CHAPTER 4
DESIGN AND DEVELOPMENT OF ONLINE AIR POLLUTION MONITORING STATION

4.1. INTRODUCTION:
It is evident that monitoring stations may need to be located in urban areas where space and land are at a premium, especially in large cities that are monitoring pollutants such as NOX, Sulfur dioxide, particulate matter. In many cases, the monitoring station may be located in a building or school or traffic police station that is gracious enough to allow an agency to locate their equipment there. Sometimes, a store room is all that is available. However, this can pose serious problems. If the equipment is located in a closet, then it is difficult for the agency to control the temperature, humidity, light, vibration and chemicals that the instruments are subjected to. In addition, security can also be an issue if people other than agency staff have access to the equipment. Keeping above considerations in mind, air pollution monitoring equipment should be set up in stand-alone shelters with limited access by modifying the existing rooms to the recommended station design. The pollution monitoring operators should also have the means and methods for validating the monitoring protocols. The following chapter gives an in detailed description of the optimal design of air pollution monitoring station and its various engineering design considerations and finally the means by which sensor systems are validated for the purpose in offer.

4.2. ENVIRONMENT CONTROL:
An air pollution monitoring station should be designed for functionality and ease of access, i.e., instrumentation easily accessed for operation and repair. In addition, the shelter should be rugged enough to withstand any weather that the local area may generate. In the past, small utility trailers were the norm in monitoring shelters. However, in some areas, this will not suffice. Recently, steel and aluminum storage containers are gaining wide acceptance as monitoring shelters (Tata-Honeywell, 2004). It is observed and recommended for future air pollution monitoring that stations should be housed in shelters that are fairly secure from intrusion or vandalism. All sites should be located in fenced or secure areas with access only through locked gates or secure pathways.
4.2.1. Monitoring station design:
The monitoring station at Punjagutta has been designed keeping the station operators in to consideration. Careful thought to safety, ease of access to instruments and optimal workspace has been given due consideration so that operator will be able to perform their duties more efficiently and diligently. The shelter’s design dictates that they be insulated to prevent temperature extremes within the shelter. All foundations are earthquake and lightning secured. The monitoring station has been designed to control excessive vibrations and external light falling on the instruments, and provision of 3 phase 110/220 VAC voltages throughout the year.

When designing a monitoring shelter, care has been exercised to make secured electrical circuits for the current load of existing equipment as well as other instruments that may be added in future such as Portable Gas Chromatograph or inorganic ion analyzers. Schematic diagram of the shelter design is shown in Figure 4.1 and figure 4.1a through figure 4.1.e shows the pictorial representation of the one shelter design that has proven adequate for the online air pollution monitoring station installation at Punjagutta, Hyderabad.

The first feature of the shelter is that there should be two rooms separated by a door. The reasons for this are twofold. The entry and access should be outside the computer/data review area. This allows access to the site without having to open the room that houses the equipment. It also isolates the equipment from the dust or hot air that can come into the shelter when someone enters. Also, the Data Acquisition System (DAS)/data review area is isolated from the noise and from outside environment. This area is the place where the operator can print data, and prepare samples for the laboratory as well as operating the equipment. This also gives the operator an area where cursory data review can take place. If something is observed during this initial review then possible problems can be corrected or investigated at that time.

The DAS are linked through cables that travel through conduit into the equipment area. The conduit is attached to the walls and then dropped down to the instrument rack. The air conditioning unit has been mounted to maintain required temperature. All air quality instrumentation is located in a modular basis.
Figure 4.1. Schematic representation of design of a shelter for online air pollution monitoring station at Panjagutta

Figure 4.1 a. Design of a shelter for online air pollution monitoring station at Panjagutta
Figure 4.1 b. Design of a shelter for online air pollution monitoring station at Punjagutta

Figure 4.1 c. Design of a shelter for online air pollution monitoring station at Punjagutta
4.2.2. Sampling Probes and Manifolds:

4.2.2.1. Design of Probes and Manifolds for Automated Methods

Some important variables affecting the sampling manifold design are the diameter, length, flow rate, pressure drop, and materials of construction. Considerations for these parameters are critically examined during the early phase of the monitoring station design. The following paragraph discusses the various aspects of both a vertical laminar flow and a conventional manifold design, which are incorporated into the monitoring station.

4.2.2.2. Vertical laminar flow design

By the proper selection of a large diameter vertical inlet probe and by maintaining a laminar flow throughout, the sample air is not permitted to react with the walls of the probe. Numerous materials such as glass, PVC plastic, galvanized steel, and stainless steel, can be used for constructing the probe. Removable sample lines constructed of Teflon or glass can be used to provide each device with sample air. Inlet line diameters of 15cm with a flow rate of 150 L/min are necessary if diffusion losses and pressure drops are to be minimized. The sampling rate is maintained to insure laminar flow conditions. Figure 4.2 is an example of a vertical laminar flow manifold.

