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Design and construction of anair pollution detection system using a laser beam and absorption spectroscopy

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Abstract

Air pollution is one of the important problems facing Iraq. Air pollution is the result of uncontrolled emissions from factories, car exhaust electric generators, and oil refineries and often reaches unacceptable limits by international standards. These pollutants can greatly affect human health and regular population activities. For this reason, there is an urgent need for effective devices to monitor the molecular concentration of air pollutants in cities and urban areas. In this research, an optical system has been built consisting of aHelium-Neonlaser,5mWand at 632.8 nm, a glass cell with a defined size, and a power meter(Gentec-E-model: uno) where a scattering of the laser beam occurs due to air pollution. Two pollutants were examined: water vapor and smoke. Experiments were conducted using these pollutants to calibrate the system and determine its detection sensitivity. With this technique the absorption coefficients, types of pollutants and their concentrations were determined.

Keywords: Air pollutants, Concentration, He-Nelaser, Smoke, Spectroscopy.

Introduction

Air pollution is a concern for society as it directly impacts the environment and human health. Air pollution is harmful as it causes damage to living organisms and the environment. The reasons for air pollution are natural sources such as dust and human sources resulting from human activity and consider the largest cause of air pollution[1] such as printing, copying centers, car, and factory chimneys smoke. Air pollutants are divided into primary pollutants and secondary pollutants. Primary pollutants are emitted directly from the source to the air, such as scattered ash or carbon dioxide emitted from factory chimneys, car exhaust and oil fineries. Secondary pollutants do not emit directly into the air, instead they are the result of the interaction of pollutants emitted from sources with particles in the atmosphere, such as smog[2]. The increase in human activities has led to deterioration in the quality of air, and this affects human health and affects the environment. In general, many studies have proven that prolonged exposure to air pollution can lead to death, especially in developing countries are at higher risk[3].

The issue of the environment and environmental pollution has become one of important issues that researchers have taken care of because it is related to the safety of the world. Among the important methods that scientists and researchers have harnessed to study environmental pollution is the use of laser beams, after they have proven successful in detecting and measuring the concentration of pollution in atmospheric air using a Helium-Neon laser and calculating its effect on air pollution[4].In the last several decades, there has been a tremendous increase in the use of, lasers for range finding information transfer determination of the speed and direction of movement of moving objects (moving targets) and in the uses of laser radar detection[5].Inaddition, with the application to optical communications and transmitting and receiving laser waves within the atmosphere or between earth and satellites, it became necessary to highlight some of the fundamental factors and influences suffered by electromagnetic waves in their trajectory or their transmission within the earth's atmosphere.

Through the properties of the laser beam, the beam is collected as the laser spreads over long distances without dispersion or losing intensity, and the laser photons can be scattered by particles in the atmosphere which can lead to a change in direction only (elastic scattering) or for a certain wavelength, where it can be absorbed by particles of pollutants in the atmosphere, and the change in the intensity of the laser beam can be a measure of the concentration of pollutants in the atmosphere where the absorption spectrum indicates the concentration of certain molecular species[6,7].

The issue of the deployment of the laser beam in the atmosphere is of great importance to determine the extent of lost energy during propagation or distortions in wave specifications. What happens to the laser beam when it propagates in the atmosphere is a very complex quantitative process as the effect of absorption and external factors is related to weather conditions such as, temperature, humidity, dust, wind speed, aerosols and rainfall? The atmospheric molecules interact with laser beam by absorbing and scattering part of the laser photons. Absorption converts part of the radiation energy into another type of energy as kinetic energy of molecules, while the rays are scattered by the aerosols, and dust particles, in the atmosphere. Choosing the right wavelength during practical applications greatly reduces absorption losses resulting from atmospheric components as certain gases in the atmosphere differently affect the amount of energy in force for a certain wavelength. An approach is particularly useful because it provides a means of correlating atmospheric transmission from a window to relative humidity, the assumption being that variations in transmission are due to changes in the water content of the air. Specifically, changes in H_2O concentration cause changes in absorption, and changes in the size and number of water droplets with moisture cause changes in the graded component. This is a valid assumption because other atmospheric components have a reasonably consistent effect on the permeability of a given atmospheric window, as illustrated by Fig.1.

