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# Experimental Investigation on the Optical and Stability of Aqueous Ethylene Glycol/Mxene as a Promising Nanofluid for Solar Energy Harvesting

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**Abstract**. In this research work, emerged nanomaterial (MXene) and Ethylene Glycol (EG) as base fluid is used to formulate a homogenous mixture of nanofluid with promising optical properties. Amphiphilic structure of ethylene glycol allows the dispersion of water and MXene nanoflakes appropriately. The studied nanofluids are prepared with a mixture of 70 % of EG and 30% of deionized water. The prepared aqueous EG is mixed with $Ti_3C_2$ nanoflakes with three different loading concentrations of 0.02, 0.05, and 0.1 wt.%. The Fourier Transform Infrared spectrum (FTIR) of the aqueous EG/MXene nanofluids is measured using a Perkin Elmer Spectrum Two-Universal ATR. Particle analyzer is used to measure the stability of the prepared nanofluids. The experimentally achieved data represents the highest stability with mean zeta potential value of -92.6 mV for aqueous EG/MXene with a loading concentration of 0.02 wt.%. Optical absorbance measurements are performed using Ultraviolet-visible (UV-Vis) spectroscopy. Perkin Elmer Lambda 750 is used to acquire spectra. The result of the observation indicates that the solution of nanofluid with a loading concentration of 0.1 wt. % of $Ti_3C_2$ exhibits the highest peak magnitude of light absorbance among the rest of the three samples. This is because of the more mass concentration value of that nanofluid solution, which is proportional to light absorption. Due to the hydrophilic nature of the utilized nanomaterial and base fluid, there is an excellent probability for them to form a potential homogenous mixture of nanofluid, which might accomplish high optical performance in terms of applying at the solar system.

Keywords: nanofluids, optical absorbance, solar energy, harvesting

## 1. Introduction

Due to the inevitable demand for high energy consumption, it is essential to exploit renewable energy as the source of generating power to fulfil the request. Since the cost of fossil fuels or petroleum energy are expensive and also sources of environmental pollution, so that from the past year's renewable energy is being utilized as the alternative source of producing electrical power such as by the wind, solar, geothermal, ocean, tidal-wave energy and so on [1]. Among those energy sources, the contribution of

solar power is increasing drastically. Owing to having the privileges of being sustainable, inexhaustible, and its non-polluting qualities, at present solar energy has been facilitated tremendously as a coherent, prominent, and convenient form of energy source. For this reason, the demand for solar energy is spreading for different purposes. As a result, solar plants are being implemented in many places around the world. The solar system contains some required accessories and elements where nanofluids are considered as one of the significant integral segments of the system. Because the adequate performance of nanofluids can improve the system efficiency of the solar plant [2]. Generally, nanofluids are formed by homogeneous mixing of nanoparticles along with a base fluid. Characteristics of nanofluids hold some significant properties such as thermal, optoelectronics, optical to maintain the energy efficiency of the solar plant. Energy efficiency is highly dependent mainly on the performance of optical properties from nanofluids because, based on optical properties, suitable nanofluids are selected [3]. Since solar energy contributes a vital role in generating power, but the system efficiency is low. Because of this issue, it is not adequate to meet the demand yet. Researchers noticed this problem, and still, they are conducting their experiments upon different potential nanofluids to enhance the efficiency of the solar plant by exploiting the waste heat along with improving the optical properties of nanofluids.

From the past decades, the scientist has elucidated plenty of experiments to improve the potential performance of optical properties of nanofluids to yield more energy from the solar system that is heading to achieve high efficiency. Light absorption, transmittance, scattering, and coefficient of extinction are the significant aspects involved in the optical properties of nanofluids. The intake of sunlight is reliable on the volume fraction of nanoparticles mixed with nanofluids. At a high-volume fraction of nanoparticles, desirable light can be captured from the sun. There are some intrinsic characteristics of nanofluids that have significant contributions to developing effective optical performance where an increasing amount of viscosity is less [4]. Like selecting suitable pH, adding a surfactant to nanofluid also has a positive effect on improving the system efficiency [3].

