CHAPTER III

INSTRUMENTATION OF LASER BASED AIR QUALITY MONITORING SYSTEM.

3.0 Brief introduction about the experimental setup

This chapter contains details about the design considerations of a new type of laser based air quality monitoring system and describes the incorporated instrumentation. Section 3.1 gives the details about the experimental setup of the laser based air quality monitoring system as a whole. Sections 3.2 to section 3.7 contains about each individual units of the air quality monitoring system. The source He-Ne laser used in our set up is discussed in Section 3.2. Section 3.4 contains details about the temperature measurement detector unit. The details about the photo-detector unit are discussed in section 3.5 Here the three detectors, the transmission photo-detector, the reference photo-detector and the scattered photo-detector used in our set up are discussed. The different constituents unit of the detectors, viz, the amplifier section, and neutral density filter and about the phototransistor is discussed. Section 3.7 incorporates about the water vapour unit and about the humidity calculation in our setup. Section 3.8 contains details about the gas unit. Finally, section 3.9 represents a little bit about the data acquisition system, which is discussed in details in chapter IV.

The parameters to be measured with this air quality monitoring system are extinction coefficient and the scattering coefficient. The techniques used for the measurement of these parameters are

1) Comparison of transmitted intensity of light with reference to the original reference light intensity and computation of the corresponding extinction coefficient.
2) Measuring scattered intensity from seven different angles scattering coefficients are computed.

These are the two basic parameters through which the monitoring of air quality is developed and specific observations of water vapour in air having varying levels of O$_2$, CO$_2$ and N$_2$ were performed. This system [64,65] constitutes a significant part reported in this thesis.

3.1. Experimental setup of laser based air quality monitoring system.

![Photograph 3.1 Laser based air quality monitoring system](image.png)

The schematic diagram of the newly designed and fabricated laser based air quality monitoring system along with the simulation chamber is shown in figure 3.1 (Photograph 3.1). The basic units of the system are a He-Ne laser source; detectors and PC based data acquisition system. The beam from the laser source A is split by the beam splitter K into two parts, a forward-transmitted beam TR and a reflected reference beam RF. The TR beam then enters through glass windows G1 into the simulation chamber L and comes out through glass window G2 and falls into the detector D. Detector C receives the scattered beam from the center of the simulation chamber at an angle $\theta_s$ through G3 and the detector B receives the reference beam RF. Also the detector E gives the temperature variation of the simulation chamber during the time of the experiment. The detector C can be placed at scattering angle from...
22.5° to 157.5° in increments of 22.5° degrees. A vacuum pump J is used to evacuate the chamber to 0.1 Torr pressure. The chamber is then filled with the test gas from the gas unit through the regulator at required amount. Consequently the level of the water vapour in the chamber is increased from the vapour unit through flow meter. The combination of A and D represents the transmissiometer while the combination of A and C represents the nephelometer and the point visibility meter. The four outputs of the detectors are fed to the analog-to-digital converter F unit, which is a part of the data acquisition system (DAS). The details of individual components are described in the following sections.

3.2 He-Ne laser source

He-Ne laser source shown in A in photograph 3.1; A in Fig 3.1; and photograph 3.2). He-Ne laser [55] device is one of the most common continuous wave laser sources available now days. This type of laser having a power ranging from 5 milliwatt to 60 milliwatts is available. In addition, it has an advantage that the dimension of this type of lasers ranging from few centimeters to few meters. The requirement of an
intense, compact, portable, coherent and highly monochromatic light source necessitates the use of a He-Ne laser. This He-Ne source has 1mW intensity beam of cross-section of 0.01767 sq.cm and with a random polarization line width. The wavelength of the laser beam is 632.8\mu m. This wavelength is chosen as it falls in the atmospheric transmission window [1,20] and can travel long distances without absorption in air. Moreover, this wavelength is scattered most prominently by water droplets. This laser source is mounted on a fabricated stand where base can be leveled by screw for alignment of the beam.