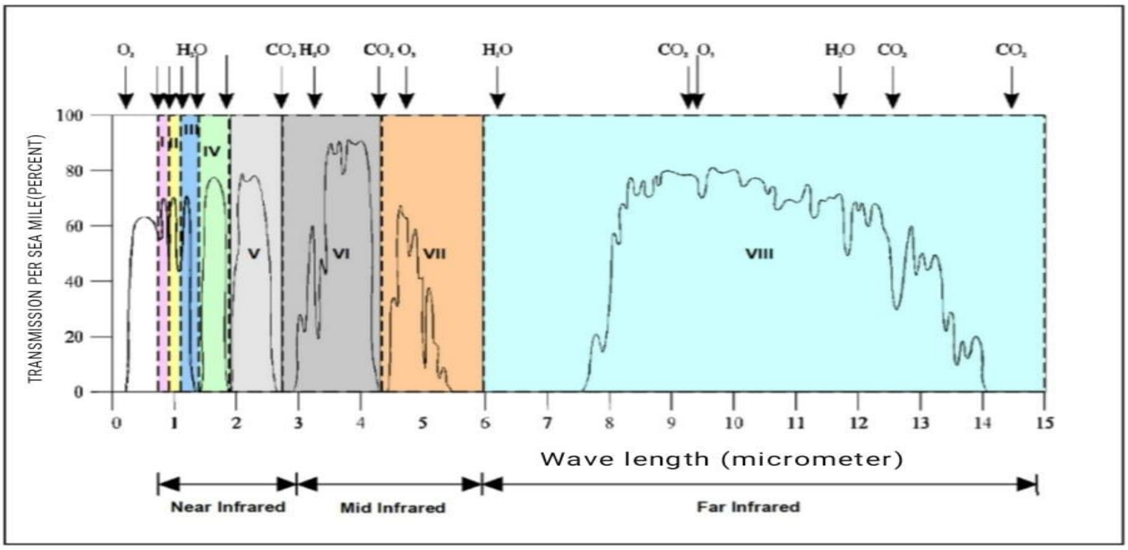

Figure 1.Infrared absorption spectrum of the atmosphere[6].

It is clear from Fig.1, that the greatest absorption occurs around wavelengths (6.0, 4.3, 1.9, 1.3, 0.94) microns and between these wavelengths are the so-called atmospheric windows where losses or attenuation are the results of losses due to rain only. Therefore, when selecting the right laser for technological applications, its wavelength must be within the air windows to reduce attenuation losses, which include losses due to absorption and beam divergence. In the rain, particles are constantly extracted from the electromagnetic wave passing through them and the radiation of the power is restored in all directions, i.e. theoretically, the electromagnetic wave citation process does not have a loss of intensity but only a change in the direction. The main reason for the electromagnetic wave's must to change is either the presence of small particles such as aerosols, dust, and fog, or due to the heterogeneity of the air density passing through the electromagnetic wave, which plays the main role in changing[8].

Theory

The premise of the early spectroscopic estimations, and many present quantitative follow gas logical strategies in the environment and the research facility, is Lambert-Lager's regulation, frequently additionally alluded to as Bouguer-Lambert regulation. The work of Pierre Boguer and Johann Heinrich Lambert on atmospheric spectrometry is well known to August Beer as exemplified by his Grundriss des photometric chin calculus published in 1854[9,10]. Beer described this part of the Beer-Lambert law as follows from the simplest assumption that the loss of intensity of light transmitted through a thin, ultrafine layer of a homogeneous medium is proportional to this density and the thickness of the layer. It the following mathematical equation was used:

$I=I_0\exp^{(-\delta x)}$ 1

Where, I_0 is the initial intensity of the light, I is the intensity after travelling the distance x in the medium and δ is its absorption coefficient.

