Study and optimization of the effect of sensor position inside a gas sensing chamber for VOC detection

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***Abstract*—The gas sensing chamber design and the arrangement of the sensors inside it influence the response of the sensing system. A suitable combination of well designed orifice plates along with the optimized sensor orientations can enhance the response time and detection rate of the system. In this paper various models of gas chamber with fixed boundary conditions utilizing Finite Element Method were simulated and optimized to obtain the most suitable structure for which the mass flow over the gas sensitive surface of the gas sensors are greatest. The simulation was performed in two different ways and for fifteen unique arrangements. The optimized model is then fabricated and tested for four different leaf samples. The responses of the two gas sensors varied in a similar manner for each sample as expected from the simulation results.**

***Index Terms*—gas chamber, VOC, electronic sensing system**

I. INTRODUCTION

Volatile Organic Compounds (VOCs) are the main constituents of the gas emitted from vegetation. The sources of such VOCs can be anthropogenic or biogenic. Biogenic VOCs composed of organic trace gases of the atmosphere other than nitrogen, oxygen, argon, carbon dioxide and carbon monoxide [1] [2]. By profiling the compounds of biogenic VOCs, the physical changes in the surrounding environment can be monitored.

Plant stresses are the results of the variations in the physical parameters such as temperature, pressure, humidity, soil water etc. Therefore Monitoring and controlling of these physical parameters are crucial for sustainable agriculture [3]. There are several traditional methods such as molecular techniques, spectroscopic methods etc. for monitoring the stresses present in the vegetation. These methods are time-consuming and require an elaborate procedure for sample preparation [4]. A robust and non-invasive technique for recording and monitoring of these physical parameters is an electronic sensing system (electronic nose or electronic tongue) including necessary signal conditioning hardware [5] [6] [7].

An electronic nose system consists of a set of gas sensors and a pattern recognition system which can record and classify the volatile organic compounds present in the surrounding environment [8][9][10]. The gas sensors used in an electronic nose system are the Physio-chemical sensors which are capable of detecting the physical changes in the surrounding gas. These sensors comprised of an active layer that converts the chemical information of the surrounding gas or air into electrical forms such as current or voltage change, frequency change etc. [11] [12] [13]. The common application areas of the technology based on gas sensors are industrial production & automotive industry, medical applications, indoor air quality supervision, environmental studies and agricultural yield & development [14].

In case of semiconductor or metal oxide gas sensors the recovery time required after every gas exposure is high [15] which severely affects the performance of the gas sensing system. To overcome this limitation the gas concentration must be kept fixed for a long time inside the gas chamber. Therefore the optimization of the gas chamber is essential for using this sensing system in practical applications [16]. The positioning of the gas sensors inside the chamber is another important aspect to be considered. The classification accuracy and detection rates of gas sensors are affected by the position of the sensors where these are placed inside the gas chamber [17].

In this work the simulation results for different arrangements of gas chamber using Finite Element Method are presented [18]. The simulations are performed to calculate the mass flow above the gas sensitive surfaces of the gas sensors at different conditions. The experimental setup is also developed for the optimized gas chamber using two similar gas sensors to record the VOCs emitted by different plant leaves.

II. COMPUTER SIMULATION

The gas chamber model is implemented with a set of orifice plates of same dimension and two similar gas sensors inside it (as shown in Fig.1). The orifice plates are used to compute the pressure difference inside the gas chamber [19]. The pressure difference, $\triangle P$ and Mass Flow, q_m can be calculated by using equations (1) and (2) (as shown in Fig.2):

$$\triangle P = P_1 - P_2 = \frac{1}{2}\rho(\frac{V_1^2}{V_2^2} - 1) \quad (1)$$

$$q_m = \frac{c_d}{1-\beta^4}\epsilon\frac{\pi}{4}d^2\sqrt{2\rho\triangle P} \quad (2)$$