Moreover, various types of solar collectors depend on the performance of different nanofluids are being manufactured to accumulate more solar energy. The optical properties of nanofluids have a potential impact on the performance of several types of solar collectors [5]. Khullar et al. have investigated the effect of using nanofluid based concentrating solar collectors to harvest solar energy. They concluded that while maintaining the external conditions, nanofluid based focusing solar collector exhibits 5-10% higher energy efficiency compared to the conventional parabolic solar collector [6]. Otanciar et al. have proposed a theory of enhancing the efficiency of solar collectors. They claimed that direct absorption of the solar collector has a unique advantage over conventional methods that tends to improve the effectiveness of the solar plant up to 5% [7]. Besides, optical and all other properties of nanofluids are size-dependent, which indicates that any desired properties of the fluid can be acquired by the proper size and shape of the nanoparticles [8]. These are also very sensitive in terms of geometrical configurations [9]. Even though theoretically, nanoparticles are adapted to enhance the efficiency of the solar plant, but in case of application, it causes some crucial issues like low specific heat, little thermal stability, altering thermophysical properties concerning temperature [10]. All these issues raised the curiosities of researchers and encouraged them to continue their investigation for the possible acceptable solution.

To overcome the drawbacks above, a new family of two-dimensional nanomaterial from metal carbides or nitrides called MXene has been emerged recently and swiftly gained the attention for the application of better energy conversion and energy storage [11, 12]. The new type of nanomaterials (MXene) is a two-dimensional transition nanocomposite material. The structure of MXene ($Ti_3C_2$) nanomaterial contains a lot of nanosheets filled composite that can display effective performance in the optical field like absorbing microwaves [13]. Optical properties are considered as the most crucial aspects in terms of metal band structure and transition of electronics in them [14]. Depending on the electronics structure of $Ti_3C_2$, it is related to the molar absorptivity, which indicates that absorption in optical properties is a sequel between the intra and interband transition [15]. In nanocomposite materials like MXenes, the dimension of the sizes of particles are so petty that it makes it perfect to yield a high absorption rate by receiving more sunlight [16]. This small size of particles forms metallic bonds that

tend to increase the band gap energy. This phenomenon eventually leads to having more high-frequency light absorption from solar energy. Because of possessing some nomadic configuration like the feature of overlapping thin film flakes, $Ti_3C_2$ can be applicable in many useful purposes such as capturing harmful gases and adsorb storage of natural gases [17] and designing metasurface that possesses broadband absorption quality [18].

Optical properties of base fluids have to be proficient enough to ensure to get high performance by the formed nanofluids. Ethylene Glycol is a crucial organic compound that is considered as one of the most efficient base fluid for synthesizing nanofluids. Ethylene glycol exhibits good qualities of optical properties that make it useful enough to work as a base fluid. Optical properties like absorption are highly dependent on the activities of Ethylene Glycol. Band gap energy of the nanofluids ordains the quality of the optical properties of it. A tremendous band gap energy can increase the performance of optical properties in Ethylene Glycol based nanofluid [19]. Gawel et al. have explained the optical properties of EG based Silicon Nitride nanofluid. They stated that in the ultraviolet region of light, with the increase of volume fraction of particles, the capacity of absorbance increases [20]. Optical properties such as the coefficient of extinction can also be enhanced with a high mass concentration of nanoparticles but only in the visible range [21]. In terms of application, Ethylene Glycol can be exploited in different sectors. This chemical intermediate can be used in the field of heating or cooling plastic, automobiles, energy, chemicals, industrial process, and solar thermal energy system [22, 23].

In terms of making a competent homogenous mixture of nanofluid, both nanoparticles and base fluid must be hydrophilic. Hydroxyl (OH) or Oxygen terminated surface can be found in the molecular structure of Titanium Carbide ($Ti_3C_2$) that makes it hydrophilic enough. These surfaces ended groups such as F, and OH has a strong influence on the optical properties, especially in transmitting light of $Ti_3C_2$. Light transmittance in the visible range can occur upon the termination of F or OH [24]. Apart from that, the molecular structure of Ethylene Glycol ($C_2H_6O_2$), it is noticeable that two pairs of OH bonds are presented that tend to mix with water at an arbitrary position [25]. These characteristics make Ethylene Glycol hydrophilic enough.