![Figure 4.2 Vertical laminar flow manifolds](image)
In practice, it may be difficult to achieve vertical laminar flow because of the elbows within the intake manifold system. Therefore, a conventional horizontal manifold system is also constructed of inert materials in modular sections to enable frequent cleaning. The system (Figure 4.3) consists of a vertical “candy cane” protruding through the roof of the shelter with a horizontal sampling manifold connected by a tee to the vertical section. Connected to the other vertical outlet of the tee is a bottle for collecting heavy particles and moisture before they enter the horizontal section. A small blower, 16.30 L/min at 0° cm of water at static pressure, is at the exhaust end of the system to provide a flow through the system of approximately 13.5 L/min. Particulate monitoring instruments, such as TEOM, each have separate intake probes that are as short and as straight as possible to avoid particulate losses due to impaction on the walls of the probe.

Another type of manifold that is being widely used is known as the “ARB” style manifold illustrated in Figure 4.4. This manifold has a reduced profile, i.e., there is less volume in the cane and manifold; therefore, there is less of a need for bypass flow. These manifolds allow the user more options than the other conventional manifolds. If the combined flow rates are high enough with the instruments at the monitoring location, by-pass flow devices such as blower motors are not required.

4.2.2.3. Conventional manifold design

It has been observed that there are no significant losses of reactive gas (NOx) concentrations in 3 conventional 13 mm inside diameter sampling lines of glass or Teflon if the sample residence time is 10 seconds or less. This is true even in sample lines up to 38 m in length, which collect substantial amounts of visible contamination due to ambient aerosols. However, when the sample residence time exceeds 20 seconds, loss is detectable, and at 60 seconds the loss is nearly complete.

4.2.2.4. Residence time Determination:

The residence time of pollutants within the sampling manifold is critical. Residence time is defined as the amount of time that it takes for a sample of air to travel from the opening of the cane to the inlet of the instrument and is required to be less than 20 seconds for reactive gas monitors (www.Citytech.com, Sensors, Technical manual). It is recommended that the residence time within the manifold and sample lines to the
instruments are less than 10 seconds. If the volume of the manifold does not allow this to occur, then a blower motor or other device (vacuum pump) can be used to decrease the residence time. The residence time for a manifold system is determined in the following way. First the volume of the cane, manifold and sample lines must be determined using the following equation:

Total Volume = Cv + Mv + Lv

Each of the components of the sampling system must be measured individually, then the following calculation is used to measure the volume of the components.

\[ V = \pi r^2 \times L \]

Where \( V \) = volume of the component, \( \pi = 3.14159 \), \( L \) = Length of the component and \( d \) is the inside diameter.

Figure 4.3. Conventional manifold design
4.2.2.5. Placement of tubing on the Manifold:
If the manifold that is employed at the station has multiple ports (See Figures 4.3) then placement of the instrument lines can be crucial. If a manifold similar to Figure 4.4 is used, it is suggested that instruments requiring lower flows be placed towards the bottom of the manifold. The general rule of thumb states that the calibration line (if used) placement should be in a location so that the calibration gases flow past the instruments before the gas is evacuated out of the manifold. Figure 4.4 illustrates two potential introduction ports for the calibration gas. The port at the elbow of the sampling cane provides more information about the cleanliness of the sampling system.

Figure 4.3a Conventional manifold design

Figure 4.4 & 4.5 Positions of calibration line in sampling manifold
4.2.2.6. Placement of Probes and Manifolds
Probes and manifolds must be placed to avoid introducing bias to the sample. Important considerations are probe height above the ground; probe length (for horizontal probes), and physical influences near the probe. Some general guidelines for probe and manifold placement are considered before placing manifolds:

1. Probes are not be placed next to air outlets such as exhaust fan openings
2. Horizontal probes must extend beyond building overhangs
3. Probes are near physical obstructions such as chimneys, which can affect the airflow in the vicinity of the probe
4. Height of the probe above the ground being same for all the pollutants measured particulate as well as gaseous pollutants.

4.3. AIR QUALITY MONITORING TECHNOLOGIES:

4.3.1. Air quality monitoring sensors system:
For an air quality monitoring technology to be suitable for integration within online air pollution monitoring system, the following criteria are examined:

4.3.1.1. Sensitivity: The technology must be sensitive enough to measure target analyte concentrations over the range typically encountered at locations where pollution monitoring systems are likely to be employed (i.e., urban roadside areas), most importantly to differentiate between 'low pollution' and 'high pollution' periods.

4.3.1.2. Reliability: The technology must be accurate, precise and specific enough to provide a reasonable measure of target analyte concentrations.

4.3.1.3. Time-resolution: The technology must possess a time-resolution that allows it to provide new air quality data at a rate that is sufficient for the online air pollution monitoring system to implement timely traffic management actions.

