International Journal of Innovative Technology and Exploring Engineering (IJITEE)
ISSN: 2278-3075 (Online), Volume-8 Issue-10, August 2019

Enhanced Thermal Characteristics of NG Based Acetamide Composites

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Abstract*: Fatty acids are a distinguished category of phase change materials (PCM). However, their inferior thermal conductivity value restricts their potential for thermal energy storage system. Carbonaceous nanomaterials have emerged as promising thermal conductivity enhancer materials for organic PCMs. The present study focuses on preparing a novel PCM nanocomposite comprising of small amount of nanographite (NG) in molten acetamide, an organic PCM, for elevation of the thermal characteristics and examining the trend of the nanocomposite through the course of charging / discharging process. These PCM-nanocomposites are prepared by dispersing NG in molten acetamide with weight fractions of 0.1, 0.2, 0.3, 0.4 and 0.5 %. The scanning electronic microscopic (SEM) analysis was conducted for the characterization of PCM nanocomposite. The energy storage behaviour of the prepared nanocomposites were analyzed with the help of differential scanning calorimeter instruments, which showed that there is no observable variation in the melting point of the nanocomposite, and a decline in the latent heat values. Furthermore, thermal conductivity trend of the nanocomposites caused by NG addition was investigated, which indicated enhancement of thermal conductivity with increasing NG concentration. Further, nanocomposites with a 0.4 wt. % of NG, displayed appreciable increase in rate of heat transfer, reducing melting time and solidification time by 48 and 47 %, respectively. The prepared PCM nanocomposites displayed superior heat transfer trend, permitting substantial thermal energy storage.

***Index Terms*: Acetamide, Energy storage, Heat transfer, Nanographite, Phase change material**

I. INTRODUCTION

Solar energy as a renewable energy source shows a lot of promise as it is clean, free, and abundant. However, its extensive utilization is hindered by the intermittent solar irradiation. A promising solution of this time related limitation is an efficient and a reliable energy storage system. Latent heat energy storage (LHES) methods utilizing PCM has garnered worldwide attention, courtesy of their exemplary advantages like constant temperature at phase change during heat storage and retrieval and significant energy storage density. [1-3]. Several PCMs comprising of paraffin, fatty acids (organic) and salt hydrates (inorganic) have been examined for their employability in TES applications [4, 5]. Among various organic PCMs studied by the researchers, fatty acids have emerged as promising candidates for application in TES systems pertaining to their congruent melting, wider melting temperatures range, and higher heat capacity, with almost negligible sub-cooling, non-toxicity, low cost, low volumetric change and favorable chemical and thermal stability [6-10]. Still, poor solar harvesting efficiency and low thermal conductivity and are the key challenges that hinder the utilization of fatty acids in practical applications. Acetamide is one of the promising fatty acid based PCM which demonstrate desirable thermal properties. The melting enthalpy per unit volume of acetamide at phase change is large even though it being an organic PCM. It also exhibits fine chemical and thermal stability over hundreds of repeated charging/discharging cycles. This property is beneficial for its long term application in solar based energy storage.

Although acetamide being an organic PCM, at phase change it exhibits high volumetric enthalpy. Also, acetamide remains thermally and chemically stable over several hundred charging / discharging cycles. However, its potential application in energy storage is limited by its inferior thermal conductivity, despite several favorable attributes [11]. Incorporation of nanoparticles in PCM is a long term popular method for amplifying the thermal conductivity of PCM [12]. The behavior of TES systems using nanocomposites with amplified thermal conductivity have been examined on several combinations of the PCM and nano-additives focusing on heat transfer during melting/solidification.. Among the various nano-additives examined, carbonaceous nanomaterials exhibited high thermal conductivity with the added advantage of low density [13-15]. For example, experimental analysis of adding carbon nanomaterials in paraffin exhibited that as the concentration of nanocarbon additives increased, the suspension also experienced a rise in thermal conductivity [16]. An investigation by Fan *et al.* on paraffin PCM and various carbon based additives was conducted. The outcome of the experiments concluded that the nanofillers reduces the phase transition enthalpies while the keeping phase transition temperature constant. The increasing concentration of the nano-additives caused the thermal conductivity amplification of the nanocomposites [17]. Another study examined the thermal behavior of graphene oxide embedded Myristic acid [18]. The experimental results indicated a considerable amplification the heat transfer rate of the nanocomposite. Recently published article from our research group also showed that embedding of nanographite into organic PCM, $MgCl_2.6H_2O$, remarkably enhances heat transfer rate and thermal conductivity [19].