The main components of atmospheric air consist of several molecules and each molecule has its own absorption spectrum. When the laser photons interact with the material, the molecules of the material absorb some photons and convert them to another type of energy. We express the Beer-Lambert equation to calculate the absorption coefficient as follows:

$\delta =(-1/x) \ln (I/I_0)$ 2

Fig. 2, shows the fundamental idea of gas detection using absorption spectroscopy.

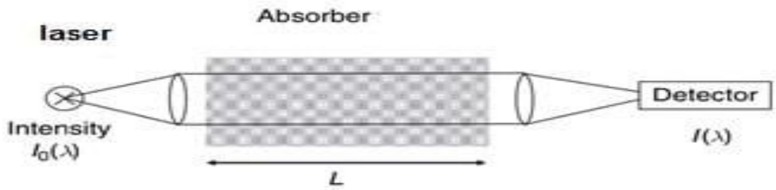

Figure 2.The fundamental idea of gas detection using absorption spectroscopy[11].

A compartment of length L containing the absorber is traversed by a beam of laser. An appropriate detector measures the intensity at the conclusion of the light path.

In which the intensities I and I_0 are derived by measurements made with and without an absorber in the He-Ne laser. But, in an open environment, applying Lambert-law Beer's is more difficult. It is challenging to estimate the true intensity I_0, as it would be received from laser source in the absence of any air absorber. It would entail removing the atmosphere's air, or more specifically, the absorbing gas[12]. The solution lies in detecting the so-called differential absorption, or the difference between the absorptions at two very different wavelengths. This may seem to offer a conundrum and render atmospheric absorption spectroscopy worthless in this circumstance.

Therefore, the use of spectroscopic analysis gives better results to detect (concentrations and types of pollutants) present and with greater accuracy.

The molar density of pollutants (water vapor and, smoke) was calculated using the following law[13]:

ρ=m/v 3

where, m is the mass in molar unit (gm/mol) , v is the volume of the cell unit (cm^3).

Instrumentation and Experiments

The details of the experimental setup and the method for extracting aerosol information from laser return signals are briefly discussed in this section, the system consists of a physical-optical model, a 5mW He-Ne laser with a wavelength of 632.8 nm as transmitter and a bore meter(gentic-E-model:uno) as a receiver. A rectangular glass cell was built 7.7*2.5*2.5 cm^3, which contains the samples of the air and pollutants introduced to it, Fig. 3, shows pollution measurement system using laser beam. Two types of pollutants were used (water vapor pollutants, and smoke) were introduced into the cell. Water vapor was obtained using type an evaporation device (Negative ion humidifier Mist) placed at the bottom of the cell as shown in Fig.4.

Fig. 5, shows the introduction of smoke pollutants resulting from combustion into the detection system.

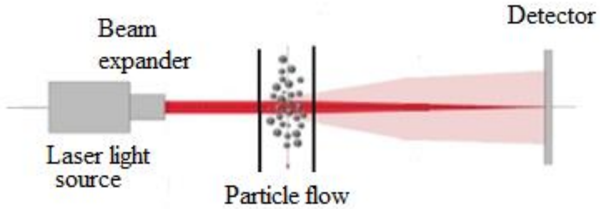

Figure 3.Schematic diagram of a pollution measurement system.

Figure 4.The system designed to detect water vapor pollutants.