4.3.1.4. Automation: The technology should be readily automated as air quality-responsive monitoring systems likely to be required to operate routinely with little or no operator input or supervision.

Practical criteria, based upon the significant number of air quality monitors likely to be required for an air quality-responsive air quality monitoring system:

4.3.1.5. Cost-effectiveness: Monitoring instruments must be as cost-effective as practically possible.
4.3.1.6. **Robustness**: Monitoring instruments should be robust as they are likely to be required to function reliably for long periods of time regardless of local weather conditions with little or no operator input or supervision.

4.3.1.7. **Failure/fault rate**: Monitoring instruments must possess a low failure/fault rate as site access for modification or repair is likely to be inconvenient. Furthermore, monitoring instruments should possess the capability to self-detect faults automatically.

4.3.1.8. **Modular**: In the event of failure or fault, monitoring instrument components should be modular and readily interchangeable (i.e., 'plug in and run' technology) so that downtime and maintenance and repair times are minimized.

4.3.1.9. **Visual impact**: Monitoring instruments should be small and/or unobtrusive as practically possible, as this minimizes their visual impact and, thereby, reduces the likelihood of vandalism.

The technical criteria, most notably sensitivity, time-resolution and automation, prevent most classes of air quality monitoring technologies from being readily integrated within online air pollution monitoring systems. Similarly, practical criteria, most notably cost-effectiveness, would significantly restrict the use of integrated path monitoring systems. A number of technologies within the remaining class, automated local monitoring have been endorsed for use in conventional air quality monitoring programmes. However, these techniques are relatively expensive and cost has been one of the major limiting factors controlling the number of monitoring stations that can be located within a given area.

A number of alternative technologies have recently become available that could meet many of the criteria identified for integration within online air pollution monitoring systems, namely sensitivity appropriate for routine air quality monitoring, time resolution in the real- to near-real-time range, high cost-effectiveness, robustness and reliability, and a compactness that would result in low visual impact.

Four alternative air quality monitoring technologies were identified, i.e., electrochemical cells, solid state (metal oxide) sensors, solid state (non-metal oxide sensors, and piezoelectric and related resonance sensors (S. Suresh Babu, 2003). Of these four classes of sensors, electrochemical cells were selected for valuation for installation into online air pollution monitoring systems upon the basis of their
performance as reported in relevant literature and commercial availability (Yourong Wang (2002), J.F. Currie (1999), C. Pijola (1999))

4.3.2. Electrochemical Cells

Gas-phase electrochemical cells are a well-established technology. Gas-phase electrochemical monitoring techniques were developed in the 1950s, and basic cell configurations have remained relatively unchanged since the 1970s (J.B. Goddard, 1997). These gas-phase Electrochemical cells measure electrochemical current (and therefore ion migration) between electrodes connected by an electrolytic medium. Electrochemical cells can, therefore, be used to detect or quantify analyte that react within the electrochemical cell to offset the cells internal electrochemical equilibrium and thereby generating electrical current.

Figure 4.6 shows the electrode configuration of a typical electrochemical sensor. Basic electrochemical cells contain two electrodes, an indicator electrode (which is analyte-sensitive) and a reference electrode (which has either a fixed voltage or zero voltage) and current flow or resistance is measured between the two electrodes. However, more sophisticated electrochemical cells typically possess an additional electrode, known as a counter electrode, which is used to measure ion formation by maintaining a constant voltage between the counter electrode and the indicator electrode (Hauptmann, P., 1991). Two main approaches have been used to develop gas-phase electrochemical sensors: (i) containing a liquid-phase electrochemical cell within a gas-permeable membrane, and (ii) connecting electrodes using an electrolytic membrane, such as an ion-impregnated, chemically-bond, polymer-impregnated or gel-immobilized membrane (Bates JR (1997)).

![Schematic electrochemical cell](image_url)

Figure 4.6. Schematic electrochemical cell
Electrochemical carbon monoxide cells are reduction-sensitive cells that measure carbon monoxide upon the basis of the general reaction:
\[ \text{CO} + [\text{O}] \rightarrow \text{CO}_2 \]

Electrochemical carbon monoxide cells are reported to have detection limits of the order of 1 ppm, quantification ranges of the order of 50 ppm and precisions of the order of ± 10-20%. However, electrochemical carbon monoxide cells are likely to be susceptible to interference from other airborne reducing species (e.g., hydrocarbons, nitric oxide and some oxides of sulphur) and there is relatively little published information regarding their accuracy either under laboratory conditions or during in-situ trials.