Manuscript published on 30 August 2019.

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All of these approaches proves that the effective thermal conductivity for a PCM could be remarkably boosted by a carbon filler material. Consequently, carbonaceous nano-addtitives in PCM nanocomposites shows a lot of promise. In the present work, the samples of acetamide nanocomposites were prepared with different concentrations of NG. The current study intend to find the effect of NG concentration on thermal characteristics of the acetamide based nanocomposites.

II. EXPERIMENTAL SECTION

A. Materials and Sample Preparation

The pristine PCM, acetamide (78°C melting point, 99% pure), was purchased from Central Drug House, India. Nano Graphite (NG) with 100-200 nm average diameter of were purchased from Reinste, Germany. 10g of PCM was poured in a glass vial and melted on IKA RCT basic hot plate. NGs, as thermally conductive nanofillers, of the desired amount were dispersed into the molten PCM, and the mixture was subjected to aggresive ultrasonic stirring by a magnetic hot-plate at a temperature 90ºC for 30 minutes, which was then followed by 2 hours of ultra-sonication (Telesonic, Ultrasonics Hot Plate Stirrer). Finally, the mixture was allowed to solidify at ambient temperature. The PCM-nanocomposite samples with small loadings of the NGs of 0.1, 0.2, 0.3, 0.4 and 0.5 wt. % were formed along with a pristine acetamide sample for reference. The images of the prepared samples are shown in figure 1.with the increase in mass fractions of MC added to PCM.

Fig 1. Photograph of pristine PCM (acetamide) and PCM-NG composite samples having different NG concentrations (0.1, 0.2, 0.3, 0.4 and 0.5 wt. %) of NG.

B. Characterization techniques and Experimental Setup

The raw NG, the pristine acetamide and the nanocomposite samples were characterized microscopically via scanning electron microscope (SEM) instrument (Zeiss EVO 18). The size of the as-received NG powder and their dispersion in the composite was observed using the SEM. A conventional heating setup is used for the analysis of melting and solidification (heat transfer) behaviour of pristine PCM and nanocomposite samples as displayed in figure 2 a. The setup has a hot plate with a temperature sensor attached and the temperature range of the setup is 30°C-400°C. For the melting experiments, the rate of increase in temperature of various samples was kept at 5ºC/min, while for the solidification experiments, the natural cooling was adopted. Thermal conductivity was calculated by a thermal conductivity meter (Transient Hot Bridge THB6N43 from Linseis), an instrument with hot disk technique as its basis as shown in figure 2 b. The material's thermal conductivity was measured keeping the temperature sensor in between two samples kept parallel ensuring that the material and the sensor have proper contact. The selection of the probe for the thermal conductivity measurement was done on the basis of range and type of the sample. The uncertainty range of the measurements was within ±1%. Testing deviation of each thermocouple in hot plate setup is 2%. The total uncertainty of the experiment can be given as

$$U_C = \sqrt{u_T^2 + {u_T}^2} \times 100 \qquad (1)$$

Where U_C is the uncertainty and U_T is the deviation in the thermocouple measurement. This equation gives the uncertainty as 2.83% which ensures the credibility of the experimental values.

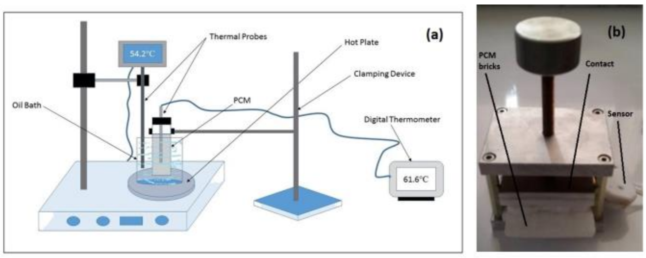

Fig 2. (a) Pictorial view of conventional heating setup. (b) Image of Thermal Conductivity Meter

III. RESULTS AND DISCUSSIONS

A. Characterization

SEM micrographs of the pure PCM, NG and nanocomposites used in the present work are displayed in Fig. 3a, 3b and 3c, respectively. The SEM micrograph of the NG is presented in Fig. 3a, which revealing 100-200 size distribution, which revealed good agreement supplier specification. The SEM images of pristine PCM nanocomposites are displayed in Fig. 3b and 3c, respectively, which are a clear indication of proper dispersion of NG in nanocomposites.

