STM JOURNALS

Journal of
Polymer & Composites

ISSN: 2321-2810 (Online)
ISSN: 2321-8525 (Print)
Volume 13, Special Issue 1, 2025
DOI (Journal): 10.37591/JoPC

https://journals.stmjournals.com/jopc

Research JoPC

# A Study on Solvent Interaction and Thermal Transport of β-Carotene

Ramya M[1,*], Bhavya Pramod[2], Navya Pramod[3], Akshaya Muralidharan[4], Anita Mary Peter[5], Kailasnath M[6]

**_Abstract_**

*β-carotene, a prominent compound of carrot pigments having a non-polar nature consisting of conjugated double bonds, plays a vital role in human health as a biological antioxidant and a precursor of vitamin A. In addition, it is also responsible for being a multicolored agent in various plant species and extensively employed in food colorants. This has centered attention on β-carotene nowadays. For the extraction of β-carotene, we used the most popular source of raw carrots. The solubility of β-carotene depends upon the polarity nature of the solvents. In this study, the extraction and solubility of β-carotene in nine different solvents namely isopropanol, methanol, toluene, ethylene glycol, dimethyl formamide (DMF), dimethyl sulfoxide (DMSO), water, butanol, hydrogen peroxide were investigated. The samples where the β-carotene was extracted and dye was formed exhibited a pale yellowish to orange color whereas few solvents remained colorless. The solubility of β-carotene is not uniform, it is the highest isopropanol. The absorption and photoluminescence characteristics were studied to further understand the concentration, efficiency of extraction, and emission properties. According to our knowledge, this paper addresses a novel study presenting the thermal-optic properties of the β-carotene dye in different solvents using a dual beam thermal lens setup and it was compared to the thermal diffusivity of solvents, and the enhanced thermal diffusivity was also noted in solvents. The enhancement in heat-transferring properties of β-carotene dye may be explored for non-linear optical applications in optoelectronic devices also.*

**Keywords:** β-carotene, carotenoid, solvents, optical properties, thermal diffusivity

***Author for Correspondence**
Ramya M

[1]Assistant Professor on Contract, Department of Physics, NSS College, Ottappalam, Palakkad, Kerala, India
[2]MSc Student, Department of Physics, SVNSS College, Vyasagiri, Wadakkachery, Thrissur, Kerala, India
[3]MSc Student, Department of Physics, SVNSS College. Vyasagiri, Wadakkachery, Thrissur, Kerala, India
[4]MSc Student, Department of Physics, SVNSS College, Vyasagiri, Wadakkachery, Thrissur, Kerala, India
[5]Research Scholar, International School of Photonics, Cochin University of Science and Technology (CUSAT), Cochin, Kerala, India
[6]Professor, International School of Photonics, Cochin University of Science and Technology (CUSAT), Cochin, Kerala, India

Received Date: July 26, 2024
Accepted Date: September 26, 2024
Published Date: December 09, 2024

**Citation:** Ramya M, Bhavya Pramod, Navya Pramod, Akshaya Muralidharan, Anita Mary Peter, Kailasnath M. A study on solvent interaction and thermal transport of β-carotene. Journal of Polymer & Composites. 2025; 13(Special Issue 1): S847–S855ᴅ.

## INTRODUCTION

Dyes are soluble organic compounds that chemically bond with the material by penetrating through the material surface used to impart color to paper, leather, and textiles. Based on the origin dyes are mainly classified into two types synthetic dyes and natural dyes. As the name suggests natural dyes are extracted from natural resources like roots, plants, minerals, and animals. Recently, interest in the use of natural dyes has been growing rapidly due to their being environmentally friendly, exhibiting better biodegradability, and generally having a higher compatibility with the environment than synthetic dyes. Although abundant and extractable from various plant sources. The manufacturing process is economically viable as the raw materials are directly obtained from natural resources and therefore the cost of production is very low which provides greater demands for natural dyes in research areas [1,2].