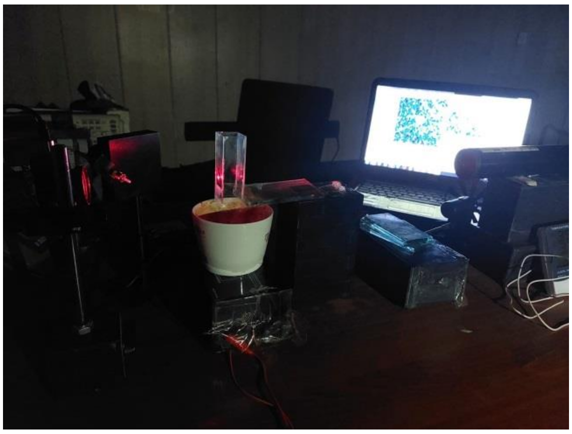

Figure 5.The system designed to detect smoke pollutants

Results and Discussion

Pollutant concentrations were studied under different atmospheric conditions for smoke and water vapor pollutants. The experimental setup is shown in Figs. 4 and 5.Table 1,showsthe variation of the power of He-Ne laser with glass thickness which leads to a change in the absorption coefficient (δ). It can be found from this figure that the lowest energy of the laser beam that can detect pollutants is, 5mW. The glass thickness was chosen to give the best results for detecting contamination. Eqs.2,3 are used to calculate the absorption coefficient and molar density for smoke and water vapor pollutants.

The relationship between the power of laser and glass thickness is shown in Fig. 6, it is clear from this figure that the power decreases as the thickness increases.

Fig. 7, shows the relationship between the absorption coefficient and wavelength for three types of lasers (He-Ne, IR, Green)for smoke and water vapor pollutants. The figure clearly shows that the values of the absorption coefficients in the case of water vapor pollutants are higher than those of smoke pollutants of different wavelengths.

Table 2, shows the variation of the power of laser and absorption coefficient using smoke pollutants which were calculated using the system shown in Fig.5.

Fig. 8, shows the variation of the laser power with time in the case of smoke pollutants.

Table 1.The power of He-Ne laser and absorption coefficient (δ)using water vapor pollutants.

Thickness glass(mm)	Power (mW)	δ (Cm^{-1})
0	2.660	0.250
5	1.955	0.375
10	1.532	0.473
15	1.114	0.600
20	0.930	0.670

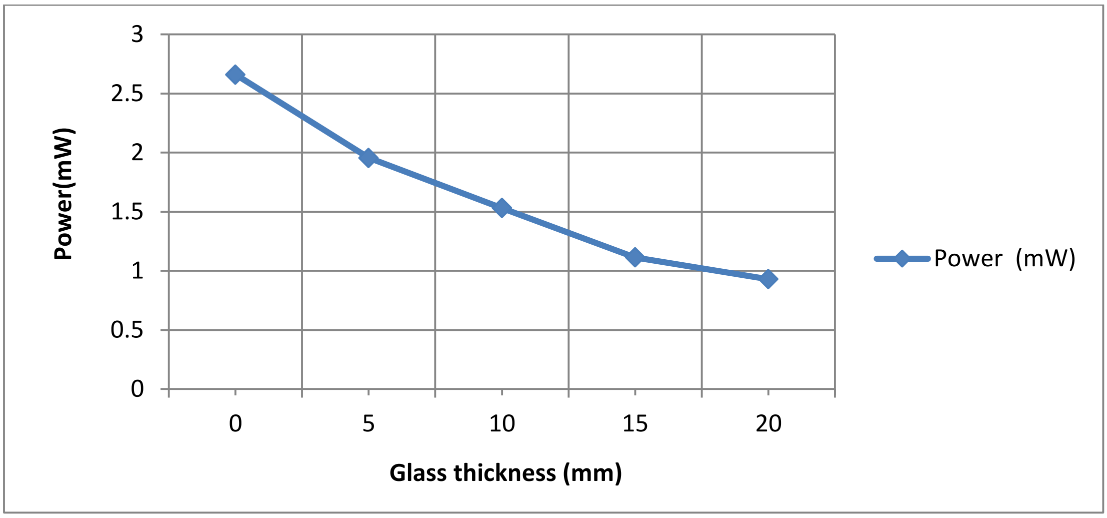

Figure 6. Relationship between laser power and glass thickness.

