Original Research Paper

Design and Construction of Optical System to Detect of Ammonia Gas

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Abstract: The idea of research is the detection of gases using the transmitter and receiver system for electromagnetic radiation in the IR region using the optical absorption method. As a result of the interaction of the light with the gas molecules can be detect and measure gas pressure adoption absorption method. It was chosen best absorption band between (1.4-1.6) *um* at the wavelength 1.5 um to build a sensor for accurate measurement of ammonia gas which is characterized by precision, where he was the measuring pressure range (1-6) bar. The importance of the oil industry has been focusing on this kind of scientific research for the detection of ammonia gas.

Keywords: Ammonia Gas Sensing, Gas Analysis, Spectroscopy

Introduction

Ammonia (NH_3) is colorless gas composed of nitrogen and hydrogen with a sharp, penetrating dour. Sensitive and continuous monitoring of NH_3 is relevant in several applications such as environment monitoring to quantify NH_3 emissions from coal waste piles in combustion (Viveiros *et al*., 2014). DeNO$_x$ processes, which are widely used in power plants and incinerators to reduce NOx emissions (Busca *et al*., 1998) or in medicine to analyses breath NH_3 levels as a diagnostic tool (Narasimhan *et al*., 2001). The main optical gas sensor technologies are based on absorption spectroscopy of fundamental bands in the 3-25 μm spectral region, near infrared vibration overtone and combination bands from 1-3 μm (Viveiros *et al*., 2015). Various NH_3 analysersand measuring methods have been developed, including the differential optical absorption spectrometer (Mount *et al*., 2002), tunable diode laser absorption spectrometer (Sickles *et al*., 1990), photoacoustic spectroscopy (Schmohl *et al*., 2002) and cavity ring-down spectroscopy (O'Keefe and Deacon, 1988). Fourier Transform infrared spectroscopy (Galle *et al*., 2000; Wyers *et al*., 1993). NH_3 has a rich spectrum in the near infrared region, in the spectral range from 1450 nm to 1560 nm. Recently, several works have been developed which use the absorption lines at 1532 nm and 1512 nm as the operating wavelength for NH_3 sensing (Claps *et al*., 2001). The Wavelength Modulation Spectroscopy (WMS) technique has also been demonstrated in a system using a Distributed Feedback (DFB) laser diode with an emission wavelength at 1532 nm in conjunction with hollow optical waveguides (Fetzer *et al*., 2002).

Such waveguides were used as long-path sample cells (optical path length of 3 m) which were coiled to reduce the physical extent of the system. A portable diode-laser-based sensor for NH_3 detection, using vibration overtone absorption spectroscopy at 1532 nm (optical path length of 36 m), was described using a fiber-coupled optical element that made a trace gas sensor rugged and easy to align (Huszár *et al*., 2008). The gas sensor was used primarily for NH_3 concentration measurements. An NH_3 sensor based on the combination of resonant photo acoustic spectroscopy and direct absorption spectroscopy techniques with a DFB laser diode operating at 1532 nm, was also described (Besson *et al*., 2006).

Detection Principles

Vibration Motion of NH_3 Molecule

Motion of molecule has three types. They are translation rotational and vibration motion. Translational motion is doing rectilinear movement as all of points do translation from space and this motion occurs vigorously in gas state. Rotational motion is that molecule rotates to rotating axis circumference that pass center of gravity and this motion offers factual information most about molecular structure. Oscillatory motion is regular motion that has amplitude that is fixed through bary center and it include periodic change of bond angle degree as well as bond length. Periodic change of bond length is called stretching vibration periodic change of bond angle degree is called flexural vibration. Vibration spectrum is used much in confirmation of molecule because it sights in infrared rays area mainly and shock depends on mass and

bonding strength of oscillated composition atom, but is unrelated with composition atom. Figure 1 is a vibration mode of NH_3 gas. 2 parallel mode that is v_4, v_1 and v_2 increased symmetrical, on the other hand, v_3 and v_4, 2 right angle modes, have degeneration style of asymmetry. These four vibration modes have four absorption bands in core infrared rays area (0.78~2.5 um) by association each other as appear in Table 1 (Claps *et al*., 2001).

