority. When an industry specially runs in risky chemicals such as production of ammonia or use of ammonia as secondary chemical, it is a need to set up a safety system inside the industry. So to overcome this problem, here is a simple and low cost solution is provided. NH4-NH3 is a one of the simple and useful gas sensor widely used in chemical industries. By adhering to industry standards for size and connection orientation, the NE4-NH3 can be retrofitted easily to existing product designs. By using PIC microcontroller the leakage of gas is analyzed and processed for implementing an alarm system. Main purpose of this system is to provide safety of an industrial environment. The leakage detection and ECS algorithms proposed here are applied to the methodology, and the collected concentration data is analyzed. A detection rate of 99.8% is achieved, with 3 alarms recorded over 7 days, and an average detection delay of 800 msec.

Key words: Ammonia Gas Sensor, Electrochemical Sensor, NH4-NH3, PIC, PPM

I. Introduction

Running a large scale industry, safety of worker and equipment is on first priority. As plenty of accidents happen in workplaces where hazardous gases involved in the process of productions, which may leads to the serious injuries, deaths, equipment loss. When an industry specially runs in risky chemicals such as ammonia it needs to set up a safety system inside the industry. So to come up with this problem, here is a simple and low cost solution is provided.

Most of these leaks, even if detected, go unreported when they do not directly lead to major physical accidents. The Ministry of Environment and Forests reports estimate that in India alone, these plants emit close to one billion cubic meters of ammonia (not taking any other gas into consideration). Most of these losses (around 90%) seem to come from leaky connectors, compressors, seals, and valves.[1] This heat intensity is sufficient to cause severe injuries and deaths at several hundred meters from the leaky compressors, depending on the quantity of gas involved.[2]

As we are focusing on ammonia, it is a natural gas that is present throughout the atmosphere. In some Ammonia producing chemical industries, automotive industries, etc. there is need of detecting the ammonia concentration level. Because the chemical industry, fertilizer factories and refrigeration systems are used pure ammonia in a large quantity, and if a leakage in the system will result in very dangerous situations. Therefore industries which use ammonia should have an alarm detection system using electrochemical sensors (ECS) and should give the warning for dangerous ammonia concentrations. The maximum allowed workspace ammonia level is stated to be 20 ppm. [3] This is a long-term maximum and no fast detectors are required, a response time in the order of minutes is sufficient. Especially in ammonia production industries, where ammonia is produced, detectors should be able to bare the high temperature, which is up to 500ºC. [4]

In this paper, we explained detailed hardware and application for an ammonia gas detector to find the hazardous area where many stationary detectors are unpractical or too expensive. Therefore, we create hardware with simple self-driven detection algorithm for detecting dangerous ammonia gas. In the project, we focused on collecting, processing, and sending data. For this purpose, the PIC microcontroller is used as it is an open source, effective, low-cost device.

To overcome this problem we proposed a detection algorithm. This paper categorized as follows. Section I gives brief introduction to the Ammonia leak detection, ECS, hardware and software used to achieve the proposed system. In Section II, some available solutions of ECS are reviewed to the problem. Section III presents our approach towards the Ammonia leakage problem with the help of ECS. Also the hardware, System architecture and Detection algorithm is explained in detail. Section IV presents experimental analysis and observations.in which ammonia leak measures with respect the standard is validated. Finally, Section V conclude the best solution for Ammonia leakage.

II. Electrochemical sensor review

The electrochemical sensors review consists of only in fixing the problems in the instruments because our aim is to provide the best solution against the issue. Some of the commercially available solutions are compared. There we observed that plenty of solutions have been proposed for the ammonia leakage detection [5]. This section still not applicable of direct interest here, since leakage detection near pipelines can be accomplished by organizing a linear sequence of series of sensors. This paper mainly proposed a solution is not so good practical for long pipeline installations as the high number of sensors required. Besides of all, the useful prevalent leak detection methodology is by concentration measurement. Pallister, electrochemical, semiconductor, and infrared sensors are all used to sample the ambient gas for particular species. As it measures most of the ammonia concentration in air, it raises an alarm system, which will set the threshold concentration, and alerting people in that environment and workers [6]. Although these sensors are having advantages, it also have some disadvantages, which are as follows: high energy consumption, low sensitivity, short lifetime, sensitivity to ambient conditions, high costs, drift, etc. Typically, these sensors are operated independently, so any kind of information of leakage source is private. Because of this, it consumes more energy. Hence sensors installation become more critical as the cost of cables used for this purpose directly affected on the cost of the device itself [6].