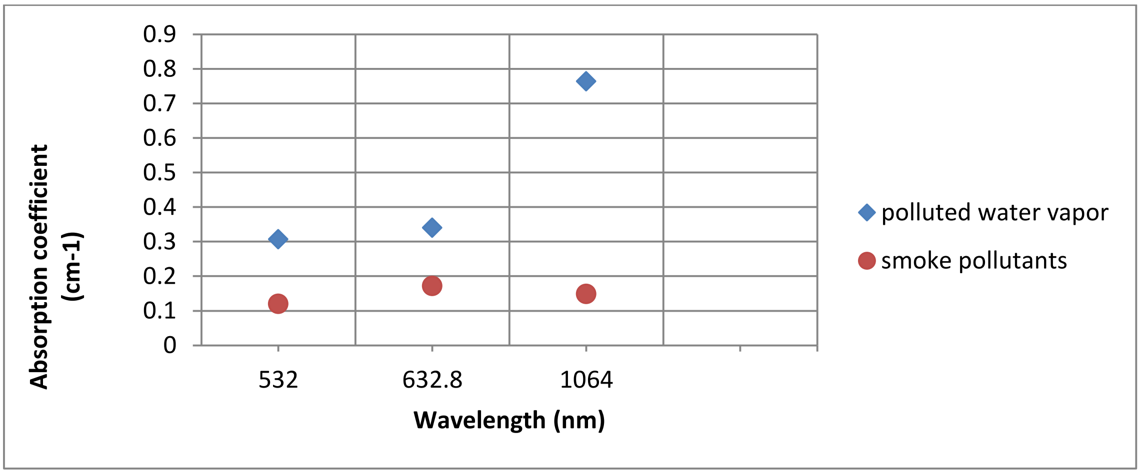

Figure 7. The relationship between the absorption coefficient and wave length for three different types of lasers.

Table 2. The relationship between He-Ne laser power and absorption coefficient using smoke pollutants.

Time (min)	Power (mW)	δ (Cm^{-1})
0	3.055	0.197
1	3.250	0.172
2	3.450	0.148
3	3.550	0.136
4	3.570	0.134
5	3.578	0.133
6	3.600	0.131

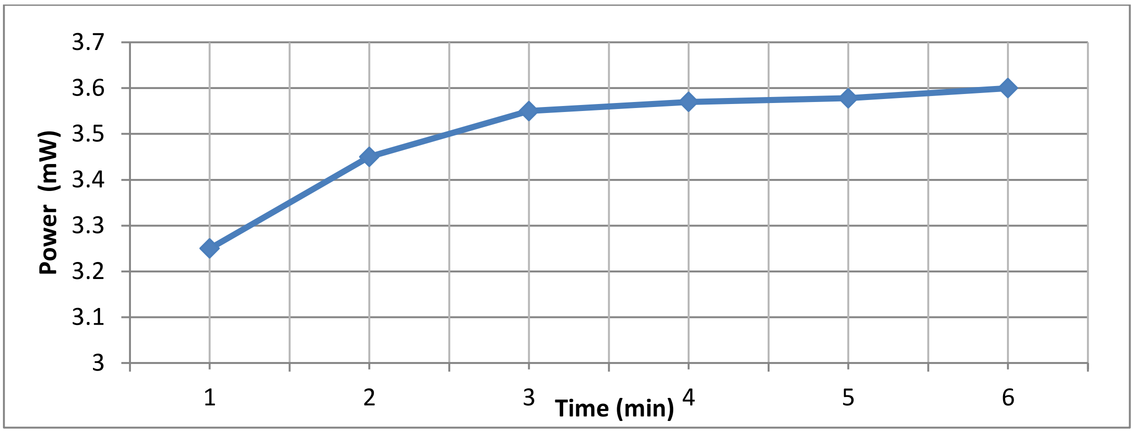

Figure 8. The relationship between laser power and measurement time for smoke pollution.