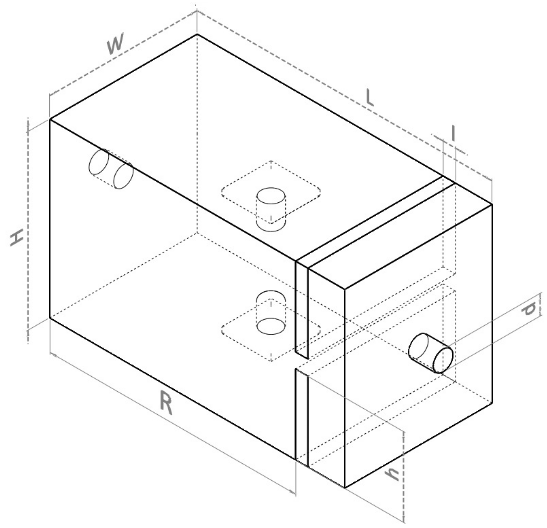

Fig. 1. Gas chamber with dimensions

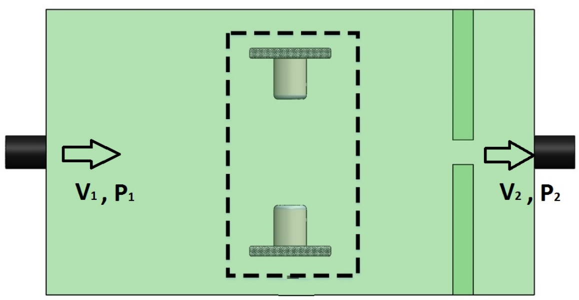

Fig. 2. Pressure change due to orifice plates

Here, $V_1, V_2, C_d, \beta, \rho, \epsilon$ and d represent the air velocity at inlet, velocity of air at outlet, discharge coefficient, ratio between the orifice diameter & chamber height, density of air, expansibility factor and orifice diameter, respectively.

A stationary analysis has been accomplished applying turbulent air flow (k-ϵ) in Computational Fluid Dynamics (CFD) at room temperature using Finite Element Method analysis. The meshing of the CFD model is shown in Fig.3.The dimensions of the gas chamber model (shown in Fig.1) are depicted in TABLE1.

TABLE I
CALCULATED DIMENSIONS OF THE GAS CHAMBER FOR SIMULATION

Parameter		Value (m.m.)
Length of the chamber	L	120
Breadth of the chamber	W	60
Height of the chamber	H	70
Height of the orifice plates	h	32
Thickness of the orifice plates	l	5
Inlet & Outlet diameter	d	8
Distance of orifice plates from inlet	R	100

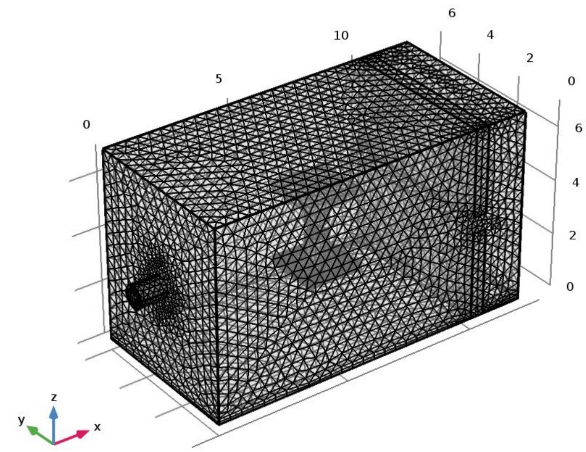

Fig. 3. Gas chamber designed in Finite Element Method

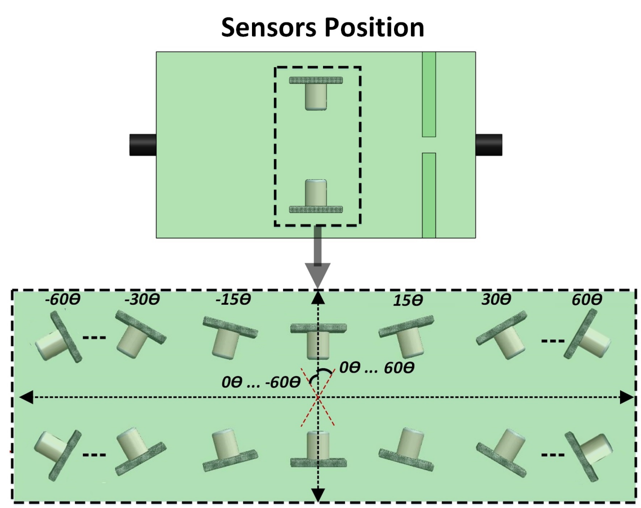

Fig. 4. Different orientations of gas sensors

The optimization based on computer simulation is done in two parts:

- The angle between the gas sensors with z-axis is varied from 0^0 to $\pm 60^0$ (as shown in Fig.4) and the optimized angle is determined for highest mass flow over the gas sensors.
- The separation between the gas sensors is changed by considering the optimized angle to get the maximum mass flow over the gas-delicate surface of the gas sensors.