Items	Features
Detected gas concentration	NH3 0~100 ppm
Output Current	40 ±12 nA/ppm
Repeatability	Less than ±10%
Response Speed	T90 : Less than 90 sec.
Zero offset Drift	Less than 15 ppm(-30~50º C)
Temperature	-40 ~ +50º C
Humidity	15 ~ 90 % RH

Table 1: Sensor Characteristics

Electrochemical sensors are minimally affected by pressure and temperature changes. TABLE 1 shows the ECS sensor characteristics. However, it is important to keep the entire sensor within the same pressure since differential pressure within the sensor can cause sensor damage. Therefore, the sensors are typically internally temperature-compensated. [7] However, it is better to keep the sample temperature as stable as possible. In general, when the temperature is above 25°C, the sensor will read higher; when it is below 25°C, it will read lower. The temperature effect is typically 0.5% to 1.0% per degree centigrade, depending on the manufacturer and type of sensor. [8]

The degree of selectivity depends on the type of sensor, the target gas, and the concentration of gas the sensor is designed to detect. The higher the ratio, the less the effect of interference gas on the sensor. In actual applications, interference concentrations can be quite high, causing false readings and/or alarms. The life expectancy of an electrochemical sensor depends on several factors, such as environmental conditions, such as temperature, pressure and humidity.[9]

III. AMMONIA LEAK DETECTION APPROCH

A. Hardware

1) PIC Microcontroller

PIC microcontroller is using the RISC architecture with Harvard architecture. In the RISC instruction set, some instruction are not used due to that microcontroller is using available instruction to do the required operation. In this instructions are design to do the operation in the one machine cycle. With the used architecture PIC microcontroller developer are able to give more feature in the given IC size. So that PIC microcontroller offer more peripherals in same cost as compare to other microcontroller.[10]

Following specification are more useful for current system

a) 16K x 14 Words of Flash Program Memory
b) Up to 1024 Bytes of Data Memory (RAM)
c) Interrupt Capability with automatic context saving.
d) Master Synchronous Serial Port (MSSP) with SPI and I2C
e) Enhanced Universal Synchronous Asynchronous
f) Receiver Transmitter (EUSART):- RS-232, RS-485
g) Enhanced Timer1, Timer2, 4, 6: 8-Bit Timer/Counter with 8-Bit Period

2) ADC with SPI Interface

12 bit ADC converter is used to read the sensor input. ADC is using successive approximation method to do the analog to digital conversation of signal. Successive approximation method is fast and accurate as compared to the other type of methods. There two protocol is mostly used to communicate with in the IC first is SPI, second is I2C. For the I2C speed limit is given but in case of SPI there no any specific speed limit is given it is depends on the master and speed of slave.

Below features are useful in current system.

a) 12-bit resolution
b) SPI serial interface (modes 0,0 and 1,1)
c) 100ksps max. sampling rate at VDD = 5V
d) Industrial temp range: -40°C to +85°C.

3) EEPROM with I2C Protocol Interface

EEPROM is used to store the user set configuration. EPROM is using the I2C protocol for the communication. Due to the I2C communication required interface pin is reduced. I2C is using the Acknowledgement policy from slave as well as master. So that it will help to store the user configuration without fail.

Following features are useful for the current

a) Internally Organized 128 x 8 (1K).
b) Two-wire Serial Interface
c) 100 kHz (1.8V) and 400 kHz (2.7V, 5V) Compatibility.

4) Hooter

It is used to inform the user regarding alarm condition. It is operate on 12 power supply.

5) Indication Led

It is used to indicate the status of each channel. It will help to display status of each channel. It is operate on the 5V DC supply.

