WHITE PAPER

Passive vs Active Sampling for Sensor-based Ambient Air Quality Monitoring

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Introduction

Air pollution with its cascading effects across the population has become a serious matter of concern. To address this air pollution problem, availability of accurate and reliable air quality data is crucial. The quality of air monitoring depends upon how the sample of air is collected and how it is analysed.

Methods and techniques for air pollution sampling and measurement have evolved over time. Conventionally, air pollutant concentration measurement was carried out by manual air sampling followed by laboratory analysis. Pollutant concentration was determined by either collecting particles on a filter or by titrating the absorbed gaseous pollutants with chemicals. Continuous monitors replaced conventional manual methods to get quicker results with high temporal resolution. Such CAAQMs analyse various gases and particulate pollutants by appropriate analysers. However, such instruments are expensive to install and maintain. Therefore, they are sparsely deployed and provide air quality only for a few locations.

With innovation and evolution of IoT, sensor-based systems started penetrating all possible measurement technologies including air quality monitoring. Such systems are leaner, smarter, cost-effective, compact and can be easily installed on a roof or on a pole. Sensor-based air quality monitors measure all gases and particulate matter from a single compact device with high accuracy and precision. However, various environmental parameters such as temperature, humidity, dust, wind etc. affect the performance of these sensors. This paper explains what influence such parameters have on sensors and how sampling methods can influence the data accuracy. In addition to this, the difference between passive and active sampling methods is identified.

Factors affecting the accuracy of air quality monitoring

Air pollutant sensors can be classified into two groups; those that measure gaseous pollutants, and those that measure particulate matter. Sensors such as non-dispersive infrared (NDIR), photo-ionization detector (PID), electrochemical sensors, etc. are gas sensors, while sensors based on light scattering techniques measure particulate matter. Sensors are designed to work under specific environmental conditions. Various environmental factors such as temperature, relative humidity, wind speed, dust, etc. affect the sensor's ability to measure correct concentration.

Temperature and Humidity

Studies have found that sensors tested under steady temperature and relative humidity (RH), gave high correlation (R2 > 0.9), compared to reference stations. While in real-world conditions, concentration measurement was less accurate. It is associated with exposure to harsh environmental conditions, especially high temperature and RH. It also depends upon the time period of its exposure to such a condition, which is quite frequent for a tropical region like India.
Sensor response with such environmental conditions could be positive or negative. But, the nature of such a positive or negative sensor response is usually non-linear. A study carried out using electrochemical sensors showed that sensor response erroneously increased with increase in temperature. In the case of H_2S, the response was positive, while in the case of CO, a negative response was observed after a certain increase in temperature. Temperature depende-

nce of pollutant chemistry also plays a vital role. For example, an increase in temperature up to 20 °C decreases NO_2 concentration, after that as temperature increases, NO_2 concentration also increases due to secondary NO_2 formation.

Sensors used for particulate matter (PM) measurement are particularly sensitive to relative humidity (RH). Significant increase in particle number and mass concentrations is observed at relative humidity above 70-80%. Studies have found that, as a result, higher RH can influence the underestimation of $PM_{2.5}$ and overestimation of PM_{10}. An increase in relative humidity (RH) also increases sensor signal of gas measuring sensors such as photoionization detector (PID). Moreover, studies show that temperature has no adverse effect on NDIR sensors for measuring carbon monoxide(CO). While the accuracy of sensors declined with increasing humidity at 50 ppm concentration of CO. Also, relative humidity and temperature are negatively correlated. Therefore, an increase in RH shows the overestimation of NO_2 and the underestimation of O_3.

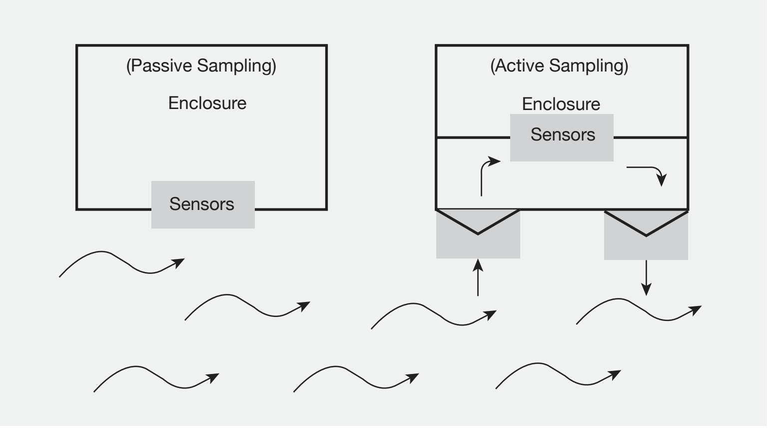
Dust

Multiple sources of dust include dust from construction activities, fugitive road dust, vehicular emission, and sometimes dust storms. In such a dust-laden atmosphere, where PM_{10} values are generally on the higher side (i.e. >300-400 µg/m3), there are possibilities of dust deposition on the exposed surfaces of air monitoring sensors. When the relative humidity exceeds the threshold of 85% (RH > 85%), finer particulate matter PM_1 and $PM_{2.5}$ agglomerates and gets stuck on the sensors. In such conditions, sensors generate erroneous data. Resultantly, the working life of sensors is significantly reduced, which leads to frequent maintenance and replacement of sensors. Construction and mining sites are particularly prone to such problems. Sites with nearby dust-laden or unpaved roads also face similar issues.