In the present study, a novel highly stable EG/Water/MXene ($Ti_3C_2$) nanofluid has been prepared successfully. The studied EG with a molecular weight of 62.07, represented an excellent dispersion with DI water due to the presence of hydroxyl groups and hydrophilic nature. To the best of authors' knowledge, this is the first report of the utilization of MXene nanoparticles as filler for aqueous EG-based nanofluids with promising optical and stability properties. Interestingly the unique balance and optical performance of this promising EG/Water/$Ti_3C_2$ nanofluid were revealed according to the experimental achieved data. This highly promising EG/Water/$Ti_3C_2$ nanofluid might contribute to the development of the next-generation of optical-based nanofluids for efficient solar energy harvesting.

## 2. Materials and Method

### *2.1. Materials*

Ethylene glycol ($C_2H_6O_2$) with a molecular weight of 62.07 and CAS number of 107-21-1 was procured from R&M Chemicals and used as received without further purification. The aqueous solution was obtained in a predefined ratio (70% EG+30% water). MAX phase material ($Ti_3AlC_2$) was procured from Y-Carbon Ltd.

### *2.2. Synthesis of MXene ($Ti_3C_2$) Nanomaterials*

In the synthesis of MXene ($Ti_3C_2$,) the following materials were used without any further purification: MAX Phase material ($Ti_3AlC_2$) from Y-Carbon Ltd., lithium fluoride (325 mesh powder, 98.5% purity, Alfa Aesar), hydrochloric acid (37% wt., Fisher chemicals), and sodium hydroxide (97% purity, pellets, Sigma Aldrich). Firstly, 15 ml of DI water was added to a 50 ml volume beaker followed by adding 15 ml of HCL to obtain 30 ml of HCL (6M). Then 3 g of LiF was added to the HCL solution with stirring at 300 rpm for 30 minutes until dissolved. This etching process was continued with adding 3 g of MAX phase material ($Ti_3AlC_2$) to the solution slowly (within 15 minutes) to avoid overheating (exothermic

reaction), and the resultant solution is left to stir at 40 °C for 48 h. After the etching process, a dilute solution of NaOH was added slowly until the pH of the solution reached 6 and was filtered and rinsed several times with deionized water. The washing process was conducted using an ultrahigh centrifuge (Sorvall LYNX 6000, Thermo Scientific) for four times (each time of 10 minutes) at 3500 rpm. The achieved multilayered MXene (m-$Ti_3C_2$) was sonicated for one h using an ultrasonic probe sonicator (FS1200N) to obtain delaminated flakes of the MXene (d-$Ti_3C_2$). The synthesized delaminated flakes of MXene nanomaterial was dried in a vacuum oven (VO 500, MEMMERT Germany) overnight.

### *2.3. Preparation of EG/Water/Ti3C2 Nanofluid*

The aqueous solution of EG/Water was prepared with ratio of 70% EG and 30% DI water. The total volume of each sample was 50 ml were comprised 35 ml of Ethylene Glycol and 15 ml of deionized water. Mixing the Ethylene Glycol with deionized water is required prior to becoming a suitable base fluid. Because at the time of mixing, deionized water opens the chain structures of the molecules of Ethylene Glycol so that it becomes less viscose. The viscosity of Ethylene Glycol must be less to make potential homogenous mixing with $Ti_3C_2$ nanoparticles.

Firstly, 35 ml of EG was added to the beaker followed by adding 15 ml of DI water. Acquired 50 ml of the aqueous EG/Water was weighed using a microbalance (TX323L, UNIBLOC) to calculate the amount of MXene in terms of weight percentage. The weight of the solution was measured in 100.98 g. Secondly, for preparing three different loading concentrations of MXene nanoparticles, including 0.02, 0.05, and 0.1 wt.%, the amount of the required Ti3C2 nanoflakes was calculated in 20.2, 50.95 and 100.1 mg respectively. The amount of 50 ml of aqueous solution (EG/Water) was stirred at 1000 rpm for 10 minutes to obtain homogenous dispersion. The required amount of $Ti_3C_2$ for loading concentration of 0.02 wt.% was weighed using a microbalance (EX224, OHAUS), then it was added to the solution followed by stirring for another 60 minutes at 400 rpm. The resultant EG/Water/Mxene solution was sonicated using an ultrasonic probe sonicator (FS-1200N) for one h with the power of 60%. This protocol was conducted precisely for preparing a loading concentration of 0.05 and 0.1 wt.% as well. Figure 1 represents a schematic of the sample preparation method.