Infrared Absorption

If the molecule absorbs infrared rays, the molecule must occur essence change of dipole moment by vibration and rotational motion. When molecule oscillates, change amount of dipole moment is the more, infrared absorption is the stronger. In the case of uniformity nucleus species molecule such as N, H, O

molecules do not absorb because essence change of dipole moment does not happen by vibration or rotational motion of molecule. NH_3's dipole moment is 1.471D. So, we can know that infrared absorption occurs Fig. 2 shows that NH's absorption spectrum in 1.5, 2.0,2.3 um. Absorption spectrum in 1.5 um and 2.3 um is strong and effect of interference for other gas such as H_2O or CO_2 is less (Claps *et al*., 2001; Webber *et al*., 2001).

Table 1: Assignments for NH_3's NIR spectra, listed roughly in order of contributionto the band (Claps *et al*., 2001)

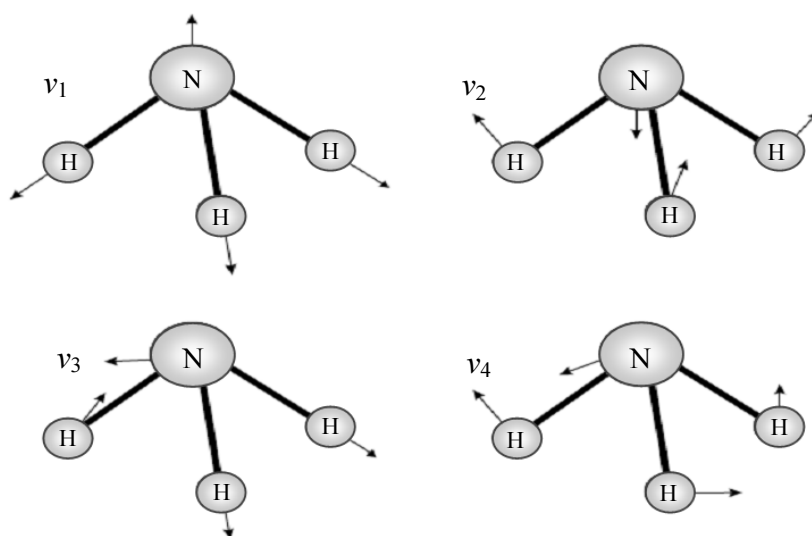| NIR region	Band assignment
1.5 μm	$v_1 + v_3$, $2v_3$, $v_3 + 2v_4$, $v_1 + 2v_4$, $2v_1$
1.65 μm	$v_2 + v_3 + v_4$
2.0 μm	$v_3 + v_4$, $v_1 + v_4$ $+2v_2 + v_3$, $4v_2 + v_4$, $2v_2 + 2v_4$
2.3 μm	$v_2 + v_3$, $v_2 + 2v_4$, $v_1 + v_2$

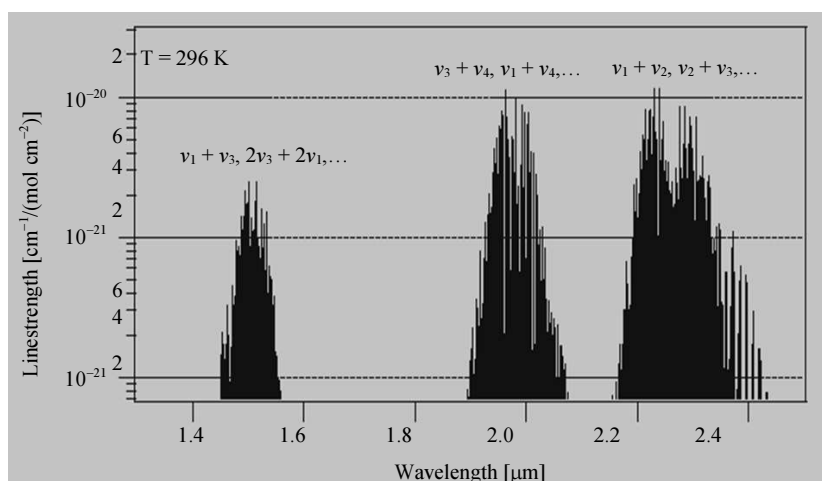**Fig. 1:** H_3's vibration modes (Claps *et al*., 2001)