B. System Architecture

8-bit microcontroller is used to process the sensor data, select required channel during channel scanning, controlling the relay as per the given configuration, to display the reading on LCD, and store the user setting in the EEPROM using I2C protocol, reading ADC count from ADC using SPI protocol. Key pad is used to configure the required setting in microcontroller. On LCD current channel reading and mode of operation is displayed like Auto mode and Manual mode. In the EEPROM user setting is store configuration like salve id, different set points, channel scan time, etc, As microcontroller have limited pin, so latch IC is used to interface the indication LED, each channel relay on the same port of Microcontroller IC. ADC with

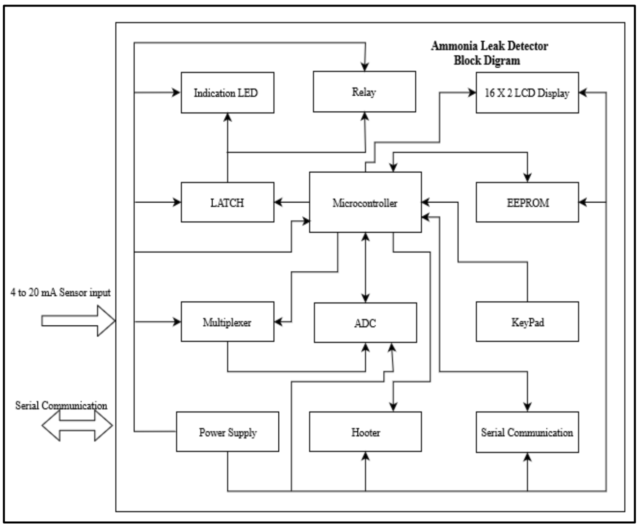

Fig. 1: Block diagram of Ammonia Leak Detection

SPI protocol is used to read the channel reading and sends read date over SPI protocol, Due to use of ADC with SPI protocol communication as well as data processing speed is increased as compare to other protocols. Here Hooter is used to indicate panic state.

In this system microcontroller select the required channel to read the sensor output current.

Sensor output current is given to the signal conditioning circuit through the multiplex. Signal conditioning circuit will covert current into the respective voltage. Signal conditioning voltage is converted into the digital form using ADC. ADC reading will read by the microcontroller through SPI protocol. SPI protocol is using speed of 400kbps. Microcontroller will process the read data. As per the user configuration it will display reading on 16*2 LCD display, turn on the contamination, early warning, alarm LED if current sensor reading exceed the given threshold. It will turn on the hooter for the given time period. [11]

C. Detection Algorithm

1) After the power cycle initialize all peripherals.
2) Read all configuration from EEPROM.
3) Start the scanning each channel.
4) Store the reading in the buffer. This process is continuously running in the background.
5) It will check for respective channel reading, if it is greater than contamination set point, than it will turn on respective contamination error LED. Start the hooter OFF timer.
6) While hooter is in ON state, if acknowledge key is pressed then stop hooter off timer and turn off hooter.
7) If hooter off timer is elapse before acknowledgment then turn off Hooter.
8) If channel reading is greater than early warning set point, then turn on contamination LED as well as early warning LED and start the hooter off timer. Go to step 6 and 7.
9) If channel reading is greater than alarm set point then turn on contamination LED, Early Warning LED and Alarm LED. Turn on the hooter. Here hooter off timer is not set, so that hooter will off only after the acknowledgement key pressed.
10) In the alarm condition respective channel relay will turn on.
11) In the regular operation, as per the configuration of channel scan time set the timer.
12) If channel scan timer is elapse then display the next channel reading.
13) If in the configuration the channel is skip. During the regular scan operation that channel reading should not display on LCD.
14) If Modbus read command is receive the send the required response.

IV. EXPERIMENTAL ANALYSIS & OBSERVATIONS

A. Detection Results

As TABLE 1 shows, the results of NH3 concentration using long run test. To do the long run test we have connected the recommended gas leak detection setup to the detector. In that known concentration of NH3 cylinder is connected to sensor.

Day wise Concentration reading in Days	Standard ammonia bottles value (in PPM)		
1	100	500	1000
2	100	506	1000
3	103	501	997
4	102	498	999
5	98	500	1000
6	101	502	1000
7	106	503	1000

Table 2: Long Run Test Results with known value of NH3 concentration

Fig. 2 shows that, the the sensor output current is measure using the multimeter and same sensor output current is connected to the ADC. 2.5V is given to ADC ref(+) and GND is given to the ADC ref(-) . In the firmware averaging method is used to read the ADC count.For the sensor current respective ADC count is measure.Theoretical ADc count and the practical measured count with respect to the sensor output current is plotted in graph. From ADC count it is observed the over sampling is lossing the date. So that less samples are collected. In the lower concentration of NH3 theoretical ADC count is matching with the practical ADC count, but in case of higher concentration theoretical and practical ADC count is deferred by 10 to 50 count.