Electrochemical nitrogen dioxide and ozone cells are oxidation-sensitive cells that measure respective analyte according to the general reactions:
\[ \text{NO}_2 \rightarrow \text{NO} + [\text{O}] \]
\[ \text{O}_3 \rightarrow \text{O}_2 + [\text{O}] \]

Electrochemical nitrogen dioxide cells are reported to have detection limits of the order of 10 to 20 ppb and quantification ranges of the order of 400 ppb. Electrochemical ozone cells are reported to have detection limits of the order of 1 ppb and quantification ranges of the order of 400 ppb. There is very little data currently available regarding the accuracy, precision or reliability for either nitrogen dioxide or ozone electrochemical cells. However, both electrochemical nitrogen dioxide and ozone cells are likely to be susceptible to interference from other airborne oxidants.

A number of advanced air quality monitoring systems are now commercially available based on electrochemical cell technology, e.g., Siemens RPM (www.siemens.com), Marksman (www.marksmann.com), Learian Streetbox, Remco (www.Remco.com), Citysensors (www.Citytech.com). Some of these, for example the Siemens RPM system, incorporate complex air intake systems and dedicated analysis chambers, whilst other instruments function passively by directly exposing the electrochemical cell(s) to ambient air.

An sophisticated air intake system is likely to reduce the chances of electrochemical cell damage, fouling and/or contamination, and facilitates the development of simple calibration and auto-zeroing procedures. However, it is also likely to significantly increase the purchase cost of the instrument and the introduction of moving parts.
such as an air pump, can significantly reduce the operational reliability of an instrument.

In the design of online air pollution monitoring system, City Sensor’s advanced electrochemical sensors were selected as: (i) the all incorporated electrochemical (carbon monoxide, nitrogen dioxide and zone) cells were reported to be high specification models (i.e., high sensitivity and good reliability). The electrochemical cells were imported supplied as part of an integrated air quality monitoring system (i.e., electrochemical cells, data loggers, controllers, modems and management software). All individual system components were purchased from independent commercial suppliers and configured with the technical support from M/S Spectrochem Instruments Pvt. Limited. Figure 4.7 and figure 4.8 presents the pictorial representation of different electrochemical cells employed for the design of online air pollution monitoring station and the sensor system. Figure 4.9 and figure 4.10 shows the electrochemical sensor based air pollution monitoring and meteorological information system. A self-contained (or ‘one-box’) unit with electrochemical sensors mounted upon the exterior surface of a weatherproof box and all other system components housed within the same box. Table 4.1 shows the sensors and their operational range utilized in the online air pollution monitoring system.

**Table 4.1. Pollution data monitoring range used in the present monitoring system**

<table>
<thead>
<tr>
<th>Gaseous pollutant monitoring sensor system</th>
<th>Range, ppm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sulphur dioxide</td>
<td>0 - 5</td>
</tr>
<tr>
<td>Nitrogen dioxide</td>
<td>0 - 5</td>
</tr>
<tr>
<td>Carbon monoxide</td>
<td>0 - 100</td>
</tr>
<tr>
<td>Nitrous Oxide</td>
<td>0 - 50</td>
</tr>
<tr>
<td>Hydrogen sulphide</td>
<td>0 - 10</td>
</tr>
<tr>
<td>Hydrocarbons</td>
<td>0 - 200</td>
</tr>
<tr>
<td>Mercaptans</td>
<td>0 - 50μg/m³</td>
</tr>
<tr>
<td>Ozone</td>
<td>0 - 10</td>
</tr>
</tbody>
</table>
Figure 4.7. Pictorial representation of different electrochemical sensors systems employed in the online air pollution monitoring system.

4.3.2.1. Evaluation of electrochemical sensors:

This section summarizes the findings of initial laboratory and field trials of electrochemical sensors. In laboratory trials, conducted at the M/S Spectrochem Instruments Pvt. Ltd (www.spectrochemindia.com), electrochemical are exposed to reference gas samples to evaluate their performance. Pre-gas mixtures are purchased from M/S BOC India Limited, as 100 and 1000ppm 1.5-liter cylinders. The dilution of these gases was carried out using IOLAR-III nitrogen.

The exponential gas dilution system is employed for preparation of required concentrations of test gases using the dilution system manifolds. Once suitable range diluent is prepared, those are injected onto stainless steel canisters to prepare lower concentration ranges. The results of these trials are summarized in Table 4.2.

Electrochemical cell carbon monoxide responded significantly in the presence of carbon monoxide, but is not affected by exposure to ‘zero air’, nitrogen dioxide. Electrochemical cell nitrogen dioxide sensors behaved in highly similar manners. The NOx sensors gave very minor negative responses to carbon monoxide, minor positive
responses to nitric oxide. As shown in table 4.1 NO₂ and O₃ gas sensors were not calibrated using the dilution system as the standard for above gases were not available.

