Chemical Sensors Evaluation in Explosion Risk Assessment: A Case of the Petrochemical Plant of Skikda (Algeria)

Mounira Rouaïnia, Ibtissem Bouras, Mohamed Salah Medjram.

Abstract— **The aim of this work is to exploit the chemical gas sensors for explosion risk assessment in an industrial site which present a high level of risk. The objective is to analyze and evaluate sensors abilities in explosive gas concentration monitoring. The considered site is the petrochemical plant GL1K of Skikda (Algeria). The results of our work will enable us to judge the effectiveness of these sensors, but also to create solutions for possible detection optimization and therefore a better risk prevention on site.**

Key words: Chemical gas sensors, air pollution, explosive gases, explosive levels.

I. Introduction

During the last century, industrialization and expansion of transportation has played a key role in the evolution of society. These activities meant progress, modernity and enrichment. But since then, the awareness of the environmental consequences has been growing. Indeed, large amounts of chemicals are released into the environment, most of which are considered dangerous. The introduction of these compounds involves serious risks not only for the environment and living organisms, but also to human health.

Many steps were taken to lower emissions. However, much work remains to be done to identify and understand pollution and it's long term impact, and propose solutions. To fight against this pollution, scientists were able to crate gas sensors sensitive and increasingly precise and powerful to meet more restrictive regulations. Particularly in petrochemical and industrial sites, such monitoring is critical especially when it includes evaluation of explosion risks.

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Dr. Mounira Rouainia is with the petrochemical industries and process engineering department at 20 Août university- Skikda, Algeria. She is a member of Chemical engineering and environment research laboratory of Skikda University, PO Box 21000, El Hadaek road, Skikda, Algeria. Phone/ Fax: 00213 38 70 42 43; e-mail: m.rouainia@univ-skikda.dz.

Ibtisssem Bouas is with the petrochemical industries and process engineering department at 20 Août university- Skikda, Algeria. She is a member of Chemical engineering and environment research laboratory of Skikda uuniversity, PO Box 21000, El Hadaek road, Skikda, Algeria.

Pr. Mohamed Salah Medjram is with the petrochemical industries and process engineering department at 20 Août university- Skikda, Algeria; he is the head of Chemical engineering and environment research laboratory of Skikda university, PO Box 21000, El Hadaek road, Skikda, Algeria. Phone/ Fax: 00213 38 70 43 19; e-mail: ms.medjram@univ-skikda.dz.

II. GAS SENSORS

A gas sensor is defined as a component of which at least one of its physical properties change when subjected to a change of gaseous environment. In general, a sensor is composed of two main components: the sensing element and the transducer.

The sensing element is the heart of the sensor, where the reaction happens with gaseous components and compounds. (electrical or optical signal). Sometimes, the sensing element and the transducer are combined, this is the case of MOX sensors.

A. Main families of gas sensors

Many authors classify gas sensors based on their detection principle. Table I presents the main types of sensors according to this classification [1]. In what follows, we outline the principle of detection of some types of sensors.

TABLE I
CLASSIFICATION OF GAS SENSORS [2, 3]

Principle	Measured quantity	Example of sensor
Potentiometric	Voltage	An electrochemical cell
Amperometric	Current	An electrochemical cell
Capacitive	Capacity / load	Humidity sensor
Calorimetric	Temperature	Pellistor
Gravimetric	Mass	Microbalance sensor
Resonance	Frequency	Sensor surface wave
Optical	Absorption peak	Infrared detector
Fluorescence	Light intensity	Fiber optic
Resistive	Resistance	MOX sensor

III. DESCRIPTION OF THE GL1K PETROCHEMICAL COMPLEX

The purpose of the GL1K complex is the liquefaction of natural gas that has been subjected to a physical process to liquefy it. After liquefaction, the obtained natural gas is transported by tanker. This transportation requires a reduction in the volume of the gas. The GL1K complex is supplied with natural gas from the Hassi R'Mel deposit by a pipeline with a length of 580 Km and 40 inches in diameter, through five compressor stations along the pipeline.