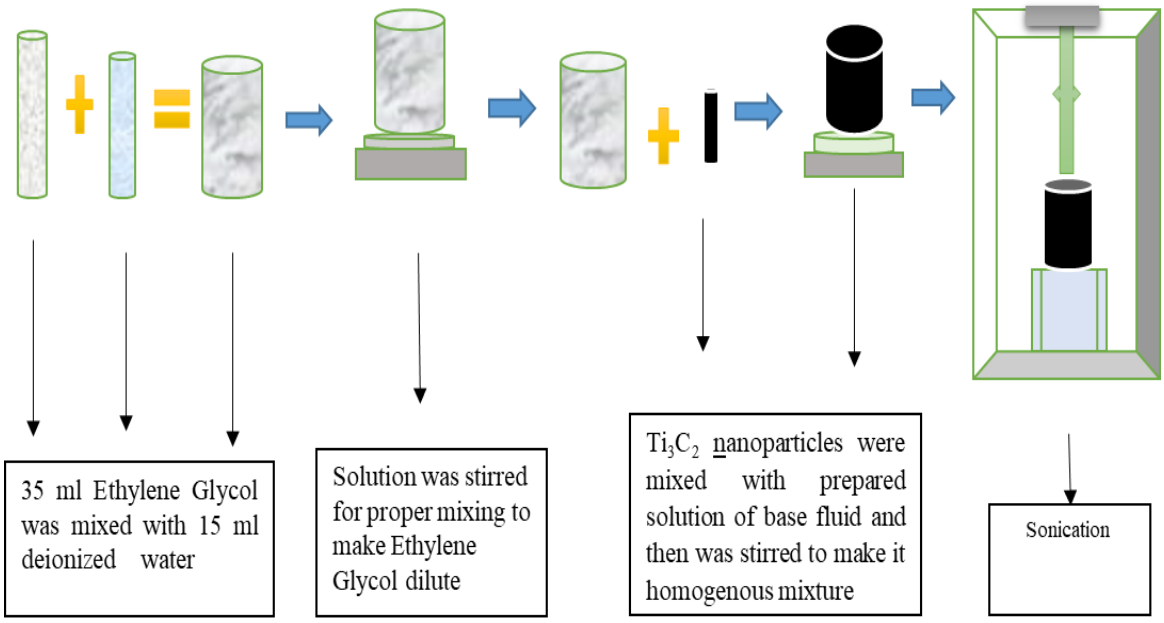


**Figure 1.** Schematic representation of the samples prepared during the experiment.

### *2.4. Fourier Transform Infrared Spectroscopy (FTIR) Test*

The Fourier Transform Infrared spectrum (FTIR) of the EG/MXene nanofluids was measured using a Perkin Elmer Spectrum Two-Universal ATR. The integrated detector of MIR TGS was used to detect the spectra. Scanning speed was 0.2 cm/s within the optimum scan range of 350-4000 $cm^{-1}$. The number of scanning was adjusted to 16 scans. The FTIR measurements for all prepared samples was followed with a unique protocol to assure the accuracy of the experiments.

### *2.5. Stability Analysis of Aqueous EG/MXene Nanofluids.*

To measure the stability of the prepared aqueous EG/MXene nanofluids, particle analyzer (LITESIZER 500, ANTON PAAR) device was used. This type of measurement is called Zeta Potential. While observing this experiment, solutions of $Ti_3C_2$ based nanofluid and 70% of Ethylene Glycol base fluid from the four samples were filled inside the Omega-cuvette and inserted those inside the device. Prior to achieving practical results, apparatus such as cuvettes must be clean enough to get rid of contamination related issues. During that stage of the experiment, some exigent parameters were required. Such as the voltage was set 200V, the temperature was 25°C (room temperature), the number of the run was 1000, and the refractive index, relative permittivity, and viscosity were also inputted in the device accordingly.