3.3 Simulation chamber

![Simulation Chamber](image)

Photograph.3.3

Here photograph 3.3 shown the cylindrical metallic simulation chamber. It is a cylindrical metal container of 80 cm in diameter, 30 cm in height and having a volume \( V_{\text{chamber}} \) of 150796 c.c. (150.796 litres). Also it consist of glass windows for entry and exit of the laser beam for monitoring the transmitted light and glass windows along the circumference of the cylinder for monitoring the scattered light.
from different angles from 0° to 337.5° with an increment of 22.5° degrees. Also there are 5 portholes of .7 cm in diameter are at the top of the chamber.

3.4 Temperature measurement detector unit

![Photograph 3.4 Detector E for temperature measurement](image)

The temperature measurement detector unit (E in fig 3.1; E in photograph 3.1; Photograph 3.4) is shown schematically in fig 3.2. It comprises of an instrumentation amplifier [56]. Instrumentation amplifier is made up of three op-amps. The first two op-amp A1 and A2 provide a high input impedance because the signals go directly into the non-inverting inputs of the op-amp and the Op-amp A3 represent the usual differential amplifier. The signal source of the Instrumentation amplifier is the output of the transducer.

Before proceeding with the bridge application, we consider the important characteristics of some resistive type of transducer. It consists of a sensor element that exhibits a change in resistance with a change in temperature, a signal conditioning circuit that converts the resistance changes to an output voltage and appropriate instrumentation to record and display the output voltage.
Resistance-temperature-detector (RTDs) is simple resistive element formed of such materials as platinum, Nickel etc. These materials exhibit a positive coefficient of resistivity. The sensor is a resistive element that exhibits a resistance temperature relationship given by the expression

$$R = R_0 \left( 1 + \gamma_1 T + \gamma_2 T^2 + \ldots + \gamma_n T^n \right)$$  \hspace{1cm} \text{3.4.1}

Where $\gamma_1, \gamma_2, \ldots, \gamma_n$ is the temperature coefficient of resistivity.

$R_0$ is the resistance of the sensor at a reference temperature $T_0$.

The reference temperature is usually specified as $T_0 = 0^\circ C$.

The number of terms retained in equation (3.4.1) for any application depends on the material used in the sensor, the range of temperature and the accuracy required in the measurement. For a limited range of temperature the linear form of equation (3.4.1)

$$\Delta R/R_0 = \gamma_1 (T - T_0)$$  \hspace{1cm} \text{3.4.2}
It is often used to relate resistance changes to temperature change. When the error owing to neglecting terms become excessive, either linearizing circuit can be used to compensate for the non-linearity or additional terms can be retained. From equation (3.4.1) to relate the measured $\Delta R$ to the unknown temperature $T$ retaining the temperature coefficient $\gamma_1$, $\gamma_2$ from equation (3.4.1) yields the second order relationship.

$$\frac{\Delta R}{R_0} = \gamma_1 (T - T_0) + \gamma_2 (T - T_0)^2$$

Equation (3.4.3) is more cumbersome to employ, but it provides more accurate results over a wide temperature range. The widely used sensors consist of a high purity (99.99 percent) platinum wire wound about a ceramic core and hermetically sealed in a ceramic capsule. Platinum is one of the superior materials for precision thermometry. It resists contamination and corrosion and its mechanical and electrical properties are stable over a long period of time. Also it has always the same resistance at the same temperature correct to .01°c. Here we used (pt -100) sensor in our setup because the resistance of the metal varies uniformly over a wide range from $-200°c$ to $1200°c$. The temperature coefficient of resistance is expressed in ohms per unit change in degrees Celsius ($°c$). The sensitivity $S$ of a platinum RTD is relatively high ($S=0.390 \Omega/°c$ for an RTD with a resistance of $100\Omega$ at $0°c$).

The simplified differential amplifier using a transducer bridge used in our system arrangement is shown in (fig 3.2). The transducer (pt –100) whose resistance changes as a function of some physical energy is connected in one arm of the bridge with a small circle around it and is denoted by $(R_T + \Delta R)$ where $R_T$ is the resistance of the transducer and $\Delta R$ the change in resistance $R_T$. 