 

In this study, we extract a β-carotene dye from the carrot plant which is one of the richest sources of the dye. Carotenoids have a broad family of diverse natural molecules, encompassing over 600 different pigments that are responsible for the vibrant colors of plants, fruits, and flowers. β-carotene is a secondary metabolite having molecular formula ($C_{40}H_{56}$) produced by plants, that belongs to an unoxidized carotenoid compound, and their main structural characteristics are derived from the acyclic structure. The functional group containing oxygen is located at both ends of the molecule leaving the conjugated double bond unaltered. The existence of conjugated double bond systems that are accountable for these pigments to absorb electromagnetic radiation in the spectral region (565-625nm). In terms of behavior β-carotene is a lipophilic compound that is hydrophobic but soluble in organic solvents like benzene, and chloroform. The demand for β-carotene has been increasing in recent years because the molecule can perform multiple physiological functions in human nutrition, acting as a precursor of pro-vitamin A, and plays a crucial role in the maintenance of normal reproductive performance and visual functions. Additionally, β-carotene serves as an antioxidant protecting the cells from oxidative damage thus its applicability extends to as an anticancer agent and also decreases the risks of degenerative disorders such as cardiovascular diseases [1,2,3]. Owing to this their identification and quantification attracted a lot of interest and various methods were applied, like UV-visible spectroscopy, etc [4,5]. The dye that is used as a photosensitizer plays an important role in the operation of DSSCs have been investigated in many studies [6]. In this study, we mainly focus on the various solvent interactions on that dye and also investigate the characterization properties by using absorption and thermal lensing techniques.

## EXPERIMENTAL

In this experiment, the carrot was chosen for the extraction of β-carotene dye which is one of the richest sources of carotene dye. The preparation started with the cleaning process of the substrate wash and peeling the carrots to remove any dirt or debris. Chop the carrot into small pieces to increase the surface area for extraction. Subsequently, 5g of each piece was weighed and kept separately. There are various approaches available for the extraction of natural dye. Solvent extraction is a method commonly used to extract natural dye compounds from plant materials. The choice of solvent depends on the nature of the dye being extracted common solvents include ethanol, methanol, etc. Afterward, the 5g sample was collected and placed into 20ml of nine different solvents in a beaker namely water, Dimethyl sulfoxide (DMSO), Butanol, Toluene, Isopropanol, Methanol, Ethylene glycol, Hydrogen peroxide, Dimethylformamide (DMF). The solution was kept in a beaker for 20 hours at room temperature. After that, the solid residues were filtrated with filter paper. The extracted solution was filtered and transferred into sample bottles for further analysis. Figure 1 shows the steps involved in the extraction process of β-carotene from carrot sources.


**Figure 1.** Illustration of the process of extraction of β-carotene from carrot source.

ISSN: 2321-2810 (Online), ISSN: 2321-8525 (Print)

Absorption spectra of extracts dye from carrots using different solvents were compared using the UV-visible spectrometer of Jasco(V-770). Jasco(V-770) is the only single monochromatic spectrometer that can measure a whole range from UV-NIR in a single scan. The optical system of V-770 includes an automatically exchanged dual-grating and dual-detector system. The unique single monochromatic utilizes fewer mirrors, providing higher throughout which results in a higher signal-to-noise ratio for the entire spectral range. They have high photometry linearity, wavelength expansion kit, step scan measurement, and dark correction and these features provide highly accurate measurement of absorbing samples.

The emission spectrum of extract dye using different solvents was compared using PL. The fluorescence spectra (excitation wavelength of 460nm) were taken using a Varian Cary Eclipse fluorescence spectrophotometer. The thermal lens technique has been successfully utilized to investigate the effect of thermal diffusivity of beta carotene in different solvents performed on a dual beam mode mismatched TLS instrument.

## RESULTS AND DISCUSSION

The resulting concentrated dye solution was orange-yellowish except for hydrogen peroxide, water, and ethylene glycol shown in Figure 2(a) and 2(b). When we came to the analysis of the solid residues, we observed that some of them were colored and fresh excluding the solutions DMF, and Toluene. From these results we can understand the solubility of β-carotene is not uniform, the extent of the solubility of β-carotene is greatest in isopropanol shown in Figure 2(c), and extremely low in the solvents namely water, hydrogen peroxide, and ethylene glycol. Due to their colorless nature, we excluded three solvents namely water, hydrogen peroxide, and ethylene glycol from the further investigations. More analysis of the spectral characteristics of the β-carotene dye was also investigated using absorption and emission spectra.

The measured and normalized absorption spectra of β-carotene in selected six solvents are shown in Figure 3. Because of their chemical structure, they possess characteristic absorption spectra in the visible region, determined by the long conjugated double bond system. The U-V spectrum of β-carotene was scanned from 200 to 800nm. This was in good agreement with that reported in the literature [7]. β-carotene spectrum demonstrates a similar red-shift of their main absorbance maxima concerning the increase of refractive index and polarity index of the solvents. The fluorescence excitation spectra at excitation wavelength 460nm are shown in Figure 4. It was noticed that the emission properties of β-carotene significantly depend on solvent-dye interaction. In Toluene emission intensity was maximum compared to other solvents. In isopropanol emission spectrum shows the Gaussian nature, it indicates the uniform distribution of β-carotene and its high solubility. The absorption and PL experiments showed a significant impact of solvent properties on the solubility of β-carotene. Table 1 depicts the relative polarity and refractive index of selected solvents.