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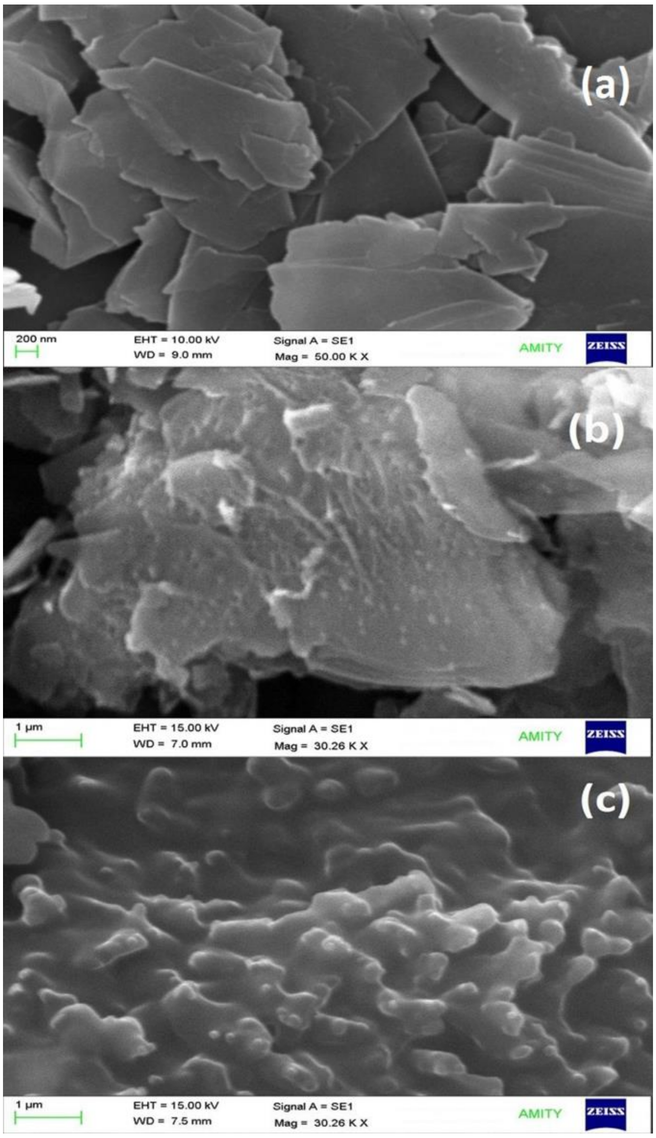

Fig 3. SEM images depicting morphological view of (a) nanographite (NG), (b) pure PCM (acetamide) and (c) PCM-NG composite at a NG concentration of 0.2 wt. %.

B. Thermal conductivity

The data for thermal conductivity for pristine PCM and nanocomposite samples were obtained in solid phase at 25 °C. The measurement of each sample was repeated 3 times and average values of the measurement are presented in the data herein with less than 1% standard deviation. The thermal conductivity values measured at ambient temperature (25 °C) in relation to the concentration NG is displayed in Figure 4. The proportion of enhancement in nanocomposites' thermal conductivity has an almost linear relation to NG concentration.

An enhancement of 190 % was observed for the 0.5 wt. % nanocomposite sample. Our results are similar to that reported by *Li* [20], where paraffin/NG composites achieved 0.365 W/m-K thermal conductivity, corresponding to a 188% enhancement from the pristine paraffin (0.1264 W/m-K). Such an exemplary behaviour of the NG powder was ascribed to its innate high thermal conductivity and immensely reduced thermal interface resistance [21]. Kardam *et al.* [22], observed almost similar enhancement of about 271% in a PCM's thermal conductivity by the dispersing 0.5 wt. % NG. An amplification of 264% in thermal conductivity was also observed by Narayanan et al. [23] by embedding 0.5 wt. % NG powder in paraffin.

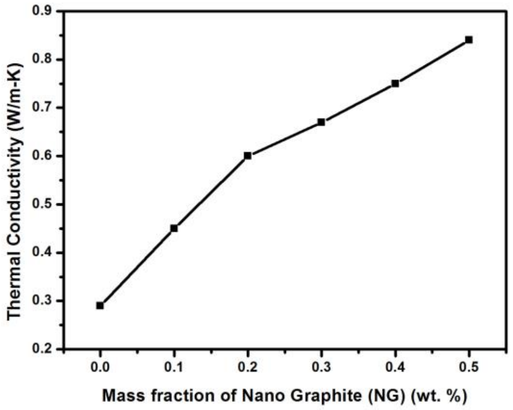

Fig 4. Thermal Conductivity Variation Of The Acetamide Nanocomposites.