71
The bridge in the circuit is d.c. Excited. For the balanced bridge at some reference condition \( V_a = V_b \)

Or \( \frac{R_B(V_{dc})}{R_b + R_c} = \frac{R_A(V_{dc})}{R_a + R_T} \)

Or \( \frac{R_c}{R_b} = \frac{R_T}{R_A} \)

Generally resistors \( R_A, R_B \) and \( R_C \) are selected such that they are equal in value to the transducer resistance \( R_T \) at some reference condition. The reference condition is the specific value of the physical quantity under measurement at which the bridge is balanced. This value depends on the transducer characteristics, the type of physical quantity to be measured and the desired application. The bridge is balanced initially at a desired reference condition. However as the physical quantity to be measured changes, the resistance of the transducer also changes which causes the bridge to unbalanced, \( V_a \neq V_b \). The output voltage of the bridge can be expressed as a function of the change in resistance of the transducer.

Let the change in resistance of the transducer be \( \Delta R \). Since \( R_B \) and \( R_C \) are fixed resistors the voltage \( V_b \) is constant. However \( V_a \) varies as a function of the change in transducer resistance. Therefore according to the voltage divider rule

\[
V_a = \frac{R_A(V_{dc})}{R_a + (R_T + \Delta R)}
\]

\[
V_b = \frac{R_B(V_{dc})}{R_B + R_C}
\]

Consequently the voltage \( V_{ab} \) across the output terminals of the bridge is

\[
V_{ab} = V_a - V_b = \frac{R_A(V_{dc})}{R_a + (R_T + \Delta R)} - \frac{R_B(V_{dc})}{R_B + R_C}
\]
However, \( R_a = R_b = R_c = R_t = R \)

Then \( V_{ab} = \frac{R(V_{dc})}{2R + \Delta R} - \frac{R(V_{dc})}{2R} \)

\[
= \frac{2R^2(V_{dc}) - 2R^2(V_{dc}) - R\Delta R(V_{dc})}{2R(2R + \Delta R)}
\]

\[
V_{ab} = \frac{-R\Delta R(V_{dc})}{2R(2R + \Delta R)}
\]

\[
V_{ab} = \frac{-\Delta R(V_{dc})}{2(2R + \Delta R)}
\]

The negative sign in the equation indicates \( V_a < V_b \) because of the increase in the value of \( R_t \). The output voltage \( V_{ab} \) of the bridge is then applied to the differential instrumentation amplifier composed of three op-amps. The gain of the basic differential amplifier is \((-R_F/R_1)\).

Therefore the output \( V_0 \) of the circuit is

\[
V_0 = V_{ab}(\frac{-R_F}{R_1}) = \frac{\Delta R(V_{dc})R_F}{2(2R + \Delta R)R_1}
\]

This equation indicates that \( V_0 \) is directly proportional to the change in resistance \( \Delta R \) of the transducer.

**Construction and installation:**

**Components:**

<table>
<thead>
<tr>
<th>Table-3.1</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Semiconductors, (Op-amps)</strong></td>
</tr>
<tr>
<td><strong>Resistors (all 1/4 watt) MFR</strong></td>
</tr>
<tr>
<td><strong>Transducer</strong></td>
</tr>
<tr>
<td><strong>Power supply</strong></td>
</tr>
<tr>
<td><strong>D.C. voltage</strong></td>
</tr>
<tr>
<td><strong>PCB</strong></td>
</tr>
</tbody>
</table>
This sensor was constructed on a single sided glass epoxy board and all components given in the table 3.1 are assembled on the P.C.B properly. The variation of voltage is drawn from the pin 6 of the IC A3 and connected to one of the channels of the ADC card, which is interfaced with the PC. To protect electromagnetic noise this card is electrically shielded.