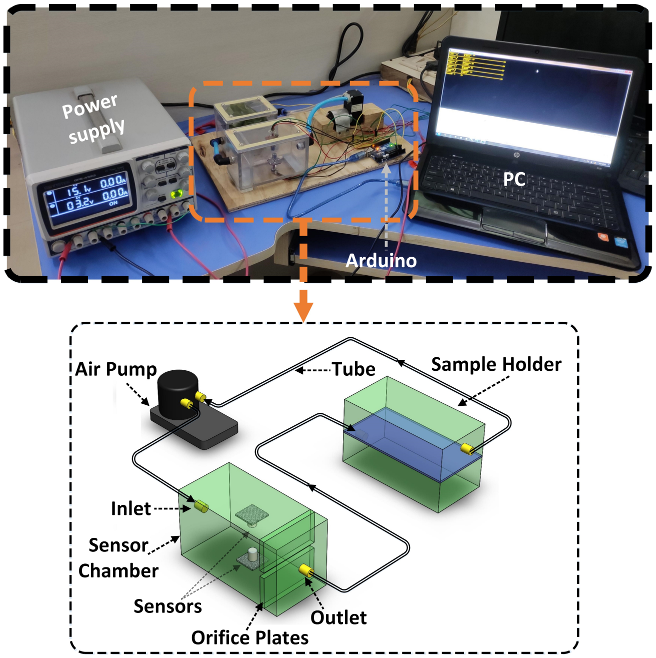

Fig. 5. Experimental Setup

III. Experimental Study

The experimental set up is developed as shown in Fig.5. The system consists of following parts:

- The sample holder: The inlet and outlet are mounted in such a way so that the flowing air can pass through the samples placed inside the sample holder.
- The gas chamber is designed according to the results of computer simulation performed to optimize the orientations of the gas sensors inside it. The two gas sensors (TGS2610) are placed as shown in Fig.2 along with the orifice plates inside it.
- An air pump provides the required air flow velocity inside the sample holder.

The inlet and outlet of the proposed gas sensing system are connected to the outlet of the air pump and the inlet of the sample holder (placed beneath the sample holding plate), respectively. The flowing air then passes through the sample leaves placed inside the sample holder (as shown in Fig.5) to the outlet (placed above the sample holding plate), which is connected to the inlet of the air pump. In this way, the VOCs released from the sample leaves reach the gas chamber where the sensors are located.

IV. Results and Discussion

A. Simulation Result

Simulations are performed in order to optimize the gas chamber as mentioned earlier. Fig.6 presents how the mass flow of air varied with different angles of the gas sensors. The model is simulated for nine different angles and it is found that at 0^0 angle of the gas sensors with z-axis, the mass flow is maximum over the gas sensitive surfaces. In Fig.7, the mass flow is presented for different values of distance, D between the two gas sensors considering the optimized angle of the gas sensors. Hence the optimized position of the gas sensors are calculated at a distance of 0.5 cm apart from each other at 0^0 position.

B. Experimental Result

The gas chamber designed using Finite Element Method is fabricated with two similar gas sensors facing each other at the optimum angles and positions (as shown in Fig.3). The sensor responses are calculated for 8 gram of each leaf samples such as lemon (Citrus limon), orange (Citrus sinensis),holy basil (Ocimum tenuiflorum) and betel (Piper betle) leaves for 40 seconds. In Fig.8 the output voltage of one sensor for the leaf samples are given. Fig.9 shows each response of the other sensor for the same samples. Since the inlet position of the designed system was slightly misarranged, therefore there is a slight difference between the sensor responses.

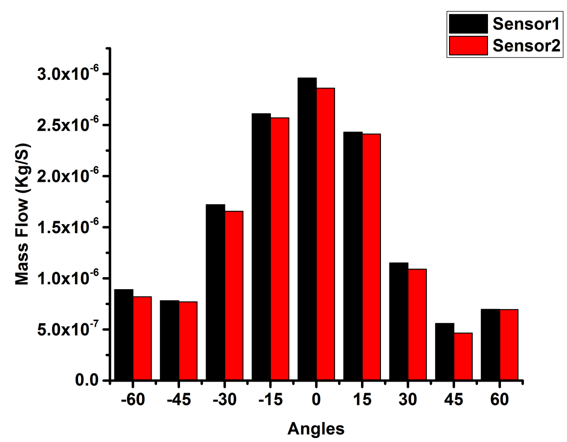

Fig. 6. Simulation results of mass flow for different angles of gas sensors

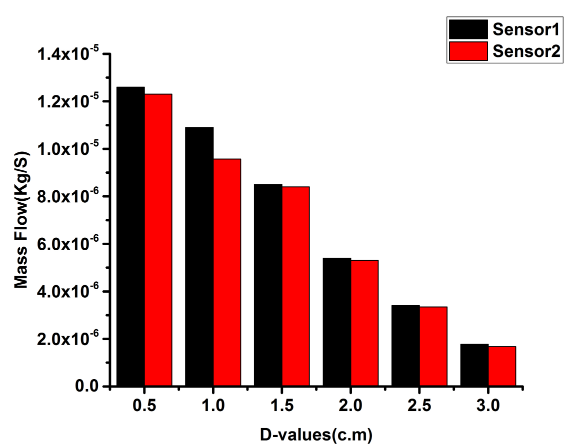

Fig. 7. Simulation results of mass flow for different distance between the gas sensors

The comparison between the responses of the gas sensors by nullyfying the effect of the inlet for each sample is shown in Fig.10. The formula used to cancel out this effect is given by (3)

$$SensorResponse = |\frac{V_{air} - V_{sample}}{V_{air}}| \quad (3)$$

From these three figures it is observed that the two gas sensors responded in a similar way. Therefore the experimental studies are in a good agreement with all the mathematical modeling and simulation results . This kind of system shows potential application towards the improvement of a gas sensing system for discriminating the VOC profiles discharged by different plants.