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A. The GL1K complex units

The GL1K petrochemical plant is divided into several units:

- Liquefaction units: 03 units (10, 5P and 6P).
- fractionator GPL unit .
- Storage unit .
- Auxiliary unit

The considered units in our study are unit 5P, unit 6P, GPL unit and unit 10.

B. Gas sensors used in the complex GL1K

Two types of chemical gas sensors are used in the GL1K plant of Skikda: SC4100 sensor with catalytic bead, and linear barrier with infrared radiation sensor IR5000 [5].

In the SC 4100 sensor, the measuring chain is based on an electrical resistance which variation cause an amplification of the signal. This signal will be transmitted to a multiplexer and then to the microprocessor. At the end, the concentration detected by the sensor is displayed in the control room. In the case where there's an explosion hazard alert will be triggered.

IV. POINT SENSOR GG SC4100

A. Point sensor calibration GG SC4100

The purpose of calibration is to establish the relationship between the concentration of gas to be detected and the value given at the sensor output.
We considered two types of calibration:
• Calibration by kit.
• Calibration by measuring chamber laptop.

Tables II presents concentrations detected in three check points by GG SC4100 point sensors in unit 6P (before calibration, for calibration and after calibration by kit and explosimeter. Table III gives the same data but before, while and after calibration with measuring chamber.
In figure 1, we present variation of the methane leakage concentration detected by GGSC 4100 sensor in unit 6P and while calibrating by kit. Figure 2 illustrate these variations for calibrating by measuring chamber.

TABLE II
METHANE CONCENTRATIONS DETECTED IN THREE CHECK POINTS BY GG SC 4100 SENSOR (KIT CALIBRATION)

Temps	Sensor 1	Sensor 2	Sensor 3
C1(BK)	4 % LEL	2 % LEL	3 % LEL
C1(FK)	0 % LEL	0 % LEL	0 % LEL
C1(AK)	4 % LEL	2 % LEL	3 % LEL
C1(AE)	8 % LEL	4 % LEL	6 % LEL

C1(BK) = Concentration of gas methane before calibration by kit.
C1(FK) = Concentration of gas methane for calibration by kit.
C1(AK) = Concentration gas methane after calibration by kit.
C1(AE) = Concentration of gas methane after calibration by explosimeter.

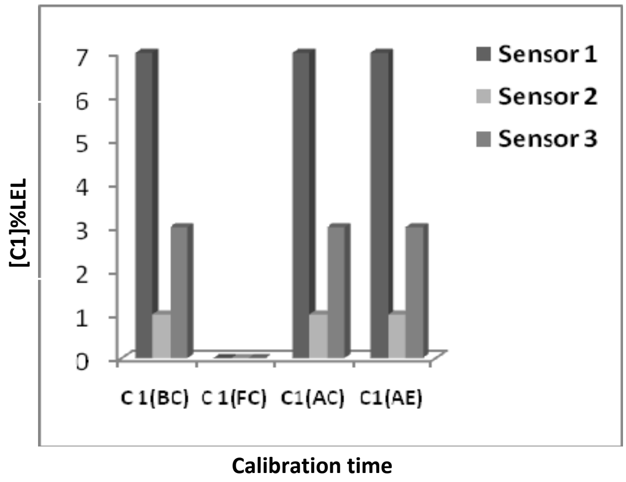

Fig1, Variation of the methane leakage concentration while calibration by kit.

TABLE III
METHANE CONCENTRATIONS DETECTED IN THREE CHECK POINTS BY GG SC 4100 SENSOR SENSOR (MEASURING CHAMBER CALIBRATION)

Temps	Sensor 1	Sensor 2	Sensor 3
C1(BC)	7 % LEL	1 % LEL	3 % LEL
C1(FC)	5 ppm	3 ppm	10 ppm
C1(FC)	0 % LEL	0 % LEL	0 % LEL
C1(AC)	7% LEL	1 % LEL	3 % LEL
C1(AE)	7 % LEL	1 % LEL	3 % LEL

C1(BC) = Concentration of methane before calibration by measuring chamber, C1(FC) = Concentration of methane for calibration by measuring chamber, C1(AC) = Concentration of methane after calibration by measuring chamber, C1(AE) = Concentration of methane after calibration by explosimeter.