**Calibration arrangement**

![Diagram of calibration setup]

**Figure 3.3(A) Block diagram for calibration**

Calibration arrangement for temperature measurement unit is shown in figure 3.3 (A). Firstly, the sensor was connected with the ohmmeter or digital multi meter through shielded wire. Now the sensor is placed in melting ice and the resistance of the sensor was recorded in terms of voltage then the sensor is placed in the furnace A. Thermometer T is kept inside the furnace to measure the temperature. When the furnace A is connected with the power supply, the temperature inside the furnace increases gradually. When the temperature of the furnace attains a particular temperature (say 30°c) and becomes steady resistance of the sensor was recorded in terms of voltage. Again the temperature of the furnace was increased up to a value
(say 60°c) and the resistance of the sensor was recorded in terms of voltage. This process was repeated up to a temperature 150°c with an increment of 30°c. Finally a graph was plotted temperature vs. resistance (in terms of voltage) a straight line was obtain which obeys the equation y=mx+c. It was calibrated over a range of temperature from 0°c to 150°c for our instrument. The calibration curve is shown in fig 3.3 (B) from the table.

### Table 3.2

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Volts</th>
</tr>
</thead>
<tbody>
<tr>
<td>0°c</td>
<td>.03 volts</td>
</tr>
<tr>
<td>30°c</td>
<td>.16 volts</td>
</tr>
<tr>
<td>60°c</td>
<td>.29 volts</td>
</tr>
<tr>
<td>90°c</td>
<td>.38 volts</td>
</tr>
<tr>
<td>120°c</td>
<td>.46 volts</td>
</tr>
<tr>
<td>150°c</td>
<td>.54 volts</td>
</tr>
</tbody>
</table>

Fig 3.3 Temperature-Volt relation curve
3.5 Photo-detector unit

Here in this Photo-detector unit the detectors, which act as transducer to convert the intensity of light to appropriate electrical voltage signal. A lens on a phototransistor focuses light entering the detector. The photo voltage generated at the phototransistor is fed to an amplifier, which produces an amplified analog voltage at the output of the detector.

There are three photo-detector units in our setup.

1). Photo detector unit (For transmitted part of the laser beam)

2). Photo detector unit (For reference part of the laser beam)

3). Photo detector unit (For scattered part of the laser beam)

All above mentioned photo detector units have the same configuration except that the neutral density filter is absent in the scattered photo detector unit.

3.5.1 Transmission and reference photo detector unit

Photograph 3.5 Detector for transmitted light  Photograph 3.6 Detector unit (internal)

The transmission and reference photo detector unit (B and D in fig 3.1; B and D in photograph 3.1; photograph 3.5 and 3.6) is shown schematically in fig 3.4. The basic
Components of this photo detectors shown in fig 3.4 are phototransistor (TIL-81 type), LM-308 based amplifier section, neutral density filter N, lens L and some resistors.

The light beam entering through the hole H of the photo detector unit is passed through the lens L and comes to focus at the neutral density filter N. Here the phototransistor T take up the light signal from the neutral density filter N and generates photo current I₁. And this current I₁ produces a voltage drop V₁ across R₁. This voltage V₁ is then amplified by a LM-308 [58] unit by A₁ (A₁ = 1000 times).

a). Photo transistor- TIL-81 type photo transistor is a very high sensitive n-p-n silicon photo transistor [59,60]. Here 5 volt biasing was provided and the base terminal remains as floating. The specifications of the phototransistor at 25° centigrade given below, which is very appropriate for our system.

Collector to emitter voltage = 45V (Maximum)

Light current (at collector to emitter voltage = 5 V and Intensity of light on the photo detector = 10mW/cm²) = 6 mA.
Dark current (at collector to emitter voltage = 10 V and intensity of light on the phototransistor = 0 W/cm²) = 100 mA.

Saturation voltage (at collector current = 10 mA) = 0.4 V.

Turn-on time (at collector to emitter voltage = 10 V, collector current = 2 mA and load resistance = 100Ω) = 8 µsec.

Turn-off time (at collector to emitter voltage = 10 V, collector current = 2 mA and load resistance = 100Ω) = 7 µsec.