### *2.6. UV-Vis Ultraviolet (UV-Vis) Spectroscopy*

Optical absorbance measurements were accomplished using Ultraviolet visible (UV-Vis) spectroscopy. Perkin Elmer Lambda 750 was used to achieve spectra. Correction curve measurements was conducted initially. Then the four solutions of different mass concentrations of Ti3C2 based Nano fluids and 70% Ethylene Glycol base fluid-filled cuvettes were inserted inside the machine to commence the investigation. At room temperature, experimental data was collected within the wavelength range from 800 to 200 nm. The adjusted scan speed was 266.75nm.

## 3. Results and Discussion

### *3.1. Chemical Structural Analysis using FTIR*

Based on the observation of the experiment, the chemical structures of the molecules of the three different mass concentration based nanofluid and 70% Ethylene Glycol based fluid were investigated by using the FTIR spectroscopy analysis. The result of the acquired FTIR spectrum was found out in a graphical exposure, and it is presented in Figure 2. Distinctive mass concentrations of $Ti_3C_2$ like 0.02, 0.05 and 0.1 wt. % involved in nanofluid and 70% Ethylene Glycol based fluid are shown separately in one single graph for better comparison. Both MXene and base fluid (Ethylene Glycol) contains common surface terminated groups such as O-H. Moreover, characteristics peaks for EG/MXene nanofluid and 70 % Ethylene Glycol based fluid revealed the presence of O-H, C-H, C-O, and C-O-C groups in the samples. The peak at 2878.89-2939.73 $cm^{-1}$ displays the skeletal vibrations from C-H, O-H groups in the chemical structure of the nanofluid. Due to O-H extending vibrations, the presence of O2-functionalities was detected in peaks at 1411.72 $cm^{-1}$ [24]. In that experiment, it is clearly observed that the wavenumber ($cm^{-1}$) characteristics peaks of the four different samples of nanofluid are similar. They are following a similar trend line in the graph. It explicates that negligible chemical changes occurred in that prepared nanofluids due to mixing a low amount of wt. % of the $Ti_3C_2$ with the base fluid (Ethylene Glycol). During that experiment, no new chemical bonding was formed. The molecules involved inside the mixture of nanofluid of the samples are chemically stable. The dispersion was occurred due to physical reaction. A chemical reaction is not required here. On the contrary, chemically unstable molecules are not suitable for homogenous mixture because it shows less hydrophilic quality. The result of this investigation reveals that the performance of $Ti_3C_2$ is potential. This quality makes the MXene more hydrophilic, which tends to mix with Ethylene Glycol since it is also hydrophilic and thus exhibited effective performance during the experiment by forming an influential homogenous mixture.

