RESEARCH ARTICLE

An investigation of carbon nanotubes on shear stress, thermal conductivity and the viscosity of Nanofluids

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ARTICLE INFO

Article History:
Received 2020-04-29
Accepted 2020-07-14
Published 2020-10-01

Keywords:
Multi-walled carbon nanotubes (MWCNT)
Nanofluids
Surfactant
Thermal Conductivity
Sodium dodecyl benzene sulfate

ABSTRACT

The Nanofluid includes suspensions containing nanoparticles, which are dispersed in the base fluid homogeneously. In this study, nanoparticles called multi-walled carbon nanotubes (MWCNT) were dispersed in a pure water-based fluid. The shape, size, and arrangement of carbon nanotubes were displayed by the transmittance electron microscope (TEM) and scanning electron microscope (SEM) techniques. The thermal conductivity and viscosity of the resulting nanofluid were measured experimentally. The carbon nanotubes within the nanofluid were stabilized using Sodium dodecyl benzene sulphate. The effect of carbon nanotubes on shear stress, thermal conductivity and viscosity of fluids has investigated. The results showed that at 308K the thermal conductivity was increased from 0.6 to 0.94 w/m.ºC with an increase in the volumetric concentration of MWCNTs from 0 to 0.015%. And the thermal conductivity was increased from 0.74 to 0.94 w/m.ºC with increase in temperature from 298 to 308K. The shear stress was increased from 10.8 to 11.9 N/m2 at 298K by increase in the volumetric concentration of MWCNTs from 0 to 0.015% and it was reduced from 11.9 to 9.2 N/m2 with enhance in temperature from 298 to 308K, respectively.

How to cite this article
*Shokri A. An investigation of carbon nanotubes on shear stress, thermal conductivity and the viscosity of Nanofluids. J. Nanoanalysis., 2020; 7(4): -7. DOI: 10.22034/jna.***.*

INTRODUCTION

Traditional fluids used in heat transfer have a low thermal conductivity; But Nano particles increase the thermal conductivity of the fluid due to their high conductivity by distribution in the base fluid. Nanofluids are a new group of fluids that are able to transfer heat and made by dispersing particles in nanometer sizes in conventional fluids to increase thermal conductivity and improve the heat transfer performance. Nanofluids obtained from the distribution of nanoparticle in ordinary fluids that are a new production of potential fluids in industrial uses. The used particle size in nanofluids is from 1 nm to 100 nm. These particles are made of metal particles such as copper (Cu), silver (Silver) or metal oxides like aluminum oxide (Al_2O_3) and copper oxide (CuO) [1]. Due to problems with the use of traditional fluids and even micro fluids, such as sedimentation, blocking of pipes, erosion and enhancing pressure drop in the flow channel, researchers have turned to nanofluids. In 1993, the idea of nanofluids was introduced by Choi and Jeff Eastman, and in fact a new look at solid nanofluid suspension with nano particles. In addition, due to the small size of the particles, the corrosion, impurities and pressure drop problems were mainly decreased and the stability of the fluids against sedimentation was significantly upgraded [2]. Nanofluids generally have high thermal conductivity and therefore high heat transfer rates. Nanofluids are made by distributing particles in nanometer sizes in conventional heat transfer fluids to enhance thermal conductivity and improve heat transfer performance.

The Carbon nanotubes (CNTs) are comparatively novel materials that have exceptional features comprising great elasticity and good thermal conductivity. Therefore, via dissolving CNTs into a liquid medium like ethylene glycol, water or engine oil, its transport and thermal features can be increased. The conventional

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approaches of heat transfer have been changed with novel methods because of advances in new techniques. So, beginning and improving nanofluids can be investigated which was first presented by Choi [3]. The carbon nanotubes have major significance between nanoparticles based on non-metal. These properties are originated from exceptional geometry of the carbon nanotubes and high thermal conductivity of carbon. The mentioned tubes are cylinder-shaped with either a multi walled or single walled, their length is not further than a few micrometers and usually their diameter is a few nanometers, therefore they are among the materials with high aspect ratios. The Synthesis of the mentioned nano tubes performed over several techniques and approach that cannot be explained in this project [4].