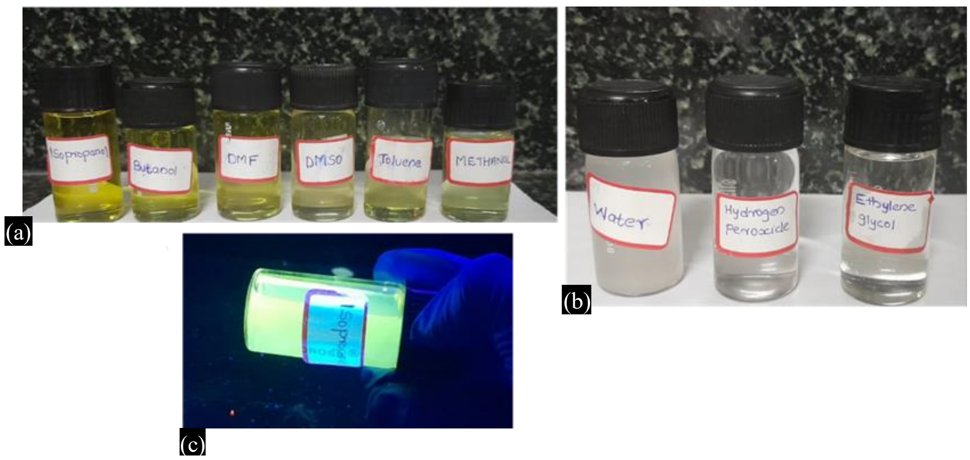


**Figure 2.** Photograph of extracted dye solutions in selected solvents.

 