Fig. 2: NH_3's absorption bands in the NIR (Chomsky, 2012)

Theory

The fundamental theory that governing absorption spectroscopy for narrow-line width radiation sources is embodied in the Beer–Lambert law, Equation (1) and is described thoroughly in Ref. 3. The ratio of the transmitted intensity I_t and initial (reference) intensity I_0 of laser radiation through an absorbing medium at a particular frequency is exponentially related to the transition line strength S_i [cm^{-2}atm^{-1}], line-shape function ϕ [cm], total pressure P [atm] of the medium, mole fraction of the absorbing species x_j and the path length L [cm] through which the radiation passes (Claps *et al.*, 2001; Webber *et al.*, 2001):

$$\frac{I_t}{I_r} = \exp\left(-S_i \varnothing P x_j L\right) \tag{1}$$

The two laser intensities can be converted to absorbance $\propto(v)$ and related to the transition parameter by:

$$\propto(v) = \ln\left(\frac{I_t}{I_o}\right) = S_i \varnothing P x_j L \tag{2}$$

Absorption coefficient, $\varepsilon(v)$ is defined with (3):

$$\varepsilon(v) = S_i \varnothing(v) P \tag{3}$$

Absorption, $\propto(v)$ can appear in simple form with way(4) from way(2):

$$\propto(v) = \varepsilon(v) x_j L \tag{4}$$

Here, absorbance $\propto(v)$ is proportional in concentration (x_j) of measurement gas.

Experimental Setups

The basic elements of an experiment for measuring absorption spectra of the NH$_3$ gas by sensor system is shown in Fig. 3 and 4. The main block of the system consists an Electrical lamp source whose radiation is directed pass through an absorbing gas medium of known path length and monitored with a detector. The Electrical lamp source with optical filter at 1.5 *um* is wavelength-tuned across the absorption transition and the transmitted intensity is recorded with the detector (THORLAB PDA30G - EC type PbS Amplified Detector 1.0-2.9 *um*) or analyzed spectrometer (Zolix – monochromatic – omni - 500) to determine the integrated area of the absorption line shape. Two modes can be chosen IR transmitter lamp at wavelength 1.5*um* connected with driver modulated circuit by the square mode of (1-3) Hz frequency and CW mode. Optoelectronic receiver includes Indium Gallium Arsenide (InGaAs) photodiode with a low noise amplifier circuit for monitor signal detection were chosen because of their good stability and responsively for 1.5 um radiation. The sensor was comprised of a single pass cell with 34 cm optical path length. The pressure monitored by gauges at the entrance and exit of NH$_3$ gas at pressure (1-6) bar. The cell was heated to a temperature of 30°C to minimize ammonia adsorption on its glass walls and to prevent potential water condensation on the cell mirrors, as monitored with thermocouple at cell.
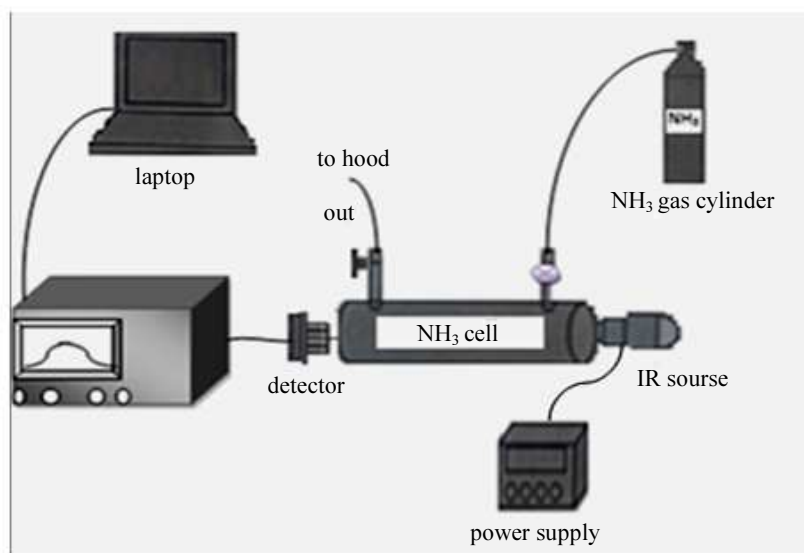