The molar density was calculated using Eq.3 for the water vapor and smoke pollutant as follows:
ρ_w =0.374 gm/cm^3.mol
ρ_s =2.119 gm /cm^3.mol
Where the molar mass of water vapor equal 18.02 gm/mol for smoke equal 102.016 gm/mol the cell size equal 48.125 cm^3.
The concentrations of pollutants have been seen under different weather conditions,Fig.9, shows two-, and three- dimensional images of water vapor concentrations in the cell by cross section of the laser beam. It can be seen that the distribution of smoke is more homogeneous than the water vapor, this is due to water vapor being heavier than smoke and is concentrated in the corners of the examination cell.Fig.10, represents the same image for smoke pollutants.

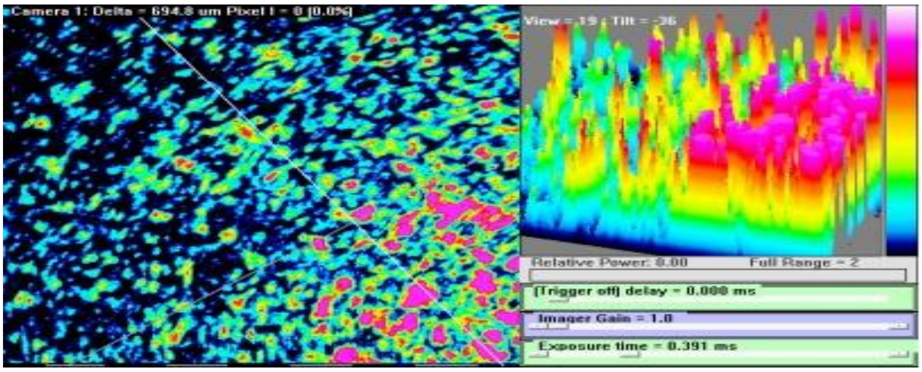

Figure 9. The Concentrations of water vapor pollutants.

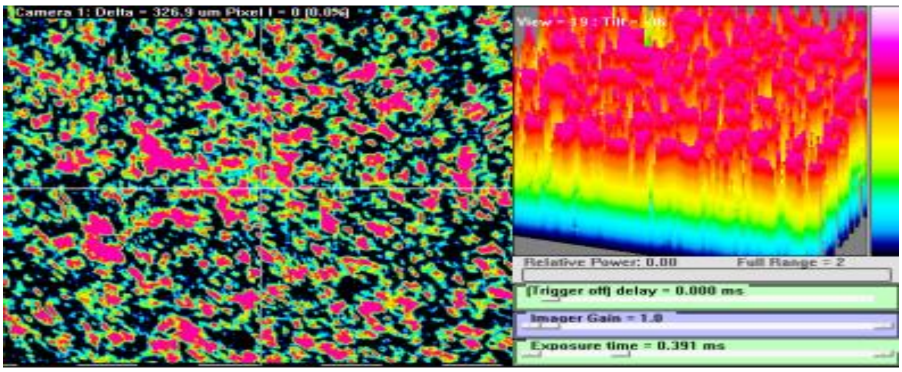

Figure 10.The Concentrations of smoke pollutants.

The water vapor pollutant was analyzed by using a spectral analyzer type (ocean 2000),the pollutant was detected and identified according to the wavelength as shown in Fig.11,from this figure we can see the existence of the following elements with the wave lengths at which it was found:
(Nitrates2909nm, Hydrocarbons3034nm,Bromine 414nm, Fluorine960nm and Hydroxyl group 3198nm).

Fig. l2,shows the spectrum of smoke pollution, the result of the spectroscopic device indicates the presence of the following elements: (Chlorine, Carbon 794nm, Hydroxyl group 2638nm, Hydrocarbons 3556nm, Nitrogen dioxide 1340nm, Carbon dioxide 1599nm).