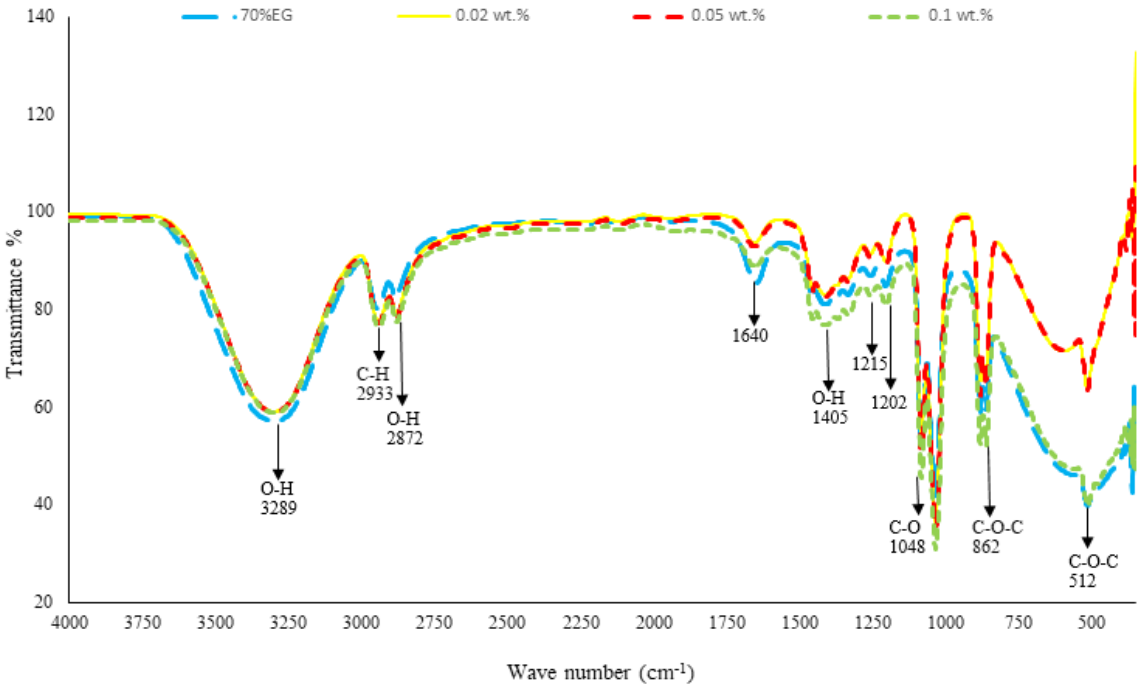


**Figure 2.** Full range (4000-350) $cm^{-1}$ FTIR spectra of $Ti_3C_2$ and 70% Ethylene Glycol (base fluid) based Nano fluid with varying MXene loading mass fraction.

*3.2. Stability Characterization of Aqueous EG/MXene Nanofluids.*

The potential difference between the stationary layer of fluid aligned to the dispersed diminutive particles and the dispersion medium is known as zeta potential. One of the crucial factors that affect zeta potential is the size of the molecules or particles. The size of particles must be small enough to achieve high molecular stability of the solution of nanofluids, and this aspect also resists the phenomena of getting agglomeration or sedimentation during the experiment. Nanoparticles inside the nanofluid follow the Brownian motion. This Brownian motion suppresses the instability condition of the tiny particles. Moreover, zeta potential is the electrostatic repulsive force between the base fluid and nanoparticles, which denotes that this high repulsive force causes high stability of the molecules of nanofluids [26]. Generally, the magnitude of mV may be defined as the estimated stability value of the nanofluid, whereas the excellent stability of the molecules of nanofluid may exceed the extent of 60 mV [27, 28].

**Table 1.** Experimentally achieved zeta potential values from different samples of nanofluid.

| Samples | Mean zeta potential (mV) | Standard deviation (mV) | Transmittance (%) |
|---|---|---|---|
| 70% Ethylene Glycol | -34.5 | 123.5 | 76.6 |
| 0.02 wt% of $Ti_3C_2$ | -92.6 | 2.4 | 67.8 |
| 0.05 wt% of $Ti_3C_2$ | -80.5 | 1.7 | 86.4 |
| 0.1 wt% of $Ti_3C_2$ | -69.5 | 1.5 | 86.3 |

According to the magnitudes above of Table 1, the experimental value of mean zeta potential for 70% Ethylene base fluid is found -34.5 mV. For this type of base fluid, the suitable range for potential molecular stability is around -35 mV to +35 mV. From this result, it is noticeable that the molecules