Fig. 3: Ingle Path NH$_3$ gas sensor with Zolix - monochromator (omni - 500)

Results and Discussion

It has been monitoring the absorption band through spectral scanning ammonia gas in the infrared region between (700-1700 um), this is illustrated in Fig. 4. It has been focusing only on the strong absorption band between (1400-1600 *um*) in ammonia gas detection.

It was built optical sensor for measuring the ammonia gas pressure without spectral analyzer and with minimal optical noise; Using optical filter type (THORLABS – FB1500 -12 -1500 nm FWHM =12 nm) is compact with photodiode (PbS) is coupled to gas sensor cell and the second end of the gas sensor cell provider optical light

source works continuous and pulse mode. In the case of a small amount of water vapor inside the ammonia gas cell. The optical filter was used to separate the overlap spectrum between the ammonia gas and water vapor. The first part: to examine the optical system for measuring the ammonia gas sensor at different pressures in (1-6) bar under temperatures constant (T = 30°C), with optical spectrum analyzer and filter at 1.5 um. Figure 5 shows the light intensity levels as a function of gas pressure was record. Then intensity peak of the spectra is at around 1500 nm and the intensity of light passing through the gas decreases with increased gas pressure, due to increased absorption.
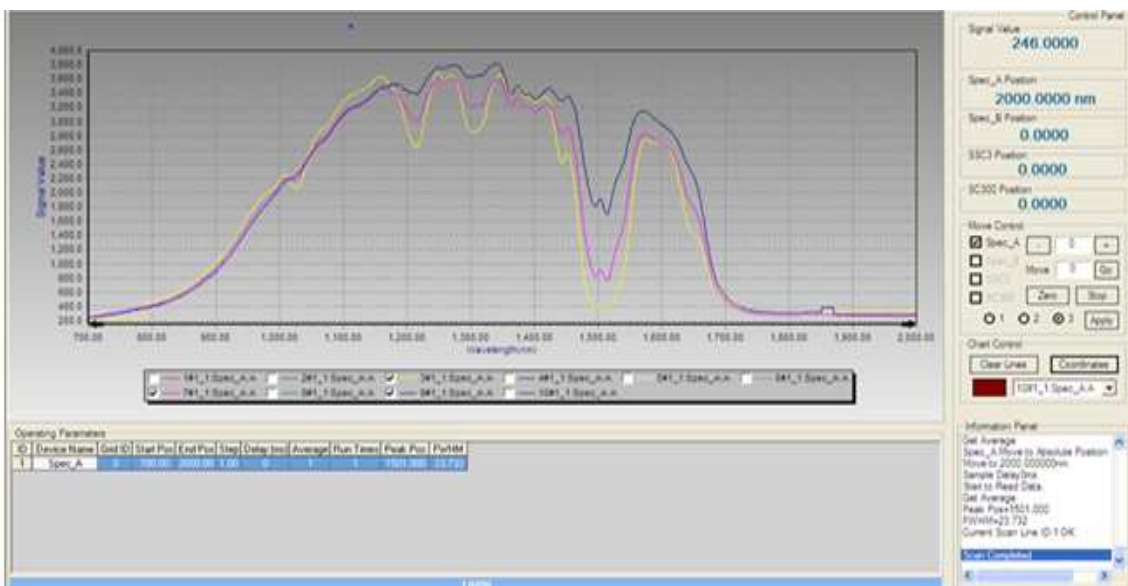