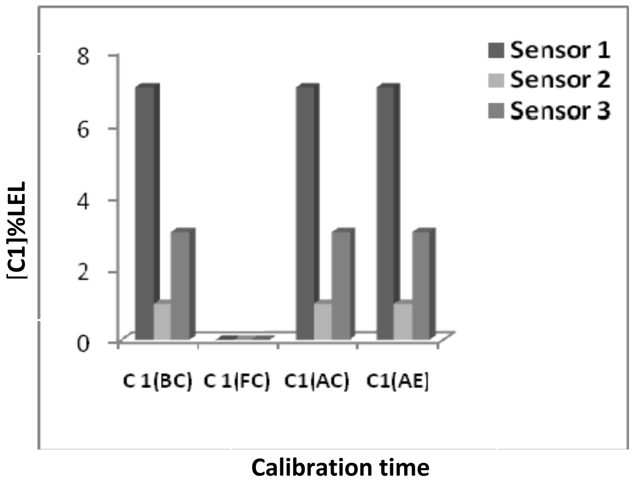

fig 2,Variation of the concentration of methane leakage while calibration by measuring chamber.

Discussion

In the calibration operation, the zero requires an absolute absence of gas in the air. Nevertheless, obtaining this zero does not guarantee an exact explosive gases detection value in the case of C1 with calibration kit. Indeed, the results obtained by explosimeter calibration are the double of those

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with the Kit calibration and for the three sensors in different locations.
With the sizing kit, the methane concentration value(C1) displayed by the sensor is obtained by the following relationship:

$$[C1K]_{real} = [C1K]_{initial} + [C1K]_{displayed} \quad \text{(Equation 1)}$$
$$[C1K]_{real} = [C1K]_{posted\ by\ explosimeter} \quad \text{(Equation 2)}$$

Where C1K is the Concentration of methane indicated by kit.
We can also remark what follows:

- The continued presence of residual gas is not only due to gas leakage. It is also caused by purges operations in the sites which release the gas to the air.
- The presence of residual gas during the calibration kit makes impossible to get a true and absolute zero. But a complete absence of residual gas at our site is never observed.
- In case of calibrating by the measuring chamber, the displayed value is the same one displayed by explosimeter calibration. This is caused by the fact that the measuring cell causes a total bailiwick of explosive gases at a time calibration:[5-10] ppm = 0 %LEL.

As we know that :

$$1\%LIE \longrightarrow 10^4 \text{ ppm} \quad \text{(Equation 3)}$$

So the actual value of C1 for calibration by measuring chamber displayed by the mobile sensor is given by the following relationship.

$$[C1C]_{real}=[C1C]_{initial}=[C1C]_{posted\ by\ explosimeter} \quad \text{(Equation 4)}$$

Where C1C is the concentration of methane in case of calibrating by measuring chamber.

B. Monitoring of gas concentrations

In order to show the sensors positions influence on their performance and sensitivity we check methane an butane concentrations at three different levels from the ground. This is illustrated in tables IV and V

TABLE IV
METHANE CONCENTRATIONS DETECTED AT THREE LEVELS OF SENSOR POSITION

Sensor level relative to the ground GG	C1 Case 1 (%LEL)	C1 Case 1 (%LEL)	C1 Case 1 (%LEL)
3m	10	5	40
1.70 m	1	0	5
30m	0	0	0

TABLE V
BUTANE CONCENTRATIONS DETECTED AT THREE LEVELS OF SENSOR POSITION.

Sensor level relative to the ground GG	C4 Case 1 (%LEL)	C4Case 1 (%LEL)	C4 Case (%LEL)
3m	10	5	40
1.70 m	1	0	5
30m	0	0	0

C4 is the detected butane concentration.