The light current versus radiation profile of the transistor (T) is shown in figure 3.6. The graph gave a relationship between $V_1$ and the incident intensity of light $E_1$ on T as

$$\frac{1}{6}(V_1 / R) = 0.0562 (E_1)^{1.25}$$

Where the factor (1/6) comes due to the fact that the specification graph in figure 3.4 is normalized at phototransistor current $I_1 = 6$ mA and $E_1 = 10$ mW/cm².
b). Neutral density filter :- The neutral density filter N placed in-front of phototransistor T to keep the output voltage of the detector below the maximum value of 5 Volts, such that the intensity on T does not go into saturation. This filter attenuates the beam passing through it by 933.4 times. As such the intensity of the radiation entering the transmission photo detector is given, using equation 3 5.1 and the value of extinction due to $N$, that is 933.436, by

\[
E_{\text{norm}}(\text{in mW cm}^{-2}) = \frac{933.436 \left( \frac{1}{V_i \text{ in mV}} \right)^{1/25} \left( 6 \times R_i \text{ in ohms} \right)^{1/25}}{\text{beam cross-section in sq.cm}}
\]

3 5.2

Where the beam cross-section = 0.01767 sq cm. is used

c). Amplifier section.- LM308 operational amplifier have 8 base pin [58]. This LM308 OPAMP is selected for our system because it offers high speed, low drift and low input current Fig3.4 shown, the photo current $I_1$ generated by the photo transistor T
and produces a voltage drop $V_1$ across the load resistance $R_1$ and this voltage is then amplified by LM308 [58] operational amplifier by $A_1$ times. The output of LM308 based amplifier is fed to one channel of the ADC [57] unit. When laser beam is allowed to fall on the detector, the amplification factor $A_1$ is adjusted in such a way that $V_0$ is less than 5 volts because 5 volt is the maximum limits of ADC. The following specifications given below for LM308 satisfies the requirements of the air quality monitoring system:

Supply voltage $= \pm 18$ volts. Power dissipation $= 500$ mW. Input voltage $= \pm 15$ volts. Input resistance $= 70 \text{ M}\Omega$. Common mode rejection ratio $= 110$ dB.

To improve rejection of power supply noise by a factor of ten the pin number 8 of the LM308 is connected to ground via a 100pf capacitor. This OpAMP has a linear frequency response within the low frequency range at which the monitoring system operates. Frequency responds curve of LM308 is shown in fig 3.7.
3.5.2 Scattered photo detector unit

The scattered photo detector unit (C in photograph 3.1; C in fig 3.1; Photograph 3.7 and 3.8) is shown.

Photograph 3.7 Photo detector unit for detecting scattered light  Photograph 3.8 Photo detector unit (internal view)

This scattered photo-detector has the same configuration with that of the transmission and reference photo detector except that the neutral density filter is absent because intensity of scattered radiation is very low as such there is no question the photo transistor goes into saturation. So the intensity of the scattered radiation entering the photo detector is given by

\[
E_{\text{scat}} \text{ (in } mW \text{ cm}^2) = \left( \frac{1}{0.0562} \right)^{1.25} \left( \frac{V_i \text{ in } mV}{6 \times R_i \text{ in ohms}} \right)^{1.25}
\]

3.5.3

This photo detector unit has a metal shield to cut out unwanted electro magnetic noise.
3.6. Vacuum unit

In order to produce high vacuum in the simulation chamber, connecting tubes connect an oil immersion rotary high vacuum pump with the chamber. The pumping rate of this type of pump is very high. This can reduce the atmospheric pressure of air inside the chamber to .01-.001 torr within a short interval of time.