Figure 4.9 Ambient air quality monitoring system installed at Punjagutta,

Figure 4.10 Basic Electrochemical sensor air quality monitoring unit
Table 4.2 Behavior of electrochemical sensors during laboratory trials

<table>
<thead>
<tr>
<th>Reference gas</th>
<th>SO₂</th>
<th>NO</th>
<th>O₃</th>
<th>H₂S</th>
<th>CO</th>
<th>HC</th>
<th>NO₂</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zero air (Tolair III grade Nitrogen)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>CO</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>+</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
</tr>
<tr>
<td>NO₂</td>
<td>NR</td>
<td>+</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
</tr>
<tr>
<td>O₃</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>H₂S</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>+</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
</tr>
<tr>
<td>HC</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>+</td>
<td>NR</td>
</tr>
<tr>
<td>N₂O</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>NS</td>
</tr>
</tbody>
</table>

NS: No standard available for testing the electrochemical sensor behavior
NR: No response to the standards in operation

4.3.2.2. Field trials:
Electrochemical cell instruments were deployed in field trials to evaluate their in-situ performance. Two field trial sites were selected to (i) provide a broad range of target pollutant concentrations and environmental conditions, and (ii) allow direct comparison with conventional air quality monitoring instruments (UNEP/WHO (1994)). The two sites are described as follows:

4.3.2.2.1. Punjagutta: The flow of vehicles in this area is very high owing to being a major link connecting major commercial establishments around the city. APPCB (2003) continuously monitors the pollution in this place on a daily basis and the data is available from 1996 onwards. Keeping the above considerations the electrochemical sensors systems were placed at Punjagutta and evaluated for their performance.

4.3.2.2.2 KBR Park:
It is a conserved natural forest in Hyderabad and is remote from major pollution sources (e.g., major roads, commercial incinerators, etc.) Personnel of the Andhra Pradesh Pollution Control Board conduct conventional air quality monitoring on-site and at the time of the field trials monitored pollutants include oxides of nitrogen, SPM, and sulphur dioxide.
4.3.2.3. Results of the field trials:
The electrochemical cell carbon monoxide sensor was evaluated upon the basis of deployment at Punjagutta X Roads. In general, a reasonable degree of agreement was observed between electrochemical and APPCB supplied carbon monoxide monitoring instrument obtained data during the deployment period. The point-by-point variation in monitoring data obtained using the electrochemical cell carbon monoxide sensor was higher than the data obtained using the APPCB supplied instrument. Consequently, smoothing (i.e., 'rolling point' averaging) the electrochemical carbon monoxide data set significantly improved the agreement between the two data sets.
In general, the electrochemical cell carbon monoxide sensor performed well, i.e., correlation with the conventional instrument was good (0.77 and 0.88 for raw and smoothed data, respectively) over the concentration range 0.5 to 25 ppm and data capture efficiency was better than 90%. However, the electrochemical cell detection limit was approximately 0.5 ppm with the degree of disagreement was reasonable. By comparison, the degree of disagreement for instruments is typically 5 to 10%.

4.4. PARTICULATE MONITORING SYSTEM:

4.4.1. Total Respirable Particulate Analyzers with PM10 Head
The main emphasis in ambient particulate monitoring is to determine the concentration of total particulates in the respirable and thoracic size ranges, since these have the greatest significance in relation to human health. Ambient air enters the particulate monitor through a sampling head, which has different collection efficiency for particles with an aerodynamic size distribution of less than 10 microns - the so-called PM10 fraction, PM2.5 and Total particulate matter. The PM10 size fraction encompasses a large proportion of respirable and thoracic particles.
As shown in figure 4.10 the particulate matter analyzer is composed of two components, the TEOM Sensor unit and TEOM control unit. The sensor unit contains the mass measurement hardware that continuously monitors the accumulated mass on the system’s exchangeable filter cartridge. By maintaining a flow rate of 3 l/min through the instrument and measuring the total mass accumulated on the filter cartridge, the device can measure the mass concentration of the sample stream in real time. The control unit houses a microprocessor system, flow control hardware, a gauge to determine filter lifetime, transformers and power supplies.
The monitor draws ambient air through a filter at a constant flow rate continuously weighting the filter and calculating real time (10min) mass concentrations. In addition the instrument computes the total mass accumulation on the collection filter, as well as 30 min, 1-hour, 8 hour and 24 hour averages of mass concentrations. Both RS232 and analog outputs are available to transmit the measurements to the data acquisition system.

Inside the mass transducer, the sample air stream passes through a filter made of Teflon – coated borosilicate glass fiber. This filter is weighted every two seconds. The difference between the filter’s current weight and filters initial weight gives the total mass of the collected particulate matter. These instantaneous readings of total mass are then smoothed exponentially to reduce noise. Next the mass rate is calculated by taking the change in the smoothed total mass between the current readings and the immediately preceding one and expressing this as mass rate in g/sec. This mass rate is also smoothed exponentially to reduce noise. Finally, the mass concentration in μg/m³ is computed by dividing the mass rate by the flow rate. The obtained result is then multiplied with $10^6$ to convert from g/m³ to μg/m³.