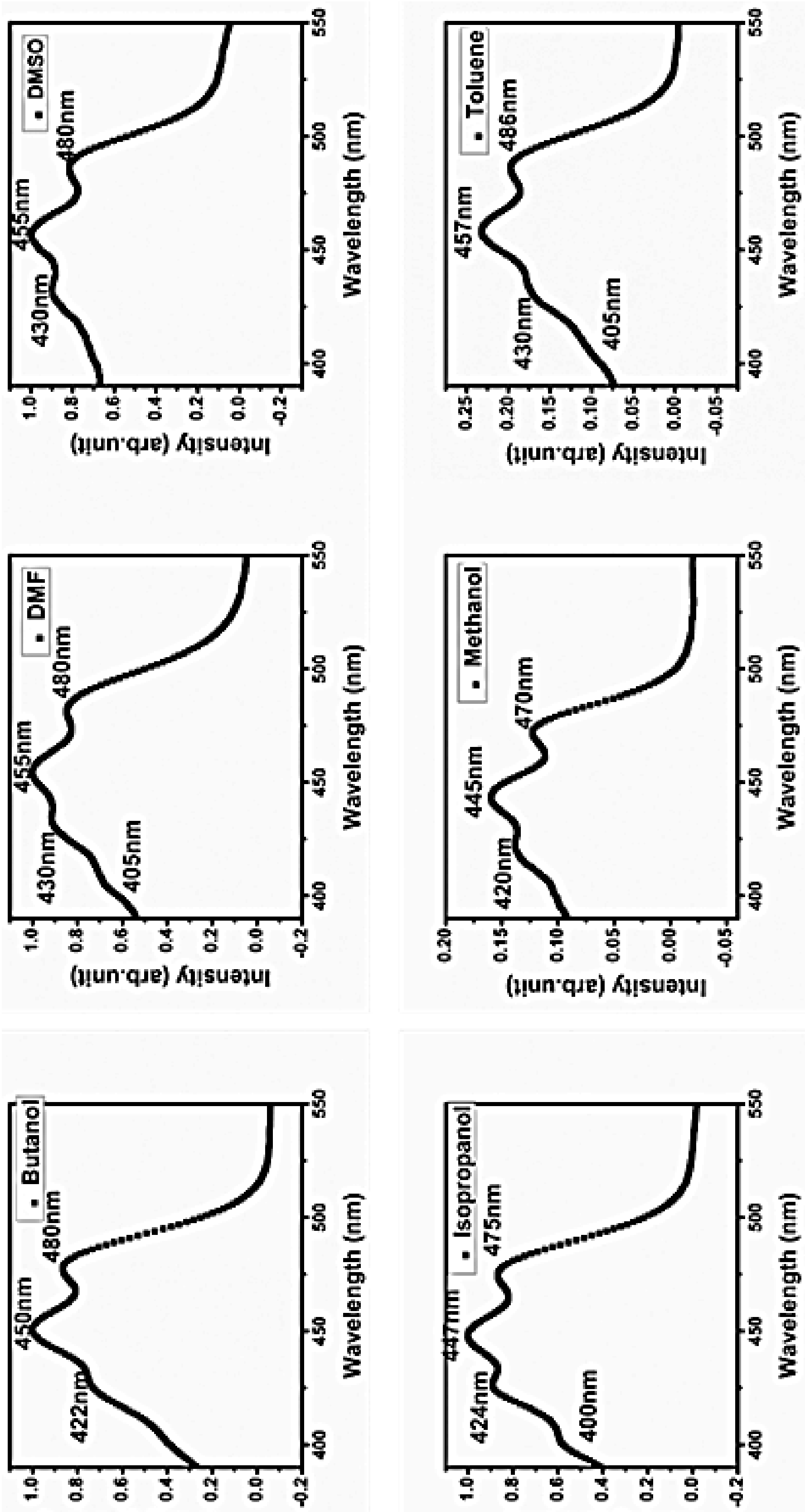


**Figure 3.** Absorption spectra of β-carotene in selected six solvents such as butanol, DMF, DMSO, isopropanol, methanol, and toluene.

 

Journal of Polymer & Composites
Volume 13, Special Issue 1
ISSN: 2321-2810 (Online), ISSN: 2321-8525 (Print)