![Photograph 3.9 Vacuum unit](image)

Vacuum pump shown in [photograph 3.1; photograph 3.9]. In order to produce high vacuum in the simulation chamber, the chamber is connected with an oil immersion rotary high vacuum pump through connecting tubes. The pumping rate of this pump is very high. This can reduce the atmospheric pressure of air inside the chamber to .01-.001 torr within a short interval of time. The pump works directly from atmospheric pressure. This type of pump in construction entirely immersed in oil and so leakage of air into the high vacuum is presented. And pressure inside the chamber is evacuated to a pressure of .02 torr. The vacuum unit showed in [photograph 3.9]. This vacuum unit has a displacement capacity of 50 liters per minute and hence the simulation chamber, with a volume \( V_{\text{chamber}} \) of 150796 cubic
centimeters (150.796 litres), is evacuated in slightly more than 3 minutes. Pure dry air is then allowed to enter the chamber and the experiments are done at the atmospheric pressure. That is why it makes possible to run a number of experiments within a short time.

3.7. Water vapour unit

The water vapor unit is shown in photograph 3.10 (1 in photograph 3.1). It is a conical flask of volume 100 milliliters connected to the system through flow meters. When the flask is heated, steam is generated and passed through the insulating pipe that is connected with the simulation chamber via stopcock arrangement. This unit introduces vapour m, equivalent to .0033 liters of water per minute into the simulation chamber.

3.8. Calculation of humidity

The simulation chamber contains some water vapour, even though the chamber is evacuated by the vacuum pump prior to the taking of experimental readings. As such the quantity of vapour in the chamber at any moment during the experiments is the
sum of the initial vapour content in the chamber and the vapour being introduced by the water vapour unit.

Applying line fitting to the vapour pressure curve of water [63] shown in figure 3.8, where the saturation vapour pressure \( p_s \) at \( 0^\circ \text{C} \) is 4.58 mm of mercury and at the critical temperature 374.1°C is 1.66x10^5 mm of mercury, the relation for saturated vapour pressure \( p_s \) (mm) at a given temperature \( T \) °C is found to be

\[
\log_{10} p_s = -2152.733 \left( \frac{1}{273 + T} \right) + 8.546333
\]

3.7(a) 1

The gas equation [61,62,39] gives the number of moles \( n_{\text{mol}} \) of water vapour as

\[
n_{\text{mol}} = \frac{p_s V_{\text{chamber}}}{R_{\text{gas}} T}
\]

3.7(a) 2

Where

- \( V_{\text{chamber}} \) is the volume of the simulation chamber
- \( R_{\text{gas}} \) is the molar gas constant

![Fig. 3.8 Vapour pressure curve of water](image-url)
$T$ (°K) is the temperature

Since the molar weight of water is 18.016, the density of saturated vapour $\rho_s$ (gm/cc) at $T$°K is given as

$$\rho_s = \frac{n_{\text{mol}} (18.016)}{V_{\text{chamber}}}$$

3.7(a).3

The relationship between relative humidity $h_{rel}$, saturated vapour density $\rho_s$ and unsaturated vapour density $\rho_u$ is given as

$$h_{rel} = \frac{\rho_u}{\rho_s}$$

3.7(a).4

Measuring the relative humidity with a hygrometer and from the fact that water vapour enters the chamber from the water vapour unit at the rate of $m_v$ (gm/sec), the density of water vapour $\rho$ (gm/cc) at any given moment $t_{sec}$ inside the chamber is thus given as

$$\rho = \frac{\rho_s h_{rel} + m_v t_{sec}}{V_{\text{chamber}}}$$

3.7(a).5

3.9. Gas unit.

Photograph 3.11 Gas unit arrangement
The gas unit (H in fig 3.1; H in photograph 3.1; photograph 3.11) is a cylinder containing Oxygen, Carbon dioxide and Nitrogen gas. This cylinder is connected with the simulation chamber via two pressure meters and with a flow meter by plastic tubing. Supply of gas flow, is regulated by a valve, and pressure is checked on the pressure meters. The flow meter monitors the flow rate during the time of experiment.

3.10. Data acquisition unit

The block diagram of the data acquisition system is shown in fig 3.9. It consists of an A/D converter stage, having ADC0809 which converts the analog output of the detector signal into digital form and 80386 microprocessor unit continuously goes on storing this data.

![Block diagrams of DAS](image)

The data acquisition system has been discussed details in the next chapter.
REFERENCES