C. Heat Transfer

Analysis of thermal behavior of the PCM and nanocomposites was carried out by conventional melting and freezing experiments. The experiments were conducted with pure PCM followed by nanocomposites. The melting graphs of the pristine PCM and nanocomposites for various concentrations of 0.1, 0.2, 0.3 and 0.4 wt. % of NG powder) is displayed in Figure 6. The samples were kept at ambient temperature at the start of melting experiments. At approximately 50 minutes from the initial stage, phase change started in pristine PCM. The variation in NG concentration from 0.1wt. % to 0.4 wt. %, caused a drastic decrease in the melting duration of the nanocomposites was achieved. The melting duration of 27 min was achieved for 0.4 wt. % concentration of NG concentration corresponding to 48% reduction in melting duration in comparison to pure PCM.

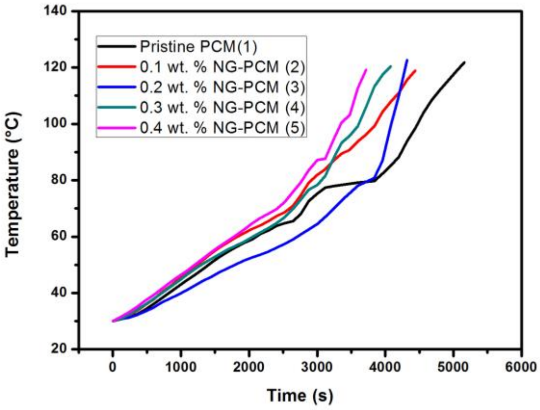

Fig 6. Melting characteristics of pure acetamide and its nanocomposites at different weight concentration of NGs.

Further, analysis of freezing behaviour of the pure PCM and its composites was also done, and the outcome are presented in figure 7.

The initial temperature of approximately 120°C was recorded for pure PCM and nanocomposites for solidification experiments. For all the samples, decline of temperature is evident from figure 7, under natural cooling process which continued up to their respective solidification temperature. Solidification process also exhibited a similar trend as melting, i.e. reduction in solidification duration with increase in NG concentration of NG (0.1 to 0.4 wt. %). In comparison to pure PCM, 0.4 wt. % nanocomposite exhibited 47% reduction in solidification duration.

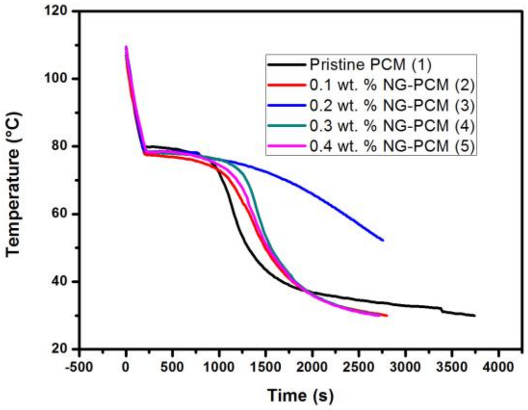

Fig 7. Solidification characteristics of pure acetamide and its nanocomposites at different weight concentration of NGs.

The above results establish that the prepared nanocomposites possess higher heat transfer rate. It can lead to the upgradation of energy utilization efficiency of the PCM while thermal charging/discharging. Similar results were also obtained with NG dispersion in magnesium nitrate hexahydrate [22].

IV. CONCLUSION

Nanocomposites based on Acetamide have been successfully prepared for their potential application in energy storage. The acetamide nanocomposites exhibited remarkable thermal conductivity enhancement by adding highly conductive NG powder. Thermal conduction was amplified by 190% with 0.5 wt. % of NG powder in PCM. This extraordinary performance of the NG powder was ascribed to its innate high thermal conductivity and immensely reduced thermal interface resistance. DSC analysis of composites revealed that the NG concentration does not affect melting point of the nanocomposites, whereas it shows inverse proportionality to their latent heat of fusion. Charging/discharging experiments on composites revealed increasing rate of heat transfer with increasing NG concentration. An enhancement in the charging/discharging rate of 48% and 47%, respectively, were measured in the melting/ freezing experiments using conventional heating set up. These novel nanocomposites can lead to an alternative, environmentally friendly and economical solution to the rising thermal energy storage demands.

ACKNOWLEDGMENT

Authors are in gratitude of Dr. Ashok K Chauhan, President and founder of Amity University, for his perpetual encouragement, motivation and guidance. The SEM characterization were carried out with the kind support of Mr. Shiv Kumar.