![Figure 4.10 Particulate matter analyzer](image)

Internal temperatures in the instrument are controlled to minimize the effects of changing ambient conditions. The sample stream is preheated to 50°C before entering
the mass transducer so that the sample filter always collects under conditions of very low humidity.

The tapered element at the heart of the mass detection system is a hollow tube clumped on one end and free to oscillate at the other. An exchangeable filter cartridge is placed over the tip of the free end. The sample stream is drawn through this filter and then down the tapered element. As in any spring-mass system, if additional mass is added, the frequency of oscillation decreases. In a spring-mass system the frequency obeys the following equation.

\[ f = (K/M)^{0.5} \]

where \( f \) = frequency (radian/sec), \( K \) = spring rate and \( M \) = mass. \( K \) and \( M \) are constant units. The relationship between mass and change in frequency can be expressed as

\[ dm = K_0 \left( \frac{1}{f_1} \right)^2 - \left( \frac{1}{f_2} \right)^2 \]

where \( dm \) is the change in mass, \( K_0 \) is spring constant, \( f_0 \) initial frequency and \( f_1 \) is the final frequency. When this equation is rearranged for spring constant

\[ K_0 = \frac{dm}{\left( \frac{1}{f_1} \right)^2 - \left( \frac{1}{f_0} \right)^2} \]

Thus the calibration constant for the instrument can be easily determined by measuring the frequencies with and without a known mass. In actual operation the monitor measures the entire mass of the system using the following equation.

\[ M = K_0/f \]

At the end of the instruments 30 minute flow and temperature equilibrium period the monitor averages the frequency for a short period and uses this frequency to compute the baseline mass. Until the next time the unit is reset or taken out of its data collection mode, the frequency is sampled every two seconds and the system mass is calculated.

The calibration of the TEOM mass transducer is determined by the mass transducer's physical mechanical properties. Since the mass of the filter cartridge with particulate matter differs from the new filter cartridge by only a small fraction, calibrating the system with a calibration mass equivalent to the filter mass allows all measurements to be made essentially the same operating point as the original calibration. The \( K_0 \) of the balance is calculated using the following formula.

\[ K_0 = M_{\text{filter}} / \left( \frac{1}{F_1} \right)^2 - \left( \frac{1}{F_0} \right)^2 \]
Where $M_{\text{filter}}$ is the filter mass (grams) $F_0$ is the filter without filter and $F_1$ is the frequency with filter. Table 4.3 shows the Tapered element calibration data. The standard deviation of 22.14 with a coefficient of variation of 0.17% is observed for the instrument.

Table 4.3 Tapered element oscillating microbalance calibration results

<table>
<thead>
<tr>
<th>Mass (mg)</th>
<th>$F_0$ (Hz)</th>
<th>$F_1$ (Hz)</th>
<th>$K_e$</th>
</tr>
</thead>
<tbody>
<tr>
<td>115.33</td>
<td>333.097</td>
<td>237.769</td>
<td>13293.51</td>
</tr>
<tr>
<td>116.95</td>
<td>333.096</td>
<td>236.829</td>
<td>13265.20</td>
</tr>
<tr>
<td>116.24</td>
<td>333.096</td>
<td>237.258</td>
<td>13281.71</td>
</tr>
<tr>
<td>115.36</td>
<td>333.096</td>
<td>237.855</td>
<td>13316.68</td>
</tr>
<tr>
<td>116.19</td>
<td>333.096</td>
<td>237.432</td>
<td>13315.50</td>
</tr>
<tr>
<td>Std deviation</td>
<td>Coefficient of variation</td>
<td>Average $K_n$</td>
<td></td>
</tr>
<tr>
<td>22.24</td>
<td>0.17%</td>
<td>Hardware cal constant</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>13295</td>
<td></td>
</tr>
</tbody>
</table>

4.5. SOUND LEVEL MEASUREMENT:

The sound level meter that is designed to be quick and easy to use when making environmental noise and occupational health related measurements, is used for online pollution monitoring system. A large LCD screen displays measurements and includes a quasi-analog bar showing the current sound pressure level. The instrument has two parallel, independently weighted detectors that enable it to display RMS and Peak readings simultaneously. Figure 4.11 shows the pictorial representation of electrochemical sensor system.

The linearly weighted AC output enables a direct calibrated recording (on Digital Audio Tape, for example), which can be used later for complete acoustical analysis. The Sound Level Meter consists basically of a microphone, an amplifier and a detector with associated frequency and time weighting circuits, an analogue DC output, and a digital display. Overload, under range and low battery indicators.

The instrument is capable of storing up to 40 records of measurement results. Each record stores the date, measurement time, $L_{eq}$, $Max P$, $Max L$, $Min L$, and overload.
status. These results can be transferred in a spreadsheet-compatible format via the built-in serial interface to a PC.