inside the 70% Ethylene base fluid are in a stable range. The rest of the three samples where different amounts of mass concentration of MXene were mixed with 70% Ethylene Glycol also displays excellent particle stability. For example, the mean potential values of 0.02, 0.05 and 0.1 wt. % of $Ti_3C_2$ based nanofluids are subsequently -92.6, -80.5, and -69.5 mV. From these illustrations, it can be clarified that nanoparticles of all these samples are in stable condition. This experimental result reveals that the molecules of three different values of mass concentration of MXene maintain excellent stability inside the samples of nanofluid because the mean potential magnitudes of these samples are in the range of 60 mV. Since molecules of the nanoparticles are in stable conditions so that those tiny particles were able to arrange chronological sequences of their position inside the solutions of nanofluid for different load concentrations. The distance of each of the particles was synced to each other, and incoming light got enough space for transmitting. Because of this reason, the magnitude of the percentages of light transmittance through the mass concentration mostly for 0.05 and 0.1 wt. % is high in this experiment, such as 86.4 and 86.3% subsequently. Surface charges of $Ti_3C_2$ are negatively surface charge because it contains surfaces terminated groups such as $OH^-$, $F^-$ and -O, which are also negative charges. In this experiment, Ethylene glycol was used as the base fluid, which surface charges is also negative. Because it contains two strong hydrogen bonds that are aligned with $OH^-$ group, which possesses negative charge, since both nanoparticles and base fluid exhibit negative charges inside the solution of nanofluid, there is a massive repulsive force between the particles and base fluid was occurred during the experiment and thus achieved excellent particle stability condition. High stability of particles inside the solution indicates a high surface area of the thin nanosheets of $Ti_3C_2$, which makes the solution into suitable nanofluid to achieve potential optical performance.

### *3.3. UV-Vis Ultraviolet (UV-Vis) Spectroscopy Characterization.*

The conversion of solar energy to any other form of energy or directly to generate power is a significant aspect. Increasing the performance of optical properties such as absorption, transmittance, scattering, and coefficient of extinction can lead to gain desired output results. The measurement of absorption of sunlight by nanofluid can be executed by using Ultraviolet-visible (UV-Vis) spectrometry. In this investigation, the typical optical absorption spectra of $Ti_3C_2$ for different mass concentrations like 0.02, 0.05, and 0.1 wt. % in the nanofluid were determined and shown in Fig 3. From the result of the figure, pure Ethylene Glycol indicates almost the same trend throughout the whole range of wavelength did not express any peak point of absorbance. Nanofluid contains 0.02 wt. % of MXene nanoparticles exhibit only one peak point of light absorbance at 280 nm based on the conjugation $\pi$ system of the electronic transition of the MXene particles. According to the beer lambert law, it is known that absorbance of light increases with the number of wavelengths and with the quantity of molar concentration of the fluid. From Figure 3, it is found that there are five peak points for 0.05 wt. % of EG/$Ti_3C_2$ nanofluids. The highest peak is observed at a wavelength of 371 nm that was happened because of the electronic transition ($n \rightarrow \pi$) of the particles—the nanofluid solution of 0.01 wt. % of $Ti_3C_2$ nanoparticles has the maximum number of peak points. The graphical expression of this nanofluid follows the beer lambert law, and at the wavelength of 781 nm it shows maximum light absorbance. Electrons of the atoms involved in the molecules of MXene nanoparticles gained energy from light and increased their strength and transited through lower bands to higher-level bands. As a result, their band gap energy enhanced, which accelerated those nanoparticles to absorb more incoming lights. In this sample of nanofluid solution, the mass concentration of MXene nanoparticles is high that made the mixture darker, which led to capture more light to meet the objectives of this experiment.