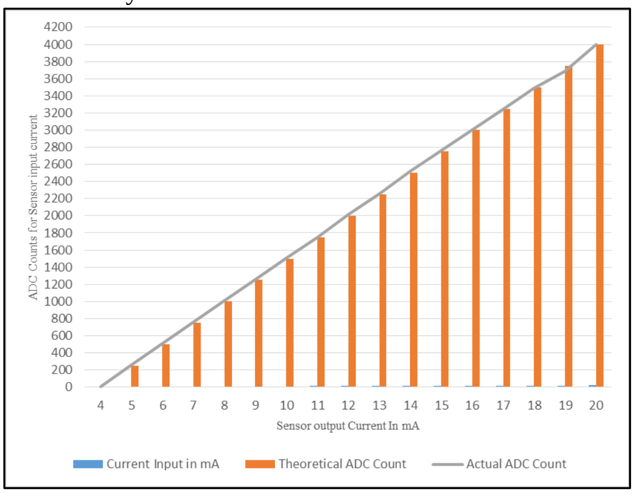

Fig. 2: Graph of ADC Count with Respect to the Sensor Output Current

V. CONCLUSION

The detection of NH3 was demonstrated using the electrochemical type of NH3 sensor. Electrochemical sensors output is stable even with change in the temperature as well as over the day period. As output of sensor is stable so that Detector displayed reading in stable. With the use of electrochemical sensor, detector is able to detect low concentration ammonia in the atmosphere. Detector and sensor sensitivity is not hampered by increased in the temperature during daytime even in long run test.

REFERENCES

[1] IL&FS 2010. Technical EIA Guidance Manual for Offshore and Onshore Oil and Gas Exploration, Development and Production, The Ministry of Environment and Forests, Government of India. IFC (International Finance Corporation). 2007.
[2] Ministry Of Environment And Forests Government of India, the Gazette of India, Extraordinary, Part-II, Section-3, Sub-section (ii) dated the 28 September 2007.
[3] Bjorn Timmer, Wouter Olthuis, Albert Van Den Berg, "Ammonia Sensors and their Applications—A Review", SENSORS AND ACTUATORS B 107 (2005) 666–677, 0925-4005/$ © 2005 ELSEVIER B.V. DOI:10.1016/J.SNB.2004.11.054.
[4] Joseph R. Setter, Williamr. Penrose and Sheng Yao,"Sensors, Chemical Sensors, Electrochemical Sensors and Ecs", Journal of The Electrochemical Society, 150 ~2! S11-S16 ~2003.
[5] P. Murvay And I. Silea, "A Survey On Gas Leak Detection and Localization Techniques," J. Loss Prev. Process Ind., Vol. 25, Pp. 966–973, 2012.
[6] X. Liu Et Al., "A Survey an Gas Sensing Technology," Sensors, Vol. 12, Pp. 9635–9665, 2012.
[7] Fabien Chraim, Yusuf Bugra Erol, and Kris Pister, "Wireless Gas Leak Detection and Localization", IEEE TRANSACTIONS ON INDUSTRIAL INFORMATICS, VOL. 12, NO. 2, APRIL 2016.
[8] Pulak Das, "Environmental Management in Oil and Gas Upstream Industry in India", Journal Of Industrial Pollution Control, 26 June 2013.
[9] Mahalingam, A., Naayagi, R. T., & Mastorakis, N. E. (2012). Design and implementation of an economic gas leakage detector. Recent Researches in Applications of Electrical and Computer Engineering.
[10] Muhhamad Ali Mazidi,Rolin D. Mckinlay, Danny Causey,"PIC Microcontroller and Embedded Systems using C for PIC18, Pearson International Edition,2008.
[11] E Balguruswamy, "Programming in ANCI C", Tata McGraw Hill education pvt. Ltd. 2011.