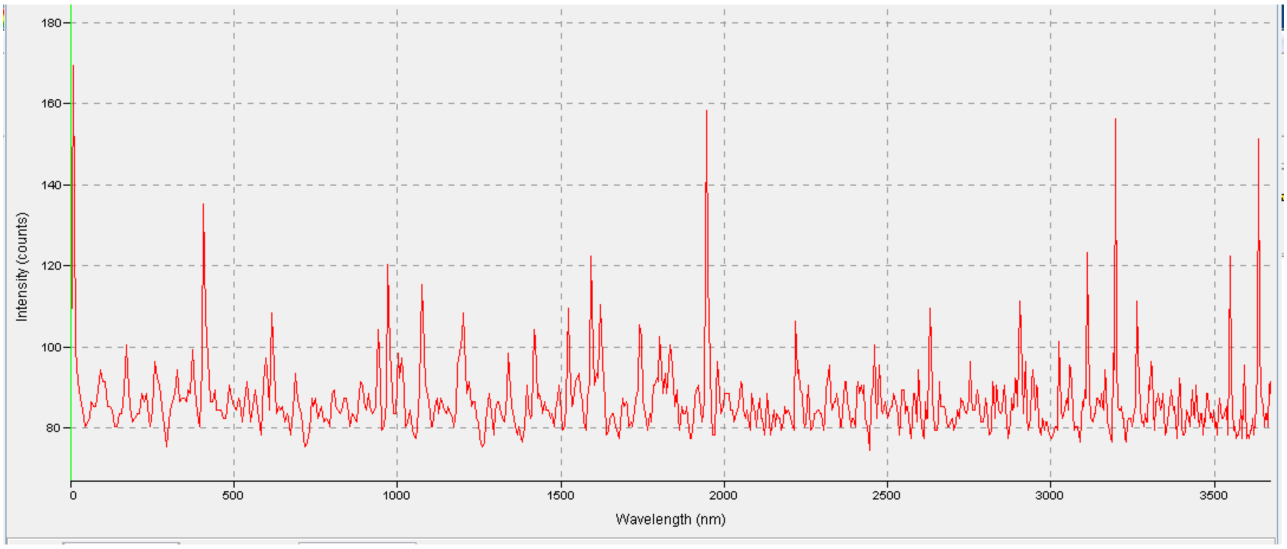

Figure 11.Absorptionspectrum of water vapor pollutant.