The investigation of dynamic viscosity of nanofluids composed of MWCNT and engine lubricant for nanoparticles with the weight concentration of 0% to 0.5% was accomplished by Ettefaghi et al. [5]. They distinguished that in small concentrations of nanoparticles in the solution, the fluid viscosity drops with increase in the extent of nanoparticles, but the fluid viscosity rises with growing the nanoparticle concentration at high concentrations of nanoparticle. In addition, they recognized that the viscosity was dropped at low concentrations of nanoparticles due to the insertion of them between the layers of lubricant, simplifying the movement of the mentioned layers at laminar stream circumstances. The nanoparticles are agglomerated with increase in their concentration, and subsequently delaying the movement of the lubricant layers. But conflicting to these finding, Segal et al. [6] perceived that by adding the magnetite nanoparticles to transformer oil the viscosity was changed slightly.

Some parameters including different methods to generate nanoparticles and the methods of dissolving them in the base fluid can be appraised as the reasons for the real strange performance of nanofluid. Besides, the blend temperature shows a major role; therefore, the nanofluid was destroyed at higher temperatures. A large number of experimental works are performed to forecast the nanofluid features such as density, electrical and thermal conductivity, and viscosity at various concentrations and temperatures. These preferred experimental results can be used in real industrial presentations with by-pass some deviations of numerical results [7–10].

There are several ways to increase the thermal conductivity of fluids by dispersing nanofluid or micro-sized particles. If solid particles have a higher thermal conductivity than the base fluid, the thermal conductivity of the fluid will increase with the addition of particles with the mentioned dimensions [1]. Thermal conductivity and viscosity of such fluids will play a vital role in the development of energy efficiency of heat conduction equipment. Therefore, nanofluid technology is a new challenge in the field of thermal conductivity, thermal temperatures, or microscopic suspensions [11-12].

Therefore, in this project the MWCNTs have been made and mixed with deionized water to form nanofluids and their abilities such as thermal conductivity, viscosity, and shear stress were investigated. In addition, the effect of different concentration of MWCNTs on shear stress, thermal conductivity and nanofluide viscosity at different temperatures studied.

EXPERIMENTAL

Materials and apparatus

All the supplied chemicals in this project such as Sodium dodecyl benzene sulfate were of analytical grade and operated as received without any further sanitization. The MWCNTs (d=30nm, $\rho = 2.61\ \frac{gr}{cm^3}$, $l = 1 - 10\mu m$) were used.

The ultrasonic bath Struers Metason 200HT model, Sartorius CP225D digital scale with the precision of 5×10^{-5} , Brookfield Viscometer LV DV-II model, thermal conductivity analyzer KD2-probe Lab teach LSB- 0155, were used in this project.

Fig. 1 shows a Brookfield Viscometer connected to a temperature control with a computer to control the temperature.

The spindle was used to measure viscosity and calibrated by standard Brookfield viscosity fluids. This Viscometer includes a sample chamber whose temperature is carefully controlled by the temperature control bath and the temperature sensor. The temperature inside the sample chamber was showed by temperature sensor during viscosity measurement. Spindle types and speeds are selected so that the rotational torque values are within the specified range.The temperature of the used bath controlled in the range of 298 to 308K through the system.

In order to balance the temperature of the nanofluids with the temperature of the bath controlling the temperature, the nanofluids were

Fig. 1. the Brookfield Viscometer and its connection to thermo bath.

placed inside the sample measuring chamber for 20 minutes before measurement.

Preparation of nanofluid

Nanofluids containing MWCNTs were prepared in volumetric concentrations of 0.0015%, 0.0045%, 0.0075% and 0.015% in water-based fluid. Related amounts of sodium dodecyl benzene sulfate surfactant (SDBS) and nanotubes were weighted based on the reference fraction. The Surfactant was used to establish the thermodynamic stability of carbon nanotubes within the nanofluid. The blend exposed to the ultrasonic water bath to increase the dispersion, acquire a homogenous nanofluid, and disperse the nanoparticles into the base fluid. It should be noted that the basic fluid containing SDBS surfactant was used to homogenize nanofluids containing carbon nanotubes.

The nanofluids were Stirred and shacked properly during the sonic process. The solution was mixed to homogenize carbon nanotubes before and during the sonic process. The required time for a sonic bath to disperse carbon nanotubes was three hours. Using SDBS surfactant in the proportion of 25% by weight of nanoparticles, 50 cc of solution with concentrations of 0.0015% and 0.0045% and 0.0075% and 0.015% was made. It was placed in an ultrasonic device for 10 minutes on a regular basis then it was removed from the device and stirred for 50 minutes with regular hand movements. This operation repeated for three hours to achieve the desired result. Throughout ultra-sonication, the temperature of bath preserved about 25±5 °C. Some surfactants such as Sodium dodecyl sulfate (SDS) and SDBS were used for MWCNT nanofluids and water base fluid by Wusiman et al [13], and the SDBS had better efficiency in thermal conductivity improvement than SDS. They attained a 2.8% advance in SDBS surfactant at 0.5% mass fraction compared to distilled water.