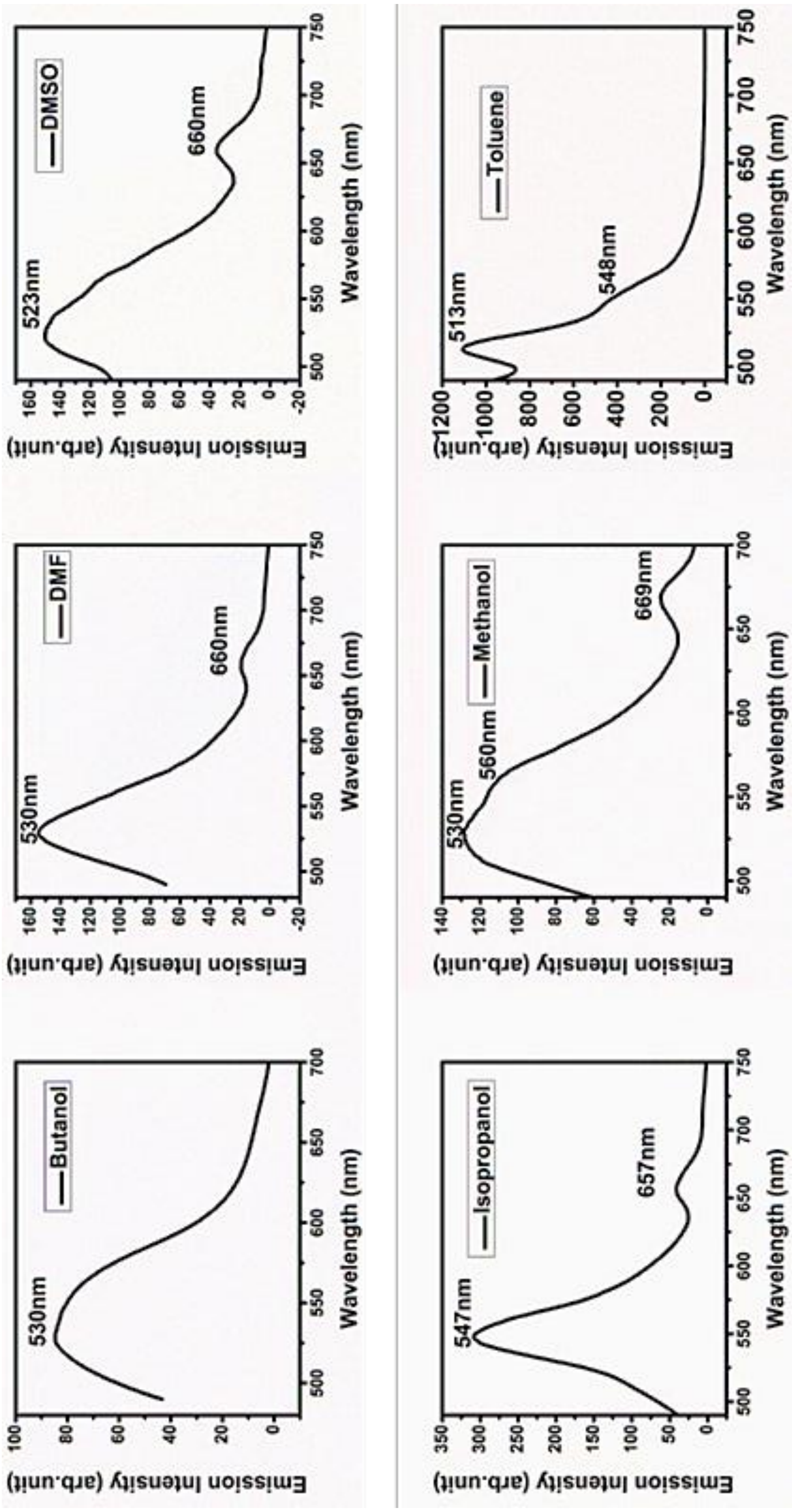


**Figure 4.** Fluorescence spectra of β-carotene in selected six solvents such as butanol, DMF, DMSO, isopropanol, methanol, and toluene.

 

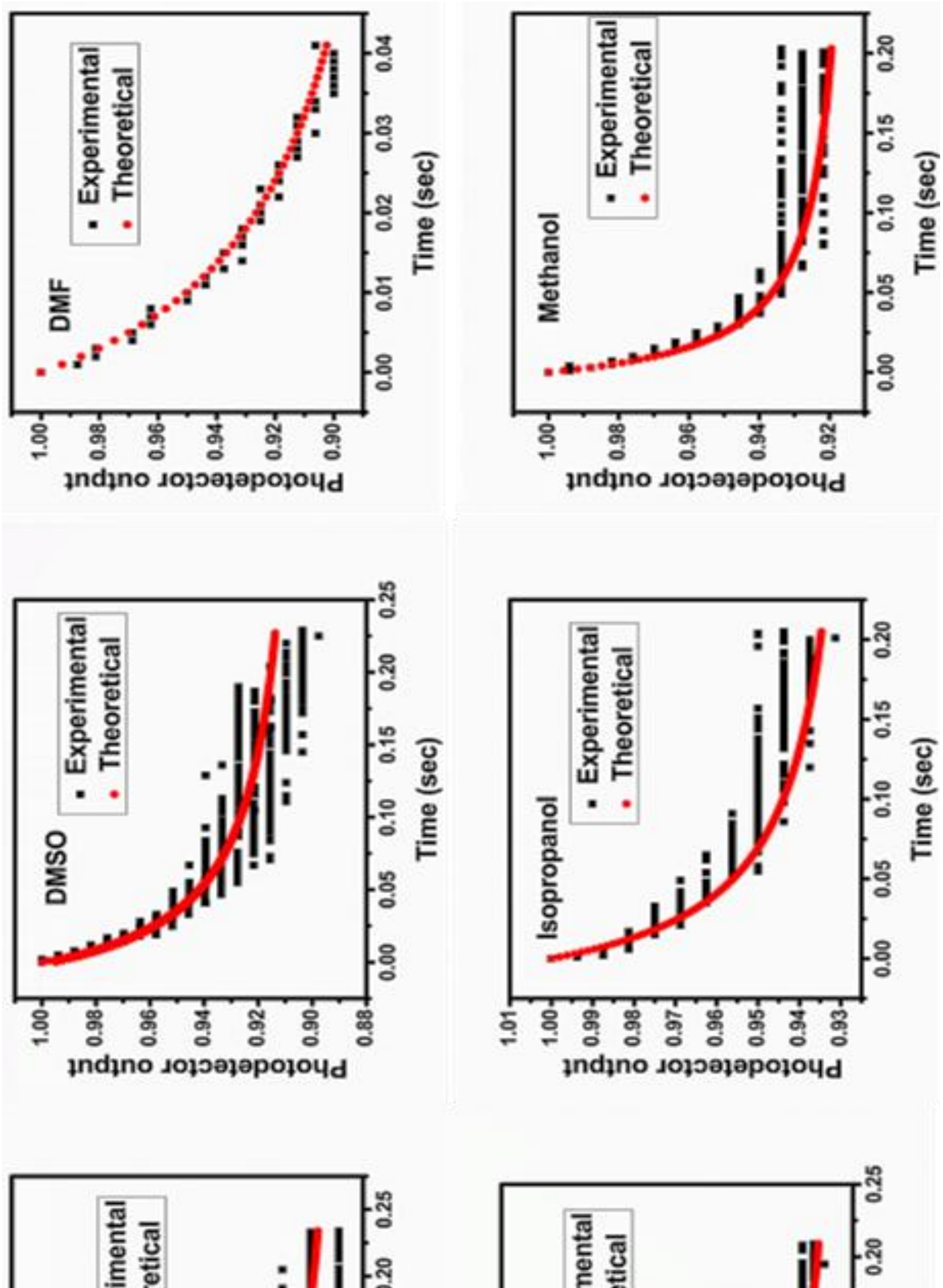


**Figure 5.** Thermal lens plot of β-carotene in selected six solvents such as butanol, DMF, DMSO, isopropanol, methanol, and toluene.