REFERENCES

1. B Zalba, JM Marín, LF Cabeza, H Mehling, “Review on thermal energy storage with phase change: materials, heat transfer analysis and applications.” Applied thermal engineering, 23(3), 2003, pp.251-283.
2. P Verma P, SK Singal, “Review of mathematical modeling on latent heat thermal energy storage systems using phase-change material.” Renewable and Sustainable Energy Reviews, 12(4), 2008, pp.999-1031.
3. AF Regin, SC Solanki, JS Saini, “Heat transfer characteristics of thermal energy storage system using PCM capsules: a review.” Renewable and Sustainable Energy Reviews 12(9), 2008, pp.2438-2458.
4. A Sharma, VV Tyagi, CR Chen, D Buddhi, “Review on thermal energy storage with phase change materials and applications.” Renewable and Sustainable energy reviews, 13(2), 2009, pp.318-345.
5. MM Farid, AM Khudhair, SAK Razack, S Al-Hallaj S, “A review on phase change energy storage: materials and applications.” Energy conversion and management, 45(9), 2004, pp.1597-1615.
6. D Feldman, MM Shapiro, D Banu, CJ Fuks, “Fatty acids and their mixtures as phase-change materials for thermal energy storage.” Solar energy materials, 18(3-4), 1989, pp.201-216.
7. A Hasan, AA Sayigh, “Some fatty acids as phase-change thermal energy storage materials.” Renewable energy, 4(1), 1994, 69-76.
8. ASK Kaygusuz, “Thermal energy storage system using some fatty acids as latent heat energy storage materials.” Energy Sources, 23(3), 2001, pp.275-285.
9. A Sarı, “Thermal reliability test of some fatty acids as PCMs used for solar thermal latent heat storage applications.” Energy Conversion and Management, 44(14), 2003, pp.2277-2287.
10. D Rozanna, TG Chuah, A Salmiah, TS Choong, M Sa'arim, “Fatty acids as phase change materials (PCMs) for thermal energy storage: a review.” International Journal of Green Energy, 1(4), 2005, pp.495-513.
11. A Sharma, SD Sharma, D Buddhi, “Accelerated thermal cycle test of acetamide, stearic acid and paraffin wax for solar thermal latent heat storage applications.” Energy Conversion and Management 43(14), 2002, pp.19-1930.
12. A Yadav, B Barman, V Kumar, A Kardam, SS Narayanan, A Verma, D Madhwal, P Shukla, VK Jain, “A Review on Thermophysical Properties of Nanoparticle-Enhanced Phase Change Materials for Thermal Energy Storage.” In Recent Trends in Materials and Devices, 2017, (pp. 37-47). Springer International Publishing.
13. CY Zhao, ZG Wu, “Heat transfer enhancement of high temperature thermal energy storage using metal foams and expanded graphite.” Solar Energy Materials and Solar Cells, 95(2), 2011, pp. 636-643.
14. AA Ranjbar, S Kashani, SF Hosseinizadeh, M Ghanbarpour, “Numerical heat transfer studies of a latent heat storage system containing nano-enhanced phase change material.” Thermal science, 15(1), 2011, pp.169-181.
15. DH Choi, J Lee, H Hong, YT Kang, “Thermal conductivity and heat transfer performance enhancement of phase change materials (PCM) containing carbon additives for heat storage application.” International journal of refrigeration, 42, 2014, pp.112-120.
16. ZT Yu, X Fang, LW Fan, X Wang, YQ Xiao, Y Zeng, X Xu, YC Hu, KF Cen, “Increased thermal conductivity of liquid paraffin-based suspensions in the presence of carbon nano-additives of various sizes and shapes.” Carbon, 53, 2013, pp.277-285.
17. LW Fan, X Fang, X Wang, Y Zeng, YQ Xiao, ZT Yu, X Xu, YC Hu, KF Cen, “Effects of various carbon nanofillers on the thermal conductivity and energy storage properties of paraffin-based nanocomposite phase change materials.” Applied Energy, 110, 2013, pp.163-172.
18. A Yadav, B Barman, V Kumar, A Kardam, SS Narayanan, A Verma, D Madhwal, P Shukla, VK Jain, “Solar thermal charging properties of graphene oxide embedded myristic acid composites phase change material.” In AIP Conference Proceedings 1731(1), 2016 p. 030030). AIP Publishing.