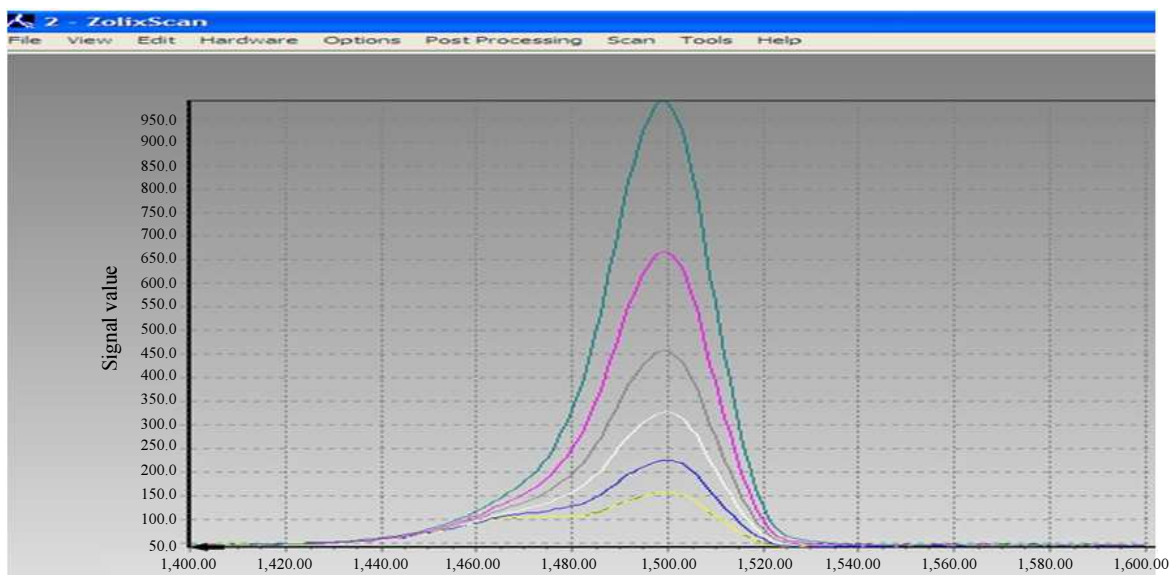**Fig. 4:** Represents three absorption band of ammonia gas regions