 

**Table 1.** Selected solvent's relative polarity and refractive index values.

| Solvents | Relative polarity | Refractive index |
|---|---|---|
| Toluene | 0.099 | 1.49 |
| DMSO | 0.444 | 1.47 |
| DMF | 0.386 | 1.43 |
| Butanol | 0.389 | 1.39 |
| Isopropanol | 0.546 | 1.37 |
| Methanol | 0.762 | 1.32 |

**Table 2.** Thermal diffusivity values from the experimental data and literature corresponding to pure solvents.

| Solvents | Thermal diffusivity Solvent + β carotene× $10^{-6}$ $m^2$/sec | Thermal diffusivity of solvents (Literature Value) × $10^{-8}$ $m^2$/sec |
|---|---|---|
| Toluene | 3.59 | 8.73 |
| DMSO | 2.39 | 8.54 |
| DMF | 4.68 | 9.40 |
| Butanol | 4.53 | 6.55 |
| Isopropanol | 2.31 | 6.76 |
| Methanol | 4.61 | 9.8 |

**Table 3.** Thermal diffusivity values measured using thermal lens technique from literature.

| No | Sample | | Thermal Diffusivity | Ref |
|---|---|---|---|---|
| 1 | Neutral dye | | $8.78\times10^{-8}$ $m^2$/sec | [11] |
| | Neutral dye + different % of Ag nanosol | | $8.02 – 5.66\times10^{-8}$ $m^2$/sec | |
| | Neutral dye + different % of Au nanosol | | $6.88 – 4.36\times10^{-8}$ $m^2$/sec | |
| | Ag nanosol | | $5.05\times10^{-8}$ $m^2$/sec | |
| | Au nanosol | | $4.13\times10^{-8}$ $m^2$/sec | |
| 2 | Different aspect ratios of silver nanorods dispersed in water. | | $1.32 – 7.36\times10^{-3}$ $cm^2$/sec | [12] |
| 3 | Grapefruit oil | | $7.3\times10^{-4}$ $cm^2$/sec | [13] |
| | different concentration of Ag nanoparticles in grapefruit oil | | $7.6 – 13.3\times10^{-4}$ $cm^2$/sec | |
| 4 | Au in water | | $15.32\times10^{-4}$ $cm^2$/sec | [14] |
| | Au in ethylene glycol | | $10.47\times10^{-4}$ $cm^2$/sec | |
| | Au ethanol | | $9.52\times10^{-4}$ $cm^2$/sec | |
| 5 | Different concentrations of $TiO_2$ nanoparticles and nanorods in ethanol | | $8.5\times10^{-4} – 9.8\times10^{-4}$ $cm^2$/sec | [15] |
| 6 | Different shaped Au nanoparticles with different concentration | | | [16] |
| | Star-shaped | | $2.0153 – 3.5\times10^{-7}$ $m^2$/sec | |
| | Bean shaped | | $1.7086 – 2.9985\times10^{-7}$ $m^2$/sec | |
| | Spherical shaped | | $1.5219– 2.3757\times10^{-7}$ $m^2$/sec | |
| 7 | Rhodamine 6G in water | | $1.43\times10^{-3}$ $cm^2$/sec | [17] |
| | Rhodamine 6G with different concentrations of Ag | | $0.0861– 0.2912\times10^{-3}$ $cm^2$/sec | |
| 8 | Urchin-like gold nanofluid | | | [18] |
| | Particle size 55nm to 115nm | Water | $14.76– 14.34\times10^{-4}$ $cm^2$/sec | |
| | | EG | $9.83– 9.33\times10^{-4}$ $cm^2$/sec | |
| | | Ethanol | $9.05– 8.44\times10^{-4}$ $cm^2$/sec | |
| | Concentration 0.2 to 1 mg/ml | Water | $14.79– 15.11\times10^{-4}$ $cm^2$/sec | |
| | | EG | $9.87– 10.25\times10^{-4}$ $cm^2$/sec | |
| | | Ethanol | $9.09– 9.56\times10^{-4}$ $cm^2$/sec | |