![Microphone](image)

**Figure 4.11 showing sound level meter**

4.6. METEOROLOGICAL MONITORING SYSTEM:

To accurately monitor weather conditions for predicting the dispersion of atmospheric pollutants requires reliable meteorological data. However, the problem is that conventional meteorological monitoring systems are inefficient and expensive. Further each sensor system in a weather station requires its own wiring and power supply requiring individual signal conditioning before being transmitted.

A weather station (see figure 412), developed by Dallas Semiconductor, which transmits data by both power and bi-directional data over a single twisted-wire cable, is considered for the present online monitoring station (WWW.Dallasmaxim.com). This MicroLAN uses a capacitor and diode half-wave rectifier to provide parasitic power from the data line for the stations various sensors and to transfer data. The basic weather station measures wind speed and direction, ambient temperature, and rainfall totals however, the system is augmented with humidity, barometric pressure for the development of present monitoring station.
Each sensor has a unique serial number that identifies it to the bus. A PC or microprocessor executing Touch Memory Executive (TMEX) software controls the station. Data transfers are half-duplex and bit sequential over a single twisted pair using short and long time slots to encode the binary 1s and 0s.

Figure 4.12 Block diagram of meteorological monitoring system

Figure 4.13 Meteorological monitoring system showing wind direction, temperature, barometric pressure, rainfall and wind speed sensor system
4.6.1. Wind Direction
Magnetically activated reed switches were selected as the wind sensors for several reasons. They do not require power to operate. Because they are neither motion nor rate dependent, they can measure static conditions. They do not require signal conditioning. And they have very high impedance in the open state and negligible impedance (150m.) when closed. A reed switch can operate over 100 million or more cycles at 50 V/100 mA levels or higher before failure. 1-Wire devices, which run at 5 V/4 mA, present almost no load, however, and can work with ON resistance values of up to 100. The functional lifetime of a reed switch in a 1-Wire environment such as the weather station is therefore much greater.

The wind direction sensor consists of eight reed switches mounted radically on a Printed Circuitry board, at 22.5° intervals. A rectangular activating magnet, polarized with a single pole facing the reed switch, is mounted in a rotor attached to the weather vane axle. The rotor is designed so that one layout can be used for both the wind speed and direction sensors. When the sensor is to be used for wind direction only, a single magnet is mounted in either of two holes near the rotor’s center. As the wind rotates the vane and attached rotor, the magnet closes the switch as it passes over the reed. When a reed is closed, its companion is connected to the bus, and the bus master can read its serial number. This number identifies both the switch and the compass point it represents. For reasons of isolation, the bus master can read wind direction information only when the addressable switch is closed. Communication would otherwise be disrupted each time a reed switch closed and its associated serial number signaled its presence on the line.

Figure 4.14 Wind directions measurement system
Communication with the wind direction sensor begins when the bus master turns on the output, connecting one side of all the DS2401s to the 1-Wire bus ground line. With its rotor and magnet, the weather vane activates (closes) at least one of the reed switches, connecting the other side of that DS2401 to the data line so the bus master can read its serial number. Because the master previously learned which compass point each DS2401 identifies, it knows which direction the vane is pointing when a particular DS2401 is on the bus. The eight reed switches directly indicate eight compass points. Because of the magnet’s length, however, when the magnet is approximately half way between two adjacent reed switches, both are closed. The bus master understands that this means the weather vane is midway between two compass points; so 8 additional points are inferred, for a total of 16.

4.6.2. Wind Speed

The weather station handles wind speed measurements in a similar manner. The sensor consists of two magnets mounted on a second rotor attached to the wind cup’s axle. The magnets operate a reed switch connected to the DS2423 counter chip that provides the sensor’s serial number. One magnet is mounted in each of the two outermost holes of the rotor, providing two counts per revolution and thus improving response at low wind speeds. The two-magnet magnet arrangement also provides rotational balance to the rotor, an important consideration given that the rotor can reach 2400 rpm in 160 km/h (100 mph) winds.

The counter chip keeps track of the total number of wind cup revolutions and transmits the data to the bus master on demand. The chip contains two 232-bit counters and can be powered for 10 yr with a small lithium battery. Power for the counter chip comes from diode CR1 and capacitor C1, which form the half-wave rectifier that steals power from the data line. The counter can be reset to zero only when this parasitic power is lost. The bus master calculates wind speed by taking the difference between two values stored in the counter, one generated before and the other generated after a clocked interval. The calculation also takes into account other factors such as the relationship of revolutions per minute to kilometers per hour.