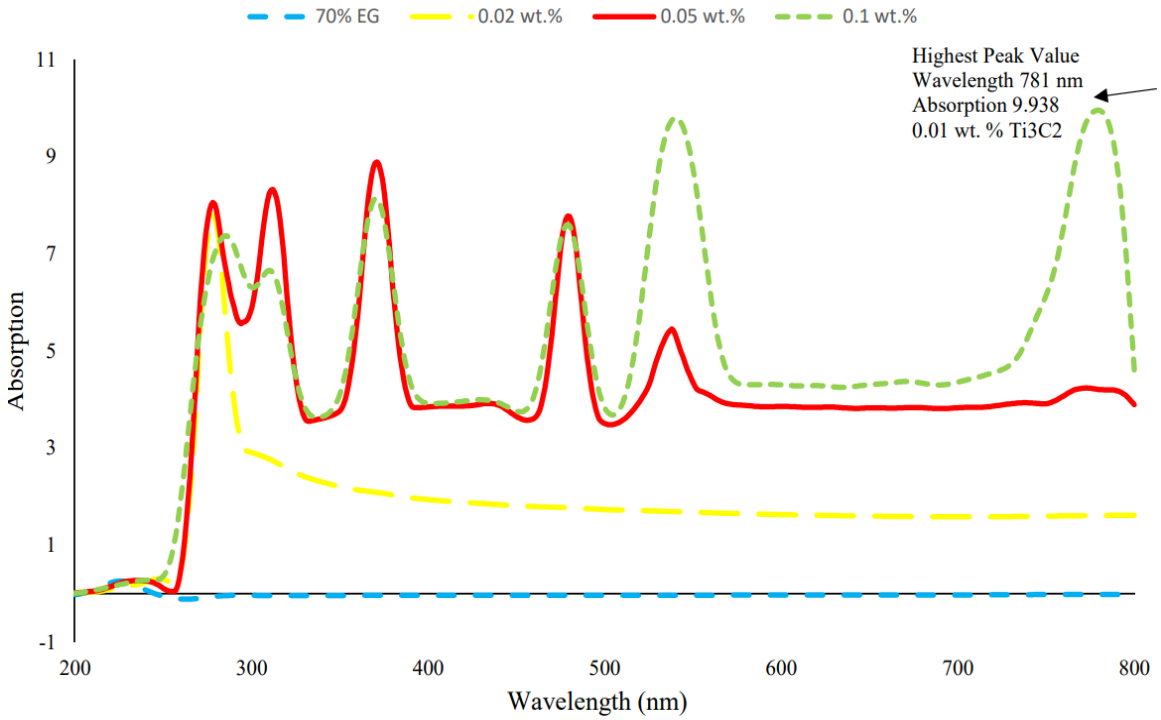


**Figure 3.** Light absorption characteristics for different loading concentration of $Ti_3C_2$ into EG/MXene nanofluids.

## 4. Conclusions

In this study, optical properties of different mass concentrations of prepared EG/MXene nanofluids were determined. Absorbance, transmittance, extinction coefficient, and scattering are the crucial parameters of the optical property of a nanofluid. Nanoparticles of $Ti_3C_2$ were mixed with the base fluid (Ethylene Glycol) to form the homogenous mixture of nanofluid. Base fluid (Ethylene Glycol) contains strong hydrogen bonds that assist in withstanding against high temperature during the experiment. For this reason, at the beginning of the investigation, it was mixed with deionized water to reduce its viscosity. Mixing with deionized water enables to open the chain structure of the molecules of Ethylene Glycol and makes it dilute enough to get mixed with the MXene nanoparticles. 0.02, 0.5 and 0.1 wt. % of the mass concentration of $Ti_3C_2$ nanoparticles were selected for comparison. These particles were mixed with 70% Ethylene Glycol to comprise a new form of nanofluid. During the experiment, it is found that the pattern of the graphs of each sample is displaying a similar trend that indicates that the molecules inside the prepared samples are chemically stable. The physical reaction occurred in the dispersion of the particles. No new chemical bonds were formed. It was also noticed that particles inside the solution of different mass concentrations of $Ti_3C_2$ expressed excellent stability performance by showing the zeta potential values in the range of 60 mV. While conducting the observation, the concentration of 0.01 wt. % of $Ti_3C_2$ nanoparticles solution reflects a darker color, which led this mixture to absorb more incoming light, and the result was collected from the graph. In the graph, it is found that light absorption is the highest with an increasing number of wavelengths for 0.1 wt. % mass concentration quantity of $Ti_3C_2$ compared to the other values of the samples. Based on this investigation, both nanoparticles and base fluid show hydrophilic property. Because of this reason, during the experiment, those were able to make the new type of homogenous mixture of nanofluid. After the observation of the experiment, it can be clarified that this novel type of nanofluid displays potential optical properties and can be applied to enhance the system efficiency of the solar plant. The future work is to investigate the optical properties such as absorption, transmittance by using this novel type of nanofluid that includes a different amount

of weight percentages of $Ti_3C_2$ nanoparticles because it is a promising nanofluid that can meet the future demand.

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