 

| | | | |
|---|---|---|---|
| 9 | Basic Fuchsin dye | $12\times10^{-4}$ cm$^2$/sec | [19] |
| | Basic Fuchsin dye + Silver sol | $16\times10^{-4}$ cm$^2$/sec | |
| 10 | Au nanoparticles in different concentration | 1.23– $3.12\times10^{-3}$ cm$^2$/sec | [20] |
| 11 | Carbon quantum dots with different concentrations | 0.143– $0.0364\times10^{-7}$ m$^2$/sec | [10] |
| 12 | Silver nanoparticles of different sizes | 9.70– $16.19\times10^{-4}$ cm$^2$/sec | [21] |
| 13 | ZnO water nanofluids with different particle size and concentration | 0.6919– $1.464\times10^{-7}$ m$^2$/sec | [8] |
| 14 | ZnO Quantum dots with different concentration | 13.69– $5.99\times10^{-4}$ cm$^2$/sec | [22] |
| 15 | CdTe quantum dots in different sizes | 0.63– $0.17\times10^{-7}$ m$^2$/sec | [23] |

Thermal-optical properties of β-carotene dye in different solvents were analyzed by measuring their thermal diffusivity using a dual-beam mode mismatched thermal lens technique. The theoretical and experimental aspects of thermal lens was described in our previous publication [8,9,10]. It is one of the popular methods widely employed for measurements of thermal diffusivity with its advantages like simple experimental setup with a minimum requirement of the sample. Thermal diffusivity indicates the speed of heat transfer in the sample and it is an important parameter to analyze thermal transport performance and it correlates well with the thermal conductivity. The transient thermal lens signal was detected and the decay curve was fitted using a theoretical equation [8]. The thermal lens plot of β-carotene in selected solvents is shown in Figure 5. Table 2 presents the summary of thermal diffusivity values obtained from the experimental data and the literature values for pure solvents. The results show that the thermal diffusivity of beta-carotene solution is higher compared to pure solvents, leading to improved thermal transport properties. The de-localized pi electrons within the conjugate chain of β-carotene allow more effective heat transfer of thermal energy. The nonradiative relaxation of excited molecules is responsible for heat generation, which enhances thermal energy transfer. Table 3 shows the thermal diffusivity data taken from various literature obtained using the thermal lens technique, revealing the significant impact of β-carotene on heat transfer enhancement in selected solvents. Hence the present study has significant industrial applications, where the efficiency of heat transfer is essential for improving productivity.

## CONCLUSIONS

The present study revealed the solvent interaction on β-carotene dye. The solubility of β-carotene dye is not uniform, it is highest in the isopropanol. Due to the non-polar nature of β-carotene, the solubility of β-carotene depends upon the polarity nature of solvents. The thermal diffusivity properties of β-carotene shed light on the possibilities of using β-carotene as a cost-effective and reliable agent that can be produced on the industrial scale for a wide range of applications as optoelectronic devices.

## REFERENCES

1. Mohammad shahid, Shahid Islam, Faqueer Mohammad. Recent advancements in natural dye applications: a review. Journal of cleaner production, 2013;53:310-331p.
2. Shailendra Yadav, Kanha Singa Tiwari, Chitrasen Gupta. A brief review on natural dyes, pigments: recent advances and future perspectives. Results in Chemistry, 2023;5:100733.
3. Ludmila Bogacz Radomska, Joanna Harasym. β-carotene – properties and production methods. Food Quality and Safty.2018;2: 69-74p.
4. S Khangar, OP Chimankar, YS Tamgadge, RY Bakale. Ultrasonic and spectroscopic investigation of aqueous polyvinyl alcohol (PVA) solutions. RP Current Trends in Applied Science.2023;2: 78-83.
5. Navneet Singh. Synthesis of $SnO_2$ nanoparticles by sol-gel method and their characterization. RP Current Trends in Applied Sciences. 2023;2:30-33.
6. N A Norhisamudiam, N Sabani, M M Shamimin, N Juhari, S Shaari, M F Ahamad, N Zakaria.The effect of different solvents in natural dyes from Roselle(Hibiscus Sabdariffa) and Green Tea Leaves (Camellia Sinensis) for dye-sensitive solar cells. Journal of Physics: Conference series, 2020;1-10p.