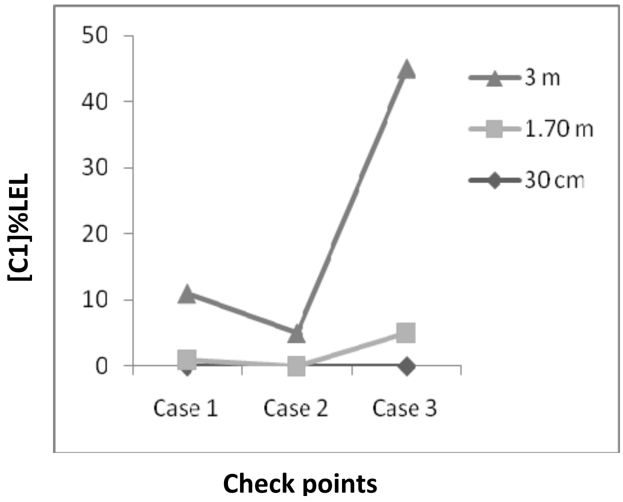

fig 3, Variation of the concentration of methane detected by GG sensor SC4100 at three different levels.

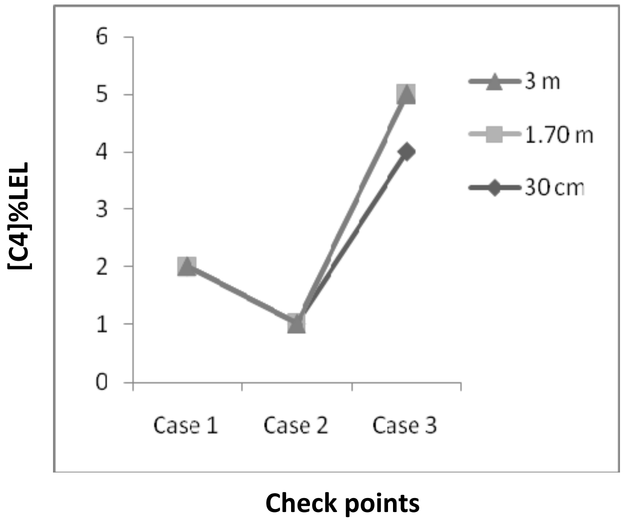

Fig 4, Variation of the concentration of butane detected by GG sensor SC4100 at the three different levels.

Discussion

In the GL1K plant, most of gas sensors devoted to methane detection are placed at a level too low to the ground (a few tens of centimeters). And this is a mistake which may cause no detection of gas even if it is present in the air

Knowing that the density of each methane hydrocarbons up to hexane gas differs from the other, the height at which the SC4100 sensors must be placed should be chosen depending on the density of the gas inspected to exist on the site. As methane is a light gas (density: 0.5), it tends to rise, butane and propane are heavier, so they tend to move downwards. That's why, any gas having a density less than that of air (density 1) will be detected from a high situated point more and any gas having a high density will be searched at a low level.

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V. LINEAR BARRIER SENSOR IR5000

A. Gas concentration readings for different gas clouds

Records of concentrations of each gas cloud are made every 2 to 5 minutes. The reading L in (ppm × m) or (LEL × m) is calculated following one of the equations below:

L (ppm×m) = $\sum_{i=1}^{N}(C\,(LEL) \times D\,(m))$ (Equation 5)

L (LEL×m) = $\sum_{i=1}^{N}(C\,(LEL) \times D\,(m))$ /100 (Equation 6)

TABLE VI
METHANE CONCENTRATIONS READINGS IN TWO DISPERSING CLOUDS.

The methane clouds	Concentration (C)	Distance from could (D)			The displayed Reading by sensor IR5000 (L)
		D	D1	D2	
	10%LEL	15m	0m	6m	2,2 LEL×m
1	5%LEL	25m	4m	10m	
	1%LEL	45m	10m	0m	
	100%LEL	1m	0m	0,5m	2,2 LEL×m
2	70%LEL	2m	0,5m	0,5m	
	50%LEL	3m	0,5m	0,5m	

D1= Distance from the cloud of gas passing through the beam by the left relative to the cloud chair (receiver side), D2=Distance from the cloud of gas passing through the beam by the right relative to the cloud chair (transmitter side).