The TEM and SEM images and characterization of MWCNTs

The synthesis of nanofluid was described in the previous section. In this project, the nanoparticles were dispersed in deionized water. The homogenization and stirring in the processes of MWCNTs synthesize can achieve some features such as shearing, great impact onto the wall, and creation of robust cavitation in the liquid. Therefore, the agglomerated particles can be broken and stable homogeneous nanofluids were produced [14]. The MWCNTs were imaged by TEM and SEM techniques. The shape, size, and arrangement of carbon nanotubes were displayed by the techniques. The TEM images of the dried MWCNTs were presented at Fig. 2, where it can be perceived that after homogenization the nanoparticles dimensions are near to the dimensions introduced by the manufacturer. However, in our future works the size distribution profile by a DLS (Direct Light Scattering) method before and after the homogenization will be explored.

The full characterization of MWCNTs were presented as the following: specific surface area(BET) at 280 m^2/gr, the length at 10 μm, diameter at 10 to 30 nm and thermal conductivity at 1500 W/m°C.

In this project, thermal conductivity and viscosity of nanofluids containing water and carbon

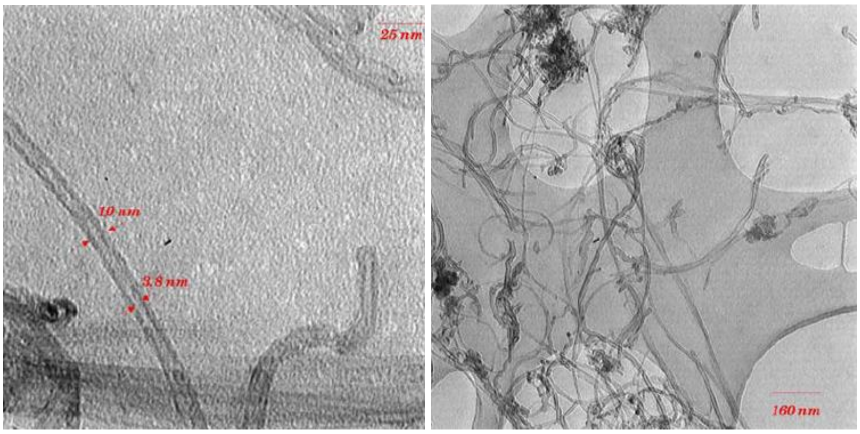

Fig. 2. the TEM images of MWCNTs.

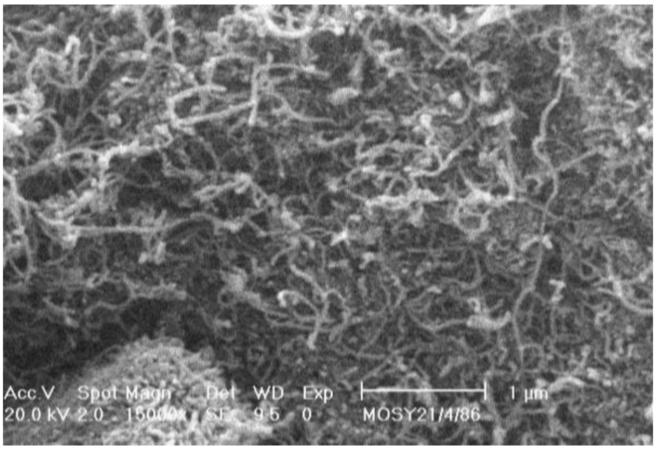

Fig. 3. the SEM image of MWCNTs.

nanotubes have been measured at three temperatures of 298, 303 and 308K. In these measurements, in addition to the effect of temperature, the effect of nanoparticle concentration was also investigated. In order to be accurate, at first, the measurement was performed at 298K and then the control bath was set at other temperatures, and the results were obtained.

RESULT AND DISCUSSION

Influence of temperature on thermal conductivity of nanofluids

The literature review revealed that many variables such as the concentration of nanoparticles, shape and size of the dispersed nanoparticles, volume fraction, the temperature of the nanofluids, and the spreading of the dispersed nanoparticles could influence the thermal characteristics of the nanofluids. The mentioned variables have been the main research field in studying heat transfer phenomena and other subjects in nanofluids. Chen and Xie, investigated the MWCNTs, and water as the base liquid with Cationic Gemini for surfactant [15] in the temperature range between 5 to 65 ^{o}C and they gained an improvement in thermal conductivity from 5.6 to 34% at a mass fraction of 0.6%wt. A functionalized MWCNT in the combination of Ethylene Glycol and water was studied by Singh et al [16], and the thermal conductivity was increased to 72% at 0.4%wt of mass fraction. Indhuja et al [17] employed Arabic gum as surfactant to inspect the impacts of temperature and mass fraction in MWCNT nanofluids and an improvement among 3.2 and 33% were stated.