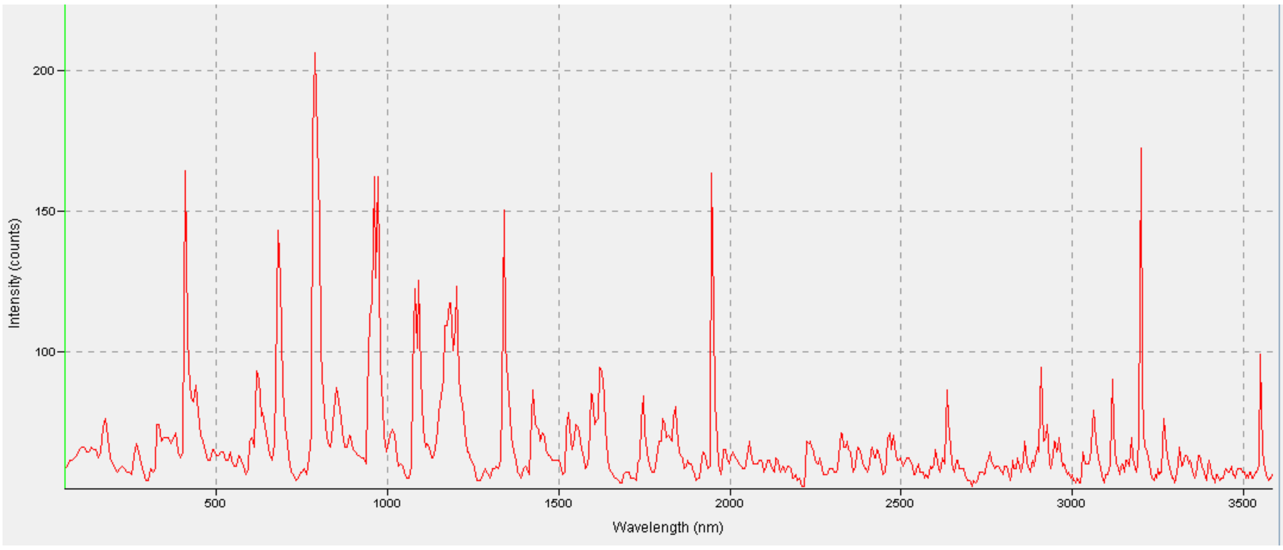

Figure 12. Absorption spectrum of smoke pollutants.

Air contaminant detection experiments were carried out by using the system that has been designed and constructed in the laboratory. The result of the examination of the air samples showed that the power of laser beam is reduced by the presence of smoke in the air while the absorption coefficient increases, the results are also shown that the absorption coefficient decreases with time while the power of laser is increased.

The results obtained from the design system showed that the ability of the system to detect the types of pollutants elements can also be obtained two- and three- dimensional figures for the construction of the pollution.

Conclusion

A System is designed to detect pollutants in the atmosphere using laser technology; this system gave good results for detecting air pollutants using different types of laser with different wavelengths. The obtained results showed the possibility of this system to measure the attenuation by laser rays of different materials with different absorption coefficients, the results of the system also gave the effect of time on the power of the laser beam that penetrates the pollutant materials. This designed system easily gave real two and three dimensional images of the concentration of the pollutant. The results of the experiments were also given the types of pollutants, present using spectroscopy technique attached to the system that was built.

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Authors' declaration:
- Conflicts of Interest: None, we hereby confirm that all the Figures and tables in the manuscript are mine ours besides, the Figures and images, which are not mine ours, have been given the permission for republication attached with the manuscript.
- Ethical Clearance: The project was approved by the local ethical committee in University of Baghdad.

Authors contribution:
F A-W A-R implemented, designed and built the system, conducted all practical experiments, obtained readings and results, and presented them.
SKY undertook the general supervision of the research and the discussion of the obtained results and the method of presenting them.
AA RD supervised the design and organization of the practical side and supervised the implementation of experiments and obtaining results.

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تصميم وبناء نظام للكشف عن تلوث الهواء باستخدام شعاع الليزر والتحليل الطيفي للامتصاص

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الخلاصة:

تلوث الهواء من المشاكل المهمة التي تواجه العراق. ينتج تلوث الهواء عن مصانع الانبعاثات غير الخاضعة للرقابة ، والمولدات الكهربائية لعوادم السيارات ، ومصافي النفط وغيرها من المصادر والتي غالبًا ما يصل إلى حدود غير مقبولة وفقًا للمعايير الدولية. يمكن أن تؤثر هذه الملوثات بشكل كبير على صحة الإنسان والأنشطة السكانية العادية. لهذا السبب هناك حاجة ملحة لأجهزة فعالة لرصد التركيز الجزيئي لملوثات الهواء في المدن والمناطق الحضرية. تم في هذا البحث بناء نظام بصري يتكون من ليزر هيليوم - نيون 5 ميغاواط وبطول موجي 632.8 نانومتر ، خلية زجاجية ذات حجم محدد ، ومقياس طاقة (Gentec - E - model: uno) حيث يحدث تشتت شعاع الليزر بسبب تلوث الهواء. تم الكشف عن نوعين من الملوثات هما بخار الماء و الدخان. وقد أجريت تجارب باستخدام هذه الملوثات لمعايرة النظام وتحديد حساسية الكشف له باستخدام هذه التقنية حيث تم تحديد معاملات الامتصاص وأنواع الملوثات وتركيزاتها.

الكلمات المفتاحية:ملوثاتالهواء،التركيز،الليزرهليومنيون،الدخان،التحليل الطيفي.