B. LEL evaluation

Case of Cloud 1

In case of a large cloud with low concentration of gas, the reading of 2.2 (LEL× m) is calculated as below:

[(1% LEL × (10m+10m)) + (5% LEL × (4m+6m)) + (10% LEL × 15m)] / 100 = 2,2 (LEL× m).

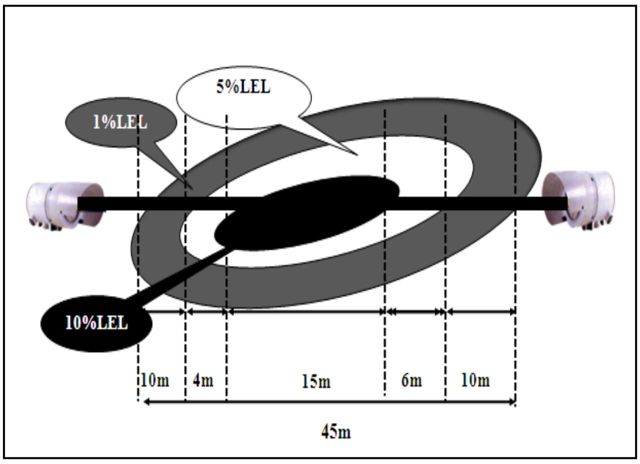

fig 5, Cloud 1 schematization.

Case of Cloud 2

In case of a small cloud with high concentration of gas, the reading of 2.2 (LEL ×m) is evaluated as below:
[(50% LEL×(0.5m+0.5m))+(70%LEL×(0.5m+0.5m)) + (100% LEL×1m)] / 100 = 2.2 (LEL×m).

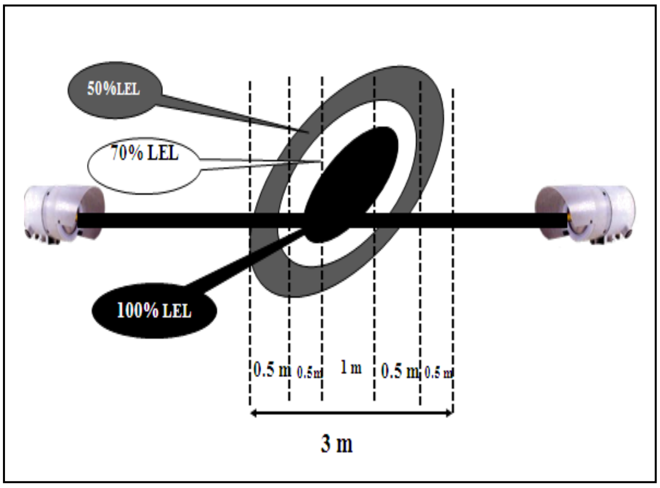

fig 6, Cloud 2 schematization

Discussion

The obtained results show that the linear sensor IR5000 placed at the unit 5P, gives the same answer (2. 2 (LEL × m)) for two different gas clouds, a cloud of methane at high concentration and a large methane cloud at low concentration. However, for the first cloud of methane, there is no explosion risk, while the second cloud presents a very high explosion risk.

We can say that the IR5000 sensor sensitivity depends on several factors including:

- The type of gas.
- The leak source size.
- The leak orientation.
- The leak pressure.
- The distance between the cloud and the barrier IR5000 sensor.
- The sensor reliability.

VI. CONCLUSION AND RECOMENDATION

The role of sensors in risk prevention and especially in explosion risk assessment is well established today. In our work we focused on the case of explosion risk generated by air pollution in a petrochemical complex. Our objective was to analyze and assess the capabilities of chemical sensors implanted into the site (GL1K petrochemical complex of Skikda) for monitoring air pollution and explosion risk assessment.

In order to optimize the detection system we advocate the application of the following recommendations:

- Combining the two types of sensors, punctual and linear, and verify the effective optimization of detection by monitoring over time.

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- Optimize the implementation levels of these sensors in order to improve their selectivity and sensitivity and to obtain reliable detections.
- Exploitation of new types of gas sensors such as: camera infrared sensors and ultrasonic sensors.

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