According to Fig. 4, it is quite clear that with increase in temperature, the thermal conductivity of nanofluids containing MWCNTs was increased. This increase is greater in the case of nanofluids with higher concentrations of nanoparticles. In high concentration of MWCNTs in the water-based fluid, the slope of the graph was increased. Based on the studies of Meyer et al [18], the thermal conductivity of MWCNT nanofluids with a water base fluid was increased about 8% at 2.6%wt.

As the concentration of nanoparticles increases, the thermal conductivity of nanofluids increases. Of course, this increase in thermal conductivity is greater at higher temperatures. Fig. 4 shows the effect of the MWCNTs concentration on the thermal conductivity of the water-based fluid at three different temperatures. As shown in this diagram, the thermal conductivity is higher than the other two graphs in terms of the concentration of nanoparticles at 298K. The results of the present study are in agreement with the findings of previous researchers, for example, Mare et al [19] explored MWCNTs and deionized water, and SDBS surfactant was used between 0.008 to 0.9% of volume fractions at 20 and 46 °C, thus the thermal conductivity was achieved between 5 to 45%.

In the present work, at 308K the thermal conductivity was increased from 0.6 to 0.94 w/m. °C at the volumetric concentration of MWCNTs from 0 to 0.015%, respectively. And the thermal conductivity was increased from 0.74 to 0.94 w/m. °C with increase in temperature from 298 to 308K. In the scale of Figs.4-6, M represent for MWCNTs.

The influence of temperature on the viscosity of nanofluid

The effect of temperature on nanofluid viscosity containing several MWNTs was investigated. The results showed that as the temperature increased, the viscosity of nanofluids decreased. Fig. 5 shows a decrease in the viscosity of nanofluids containing MWNTs with increasing temperature. As can be seen, the decreasing trend of nanofluids viscosity with increasing temperature is almost linear. With

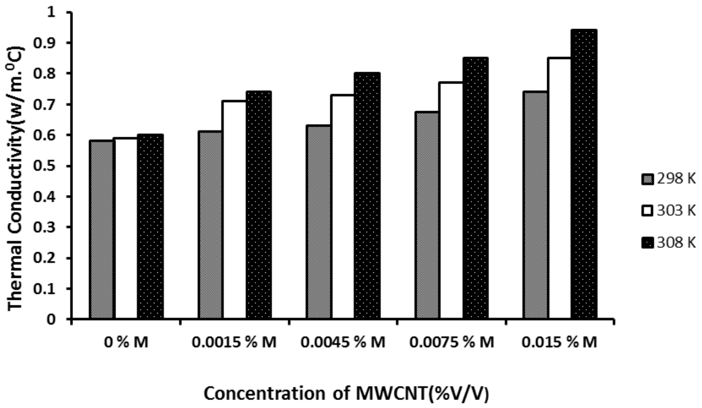

Fig. 4. effect of MWCNTs concentration on thermal conductivity of nanofluids at different temperatures.

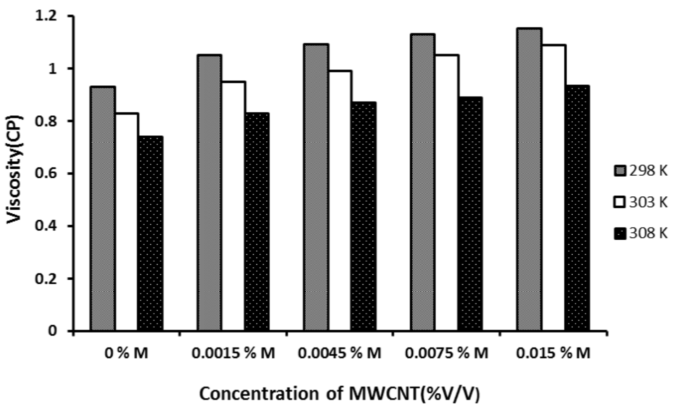

Fig. 5. effect of MWCNTs concentration on the viscosity of nanofluids at different temperatures.