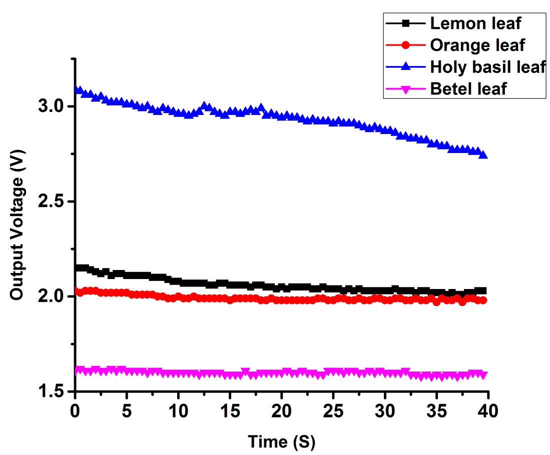

Fig. 8. Response of sensor1 for the leaf samples

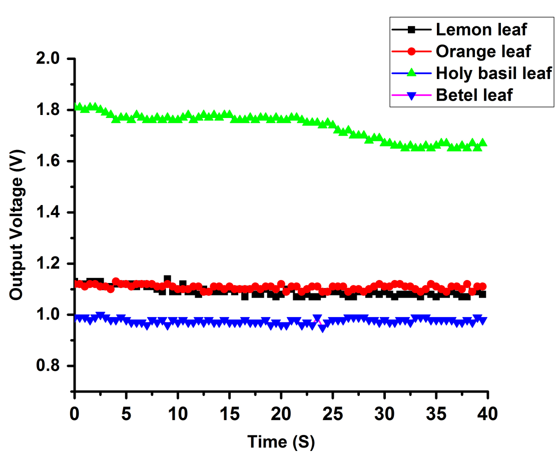

Fig. 9. Response of sensor2 for the leaf samples

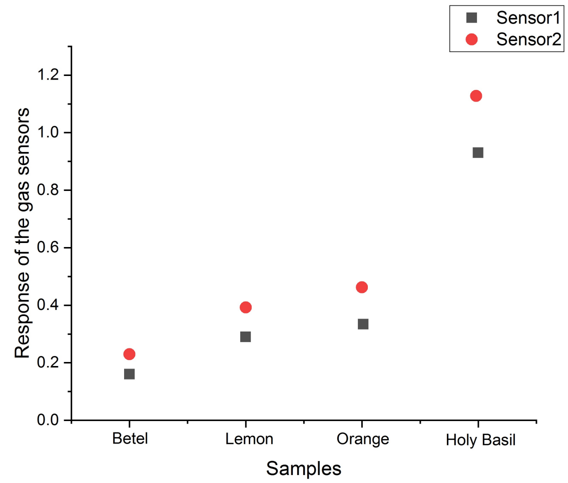

Fig. 10. Comparison between the response of the gas sensors

V. Conclusion & Outlook

In this work, a gas sensing system was successfully designed, simulated, developed and tested. A model of the gas chamber had been implemented in Finite Element Method for which the Mass flow of gas at the gas-sensitive surfaces of the sensors could be studied. It was found that the performance of the sensing system regarding the measure of mass flow over the gas sensors was influenced by the angles of the sensors with respect to the Z-axis and the separation between the sensors. Therefore the optimization was done by considering these two parameters. The experimental set up was also explained with the help of two gas sensors (TGS2610) and the sensor responses were evaluated. The response of the two gas sensors were found to be as expected from simulation.It is a novel approach towards the optimization of a sensor system by changing the angles of the sensors with respect to the inlet to achieve an optimum result. Such kind of system can be further improved by placing specific gas sensors for the detection af a particular gas. In this work, the response of the two similar gas sensors is compared. In the future, this system can be extended by placing two different gas sensors for the detection of the impurities present in a particular gas. This kind of system can be used to calibrate a fabricated gas sensor model with a standard one. Based on these observations such sensing systems may be customised for plants health monitoring by detecting the VOC profile. The technique may further be extended to environmental parameter monitoring.

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