4.6.3. Temperature

Ambient temperature is measured with the DS1820 1-Wire digital thermometer. This self-contained sensor measures temperature as the difference between two oscillators,
one of which is temperature dependent. The sensor functions over a $\pm 55^\circ \text{C}$ to $125^\circ \text{C}$ range and provide uncorrected accuracy of $\pm 0.5^\circ \text{C}$ over $0^\circ \text{C}$ to $70^\circ \text{C}$. For measurement accuracy, this sensor would normally be mounted in a separate, ventilated housing.

In accordance with the initial design's emphasis on simplicity, however, it was mounted on the weather station PCB. Because exposure to the sun can raise the inside of the housing to $20^\circ \text{C}$ over ambient, this arrangement can lead to large errors in reading. Mounting an additional digital thermometer in a separate enclosure and adding it to the bus by plugging it into the daisy-chain connector on the PCB can solve the problem. A measurement of solar radiation may then be calculated from the difference between the two temperature readings. Indoor temperature can be measured with another DS1820 mounted in the desired location and connected to the same twisted pair going to the weather station. In fact, multiple DS1820s can be added on the 1-Wire cable to measure temperature anywhere along its length, up to 300 m.

4.6.4. Rainfall

Rainfall is commonly measured with the fill-and-tip method. Rain enters the collector, drips through a small hole in its funnel shaped bottom, and falls into one of two identical receptacles of known volume mounted on either end of a beam. One vessel is up, the other down. When the upper receptacle is full, that ends of the beam pivots down. The water spills out and drains away. This action raises the lower receptacle into the up position and the cycle continues. Each time the beam moves, a magnet mounted to it momentarily closes a reed switch, with each closure typically representing 0.01 in. of rain. Because the system incorporates a DS2423 1-Wire counter chip with the reed switch, rainfall measurement capability can be added to the weather station by simply connecting its I/O pin to the twisted-pair bus.

4.6.5. Barometric Pressure

Atmospheric, or barometric, pressure is a valuable indicator of imminent weather change when a front moves past the instrument. This meteorological parameter can also be measured over a 1-Wire net using an ADI. Selecting a pressure sensor that contains comprehensive onchip signal conditioning makes the circuit very straightforward. As was the case with the humidity-sensing element, the suggested
pressure-sensing element is ratiometric, which requires that both the output voltage representing atmospheric pressure and the supply voltage across the element be known in order to accurately calculate barometric pressure.

Figure 4.15 Meteorological monitoring system showing temperature, barometric pressure and rainfall measurement system enclosed in a protective case

4.6.6. Humidity

Not only is humidity an important factor in many processing and manufacturing operations, but it also directly affects our own comfort and well-being. Too low, and we must deal with static electricity and ESD problems; too high, and mold, condensation, and mugginess affect us. With the proper sensing element, humidity can be easily measured with an ADI over the 1-Wire net. The Honeywell capacitive sensing element specified here develops a linear voltage vs. relative humidity (RH) output that is ratiometric to the supply voltage. That is, when the supply voltage varies, the sensor output voltage follows in direct proportion. This necessitates measuring both the voltage across the sensing element and its output voltage. In addition, calculation of true RH requires knowledge of the temperature at the sensing element. Because it contains all the necessary measurement functions to do the calculations, the DS2438 is an excellent choice for an ADI humidity sensor.

In operation, the bus master first has U1, the DS2438, report the supply voltage level on its VIN pin, which is also the voltage across U2, the sensing element. Next, the master has U1 read the output voltage of U2 and report local temperature from its on-chip sensor. Finally, the master calculates true RH from the three parameters supplied
Since the bus master identifies each ADI by its unique serial number, many humidity sensors can be placed on the line. This is particularly convenient in applications such as greenhouses where it is desirable to know the humidity at multiple locations within the enclosure.

4.7. CONCLUSIONS:
The design considerations for online air pollution monitoring station are discussed in the present chapter. The setup of suitable environmental control system for monitoring purpose i.e. room sizes and separation of control room from outside environment, the placement of pollution drawing manifolds and their dimensions are dealt in detail in this chapter. Description of principle mechanism, sensor performance evaluation and operational protocol for monitoring system of electrochemical sensors for air pollutants such as Sulphur dioxide, Oxides of nitrogen, Carbon monoxide, Hydrocarbons, ozone, mercaptans and hydrogen sulphide sensors, Particulate matter analyzer, sound level meter, meteorological system are also discussed in the chapter.
REFERENCES


4. Citytech sensors, UK, technical manual


9. S. Suresh Babu, 2003, “Piezoelectric crystal based sensors for direct monitoring of sulfur dioxide in ambient air” Thesis submitted to IPGSR, JNT University, Mahaveer marg, Hyderabad

10. Tata-Honeywell (2004), personal communication, 6th January, 2004, visit to Director’s office, JNT university, Masabtank, Hyderabad

12. www.APPCB.org/
13. www.citytech.com
14. www.learian.com
15. www.marksman.com
17. www.siemens.com