Fig. 5: Test NH$_3$ gas sensor used optical spectrum analyzer with a filter at 1.5 *um*
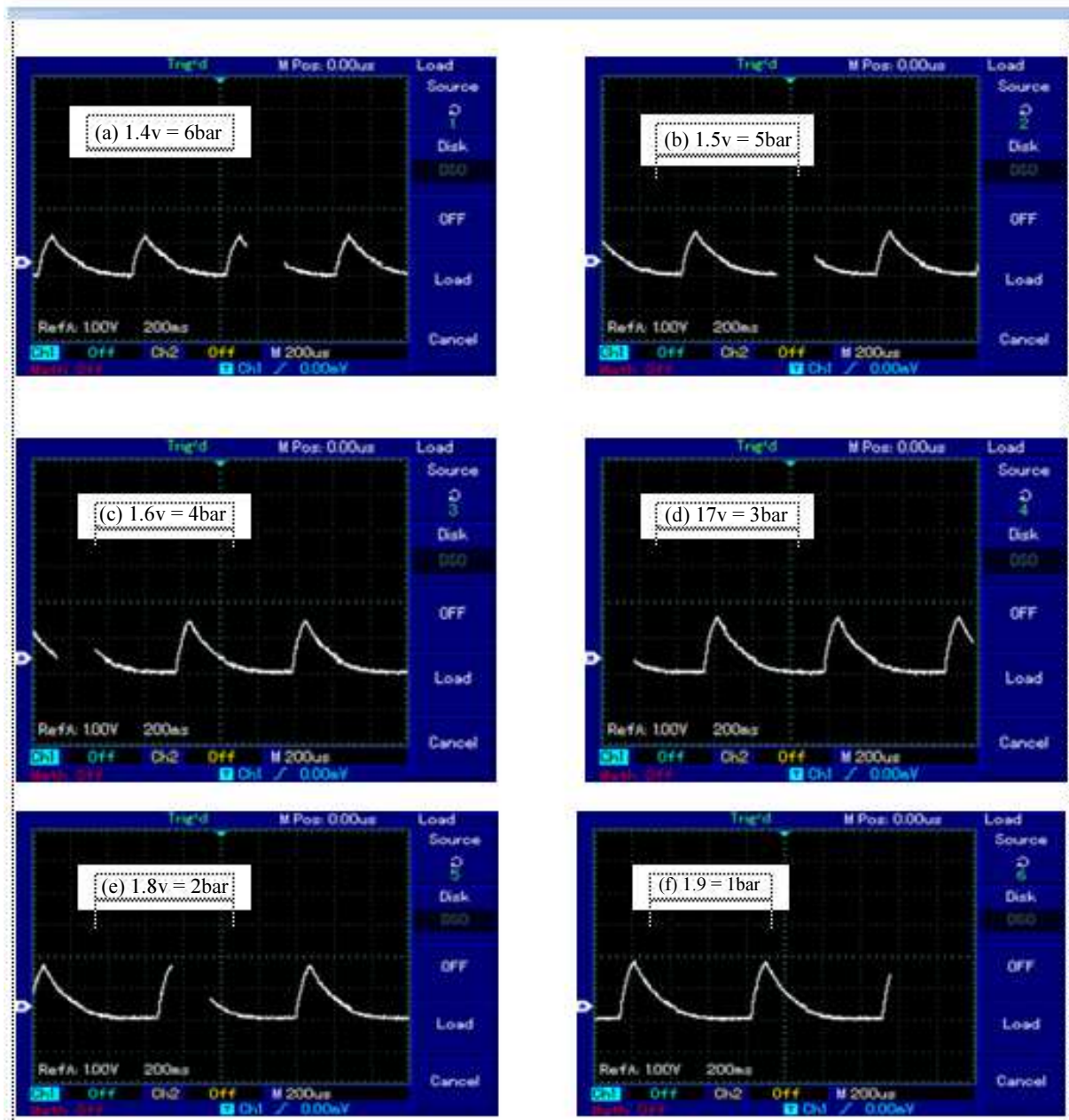
Fig. 6a-f: Represents the output signal voltage for six cases at T = 29.5°C

The proposed sensing system shows line responses in the gas ammonia range from 1 to 6 bar.

Second part: Detector has been replaced with optical filter instead of the spectral analyzer. And make the same previous tests for pressure and temperature as shown in Fig. 3. It was measured and recorded output voltages values as a function of ammonia gas pressure as shown in Fig. 6a-6f. These results were compared with pressure gauge used to obtain accurate results for measuring the ammonia gas pressure. This system could be developed for measuring the highest pressure gas.

Conclusion

In this study, we have been designing and building a system for measuring the ammonia gas pressure in the infrared region. The work includes two parts: The first measurements uses spectral analyzer to see stronger absorption regions between (700-1700 um) and the focus was exclusively on the 1.5um region.

The second parts, the sensing system of gases using the transmitter and receiver system in the IR region (1.5 um). Work the system for measuring the

ammonia gas limits (1-6) bar. The advantages of this sensor system is high accuracy and easy in laboratory and industrial applications.

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Author's Contributions

Mohanad M. Azzawi and Mohammed Jabbar Hussein: Work experimental and write manuscript.

Nibras K. Jebur and Halla F. Saad: Check crammer.

Ethics

Authors should address any ethical issues that may arise after the publication of this manuscript.

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