Wind Speed

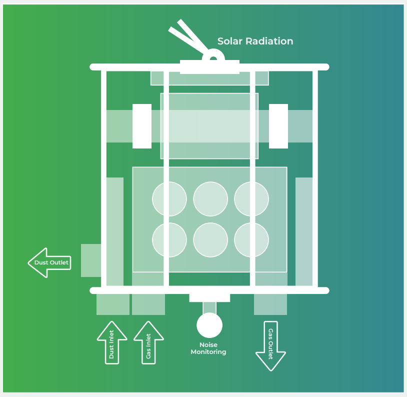
Wind circulation determines the transport and dispersion of air pollutants. However, wind speed is highly variable in its extent and strength. High wind speed, turbulence and wind gusts are capable of influencing the performance of electrochemical sensors. The controlled diffusion rate of target gas to the sensor is required to get accurate results. Kinetics of redox reaction is also affected by the rate at which target gas molecules reach the sensor. This leads to erroneous results in the detection of gas concentration.

Passive vs Active sampling



Sensor-based air quality monitoring systems have also evolved with technological advancements. Conventional sensor-based systems had their sensors exposed to ambient atmospheric conditions known as passive sampling-based sensors. Due to which, ambient environmental conditions such as heavy dust, high wind speed, temperature, and humidity affects directly exposed sensors. Such systems are highly affected by the above mentioned environmental conditions, reducing data accuracy and working life.

Technological advancements lead to further innovation and today active sampling-based air quality monitoring systems are preferred over the older systems. Active sampling is where the system draws in a specific volume of air using a pump at a particular time interval. Unlike conventional systems working on passive sampling, sensors of active sampling systems are placed inside a chamber which is not affected by ambient conditions.



Key advantages of active sampling

The main advantage of active sampling-based air quality monitoring systems is that concentration measurement by the sensor is not affected by external environmental factors. Also, active sampling systems can be provided with a controlled microclimate within the device to carry out sample preconditioning like cooling, dehumidification etc. Due to which, significantly better data accuracy can be achieved along with increased sensor life. While the design of active sampling systems prevents dust deposition and choking of sensors, frequent cleaning and maintenance are required to ensure equivalent data quality in case of passive sampling-based systems. Calibration of active sampling systems can be easily carried out by introducing reference gas to the system through separately provided inlet and outlet ports. On-site calibration of active sampling-based systems can be carried out, which is not possible in case of systems with passive sampling.

OIZOM's offerings

OIZOM has an edge over others on sensor-based air quality monitoring systems. We have patented the active sampling method with our e-breathing technology. The patented e-breathing technology of OIZOM is biomimicry of the human lung by inhaling in 325 mL of air sample inside the system and exhaling the same amount after the sensor has generated electronic signals. Our devices have been collocated against reference grade monitoring stations and R^2 values achieved have been over 0.85-0.9 in most cases. This when combined with an isolated atmosphere having no influence of temperature, humidity, wind flow or dust, ensures the highest accuracy and also increases the sensor life of the system. Following table highlights the advantages of e-breathing technology over others.

Parameter	Passive Sampling	Product Parameters
Sensor exposure to ambient conditions	Yes	No
Air sampling using a predefined airflow	No	Yes
Influence of temperature, humidity, dust or wind on data	Yes	No
Maintenance	Frequent due to reduced working life of sensors	Minimal with quarterly cleaning
On-site reference gas calibration	No	Yes
Collocation against reference-grade systems with R2 >0.85	No	Yes

References

[1] Measuring air pollution with low-cost sensors, the European Commission's Joint Research Center.

[2] Evaluation of micro-sensors to monitor ozone in ambient air. Joint Research Centre, European Commission. EUR23676EN - 2009.

[3] Evaluation of microsensors to monitor ozone in ambient air. European Commission Joint Research Centre, Institute for Environment and Sustainability.

[4] Munir, S., Mayfield, M., Coca, D. et al. Analysing the performance of low-cost air quality sensors, their drivers, relative benefits and calibration in cities—a case study in Sheffield. Environ Monit Assess 191, 94 (2019).

[5] Review of the performance of Low-Cost Sensors for air quality monitoring. Atmosphere 2019, 10(9), 506;

[6] Effect of relative humidity on the size of atmospheric aerosol particles.

[7] Field evaluation of low-cost particulate matter sensors in high- and low-concentration environ ments.

[8] The influence of humidity on the performance of a low-cost air particle mass sensor and the effect of atmospheric fog.

[9] Jo-Chun Kim, Trieu-Vuong Dinh, In-Young Choi and Kyu-Yong Song, "Physical and chemical factors influencing the continuous monitoring of carbon monoxide using NDIR sensor," 2015 9th International Conference on Sensing Technology (ICST), Auckland, 2015, pp. 316-319, doi: 10.1109/ICSensT.2015.7438414.

[10] The use of electrochemical sensors for monitoring urban air quality in low-cost, high-density networks. DOI

[11] Study of factors affecting mass transport in electrochemical gas sensors. DOI

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With an experience of more than 10 years promoting various Environmental Technologies, Ayyan Karmakar currently leads marketing at Oizom. He is an industry professional with core Environmental Engineering skills with a spirit of continuous learning.

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Accurate And Affordable Air Quality Monitoring Solutions