 

7. Valentina Domenici, Donatella Ancora, Mario Cifelli, Andrea Serani, Carlo Alberto Veracini , Maurizio Zandomeneghi. extraction of pigment information from near UV-Visible absorption spectra of extra virgin olive oils. Journal of Agricultural and Food Chemistry.2014;62: 38.
8. Ramya M , Nideep T K, V P N Nampoori, Kailasnath M. particle size and concentration effect on thermal diffusivity of water- based ZnO nanofluid using dual beam thermal lens technique. Applied Physics B, 2019;125:1-9p.
9. Ramya M , Nideep T K, V P N Nampoori, Kailasnath M. Shape dependent heat transfer and nonlinear optical limiting characteristics of water stable ZnO nanofluid. Surface and Interfaces. 2021;26:10135.
10. K R Vijesh, U sony, M Ramya, S Mathew, VPN Nampoori, Sheenu Thomus. Concentratiom dependent variations of thermal diffusivity in highly fluorescent carbon dots using dual beam thermal lens technique. International Journal of Thermal Sciences. 2018;126:137-142.
11. Anitha Prakash, Bini P Pathrose, V. P. N Nampoori, P Radhakrishnan, A Mujeeb. Thermal diffusivity of neutral red dye using dual beam thermal lens technique: A comparison on the effect using nanopulsed laser ablated silver and gold nanoparticles. Physica E. 2019;107: 203-208.
12. Misha Hari, Santhi Ani Joseph, S Mathew, B Nithyaja, V P N Nampoori, P Radhakrishnan. Thermal diffusivity of rod shaped silver nanoparticles. International Journal of Thermal Science. 2013;64: 188-194.
13. Rafael Herrera-Aquino, Jose Luis Jimenez Perez, Delia Cristina Altamirano Juarez, Genavo Lopez Gamboa, Zormy Nacary, Correa Pacheco, Rigoberto Carbajal Valdez. Green synthesis of silver nanoparticles contained in centrifuged citrus oil and their thermal diffusivity study by using thermal lens technique. International Journal of Thermophysics. 2019;40:3.
14. J L Jimenez Perez, R Gutierrez Fuenttes, J F Sanchez Ramirez and A Cruz – Orea. Study of gold nanoparticles effect on thermal diffusivity of nanofluids based on various solvents by using thermal lens spectroscopy. The European Physical Journal Special topics. 2008; 153: 159-161.
15. J L Jimenez Perez, R Gutierrez Fuentes, R Sanchez Sosa, M G Zapata Torres, Zn Correa Pachoco, J F Sanchez Ramirez. Thermal diffusivity study of nanoparticles and nanorods of titanium dioxide ( $TiO_2$) and titanium dioxide coated with cadmium sulphide ( $TiO_2CdS$). Material Science in Semiconductor Processing.2015;37:62-67.
16. Jisha John, Lincy Thomas, B Rajeesh Kumar, Achamma Kurian, Sajan D George. Shape dependent heat transport through green synthesized gold nanofluids. Journal of Physics D: Applied Physics.2015;48: 335301.
17. Santhi Ani Joseph, Misha Hari, S Mathew, Gaurav Sharma, Soumya, V M Hadiya, P Radhakrishnan, V P N Nampoori. Thermal diffusivity og rhodamine 6G incorporated in silver nanofluid measured using mode matched thermal lens technique. Optics Communications.2010; 283:313-317.
18. Gerardo A Lopez Munoz, Jose Abraham, Baldevas Lopez, Jaime Ortega Lopez, Jose A Pescador Rojas, Jaime Santoyo Salzar. Thermal diffusivity measurement for urchin like gold nanofluids with different solvents, sizes and concentrations / shapes. Nanoexpress.2012;7:667.
19. Bini Pathrose, V P N Nampoori, P Radhakrishnan, H Sahira, A Mujeeb. Effect of femtosecond laser ablated silver nanoparticles in the thermo-optic properties of basic fuchsin dye. Optik.2016;127: 3684-3687.
20. Esmaeil Shahriari, Mohammad Moradi, Morteza Raisi. An experimental study of thermal diffusivity of Au nanoparticles: effect of concentration particle size. Journal of Theoretical and Applied Physics. 2016; 10: 259-263.
21. Reza Zamiri, B Z Azmi, E Shahriari, Kazim Naghavi, E Saion, Zahid Rizwan, M S Husain . Thermal diffusivity measurement of silver nanofluid by thermal lens technique. Journal of Laser Applications. 2011; 23:4.
22. Ramya M, Nideep T K, Meenakshi M Varier, V P N Nampoori, M Kailasnath. Concentration dependent thermo-optic properties of yellow emissive ZnO quantum dots , Material Research Express. 2019; 6: 126208.
23. T K Nideep, M Ramya, V P N Nampoori, M Kailasnath. The size dependent thermal diffusivity of water soluble CdTe quantum dots using dual beam thermal lens spectroscopy. Physica E. 2020.116:113724.

 