19. A Yadav, B Barman, A Kardam, SS Narayanan, A Verma, VK Jain, “Thermal properties of nano-graphite-embedded magnesium chloride hexahydrate phase change composites.” Energy & Environment, 28(7), 2017, pp.651-660.
20. M Li, “A nano-graphite/paraffin phase change material with high thermal conductivity.” Applied energy, 106, 2013, pp.25-30.
21. F Yavari, HR Fard, K Pashayi, MA Rafiee, A Zamiri, Z Yu, R Ozisik, T Borca-Tasciuc, N Koratkar, “Enhanced thermal conductivity in a nanostructured phase change composite due to low concentration graphene additives.” The Journal of Physical Chemistry C, 115(17), 2011 pp.8753-8758.
22. A Kardam, SS Narayanan, N Bhardwaj, D Madhwal, P Shukla, A Verma, VK Jain, “Ultrafast thermal charging of inorganic nano-phase change material composites for solar thermal energy storage. RSC Advances, 5(70), 2015, pp.56541-56548.
23. SS Narayanan, A Kardam, V Kumar, N Bhardwaj, D Madhwal, P Shukla, VK Jain, “Development of sunlight-driven eutectic phase change material nanocomposite for applications in solar water heating.” Resource-Efficient Technologies, 3(3), 2017, pp.272-279.
24. AR Akhiani, M Mehrali, S Tahan Latibari, M Mehrali, TMI Mahlia, E Sadeghinezhad, HSC Metselaar, “One-step preparation of form-stable phase change material through self-assembly of fatty acid and graphene.” The Journal of Physical Chemistry C, 119(40), 2015, pp.22787-22796.
25. Z Huang, X Gao, T Xu, Y Fang, & Z Zhang, “Thermal property measurement and heat storage analysis of LiNO3/KCl–expanded graphite composite phase change material.” Applied Energy, 115, 2015, pp.265-271.

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Prof. (Dr.) V.K. Jain has done his Ph.D. in Solid State Physics from IIT Delhi. He joined SSPL in 1972 and worked as Director Grade scientist up to 2003. He is currently a Distinguished Professor and Scientist at Amity University, Noida. He was head of the silicon devices and Micro Electro Mechanical Systems (MEMS) division and developed many new technologies. His result of electro-luminescence in porous silicon was considered as the first International observation and it was reported as NEWS by Photonics spectra USA, Electronics Asia. Dr. Jain was also associated with the National Programme on Smart materials & MEMS technology from the beginning. He has published more than 160 papers in National International journals, edited a few books and has filed 32 patents. He has received the Technology award in 2002. He worked as Emeritus Scientist of CSIR at NPL up to June 2007.

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REFERENCES

1. G. O. Young, “Synthetic structure of industrial plastics (Book style with paper title and editor),” in Plastics, 2nd ed. vol. 3, J. Peters, Ed. New York: McGraw-Hill, 1964, pp. 15–64.
2. W.-K. Chen, Linear Networks and Systems (Book style). Belmont, CA: Wadsworth, 1993, pp. 123–135.
3. H. Poor, An Introduction to Signal Detection and Estimation. New York: Springer-Verlag, 1985, ch. 4.
4. B. Smith, “An approach to graphs of linear forms (Unpublished work style),” unpublished.
5. E. H. Miller, “A note on reflector arrays (Periodical style—Accepted for publication),” IEEE Trans. Antennas Propagat., to be published.
6. J. Wang, “Fundamentals of erbium-doped fiber amplifiers arrays (Periodical style—Submitted for publication),” IEEE J. Quantum Electron., submitted for publication.
7. C. J. Kaufman, Rocky Mountain Research Lab., Boulder, CO, private communication, May 1995.
8. Y. Yorozu, M. Hirano, K. Oka, and Y. Tagawa, “Electron spectroscopy studies on magneto-optical media and plastic substrate interfaces(Translation Journals style),” IEEE Transl. J. Magn.Jpn., vol. 2, Aug. 1987, pp. 740–741 [Dig. 9th Annu. Conf. Magnetics Japan, 1982, p. 301].
9. M. Young, The Techincal Writers Handbook. Mill Valley, CA: University Science, 1989.
10. (Basic Book/Monograph Online Sources) J. K. Author. (year, month, day). Title (edition) [Type of medium]. Volume(issue). Available: http://www.(URL)
11. J. Jones. (1991, May 10). Networks (2nd ed.) [Online]. Available: http://www.atm.com
12. (Journal Online Sources style) K. Author. (year, month). Title. Journal [Type of medium]. Volume(issue), paging if given. Available: http://www.(URL)