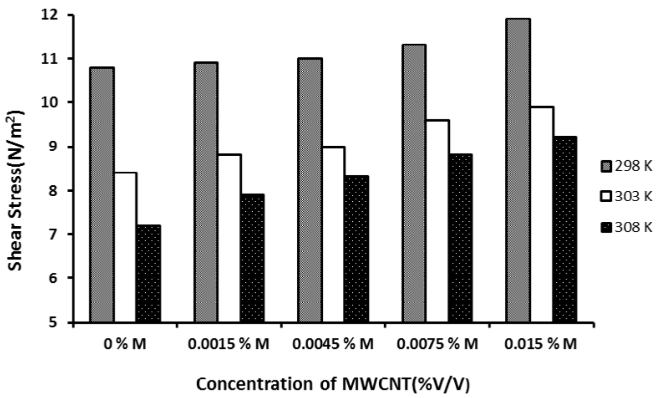

Fig. 6. effect of MWCNTs concentration on the shear stress of nanofluids at different temperatures.

increasing the concentrations of nanoparticles, the increase in nanofluid viscosity was negligible. So, these nanoparticles were used to increase thermal conductivity because the proper viscosity of nanofluids relative to the base fluid is one of the most important factors in the application of nanofluids in heat transfer industry. As a result, the viscosity of nanoparticles was increased slightly with increase in MWNTs concentration.

Decreasing the viscosity of such nanofluid by increasing the temperature will increase its use in easy heat transfer. This causes the heat transfer industry to use less energy to transfer fluid through the pipes.

Garg et al. [20] investigated that for nanofluids comprising 1 wt% MWCNTs with water as the base fluid, and Arabic gum as the surfactant at 35 °C, the viscosity was increased from 3 to 5% in ultra-sonication from 20 to 80 min, respectively. Phuoc at al [21] accompanied tests on MWCNTs and water as the base fluid and Chitosan surfactant; with mass fractions between 3 and 5% wt. Their results showed that MWCNTs could be employed to either increase or decrease the viscosity of fluid base based on the weight portions. A decrease up to 20% was achieved in the case with viscosity drop and in the viscosity-enhancement case, the fluid worked as a non-Newtonian and shear-thinning liquid in the case with viscosity rising.

The influence of temperature on shear stress

As a result, the shear stress of nanofluids containing MWCNTs was decreased with increase in temperature. Fig. 6 shows a decrease in shear stress with increasing temperature for nanofluids with different concentrations of MWCNTs. The temperature was varied at 298, 303 and 308 K. Of course, the expected reduction in shear stress of these nanofluids is obvious with increasing temperature, because viscosity and shear stress are directly related. The main cause of relation between viscosity and shear stress is due to the torsional pressure and slipping of different layers of fluid on each other, which causes a direct connection between these two physical parameters [22]. As can be seen, as the concentration of nanoparticles increased, the shear stress of water-based fluid was increased.

The shear stress was increased from 10.8 to 11.9 N/m^2 at 298K by increase in the concentration of MWCNTs from 0 to 0.015%. It was reduced from 11.9 to 9.2 N/m^2 with enhance in temperature from 298 to 308K, respectively.

CONCLUSION

The addition of a small amount of MWCNTs, which is a non-metallic solid, is a great way to increase the thermal conductivity of the base fluid and nanofluids mostly than the metal nanoparticles rise. The shape, size, and arrangement of carbon nanotubes were showed by TEM and SEM images. The presence of carbon nanotubes in nanofluids reduces the viscosity of the nanofluid, and subsequently increases the heat transfer. The main methods for increase the stability of nanofluid are adding surfactants and using ultrasonic devices.

The viscosity of nanofluid was decreased with decrease in the concentration of nanotubes and the decrease in viscosity at higher temperatures was greater for lower concentrations.

The results showed that at 308K the thermal conductivity was increased from 0.6 to 0.94 w/m.

°C due to increase in the volumetric concentration of MWCNTs from 0 to 0.015%. And the thermal conductivity was increased from 0.74 to 0.94 w/m.°C with increase in temperature from 298 to 308K. The shear stress was increased from 10.8 to 11.9 N/m^2 at 298K by increase in the volumetric concentration of MWCNTs from 0 to 0.015% and it was reduced from 11.9 to 9.2 N/m^2 with enhance in temperature from 298 to 308K, respectively.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this manuscript.

REFERENCES

1. V. Trisaksri, S. Wongwises, Renewable and sustainable energy reviews 11, 512 (2007). https://doi.org/10.1016/j.rser.2005.01.010.
2. Eastman JA, Choi US, Li S, Thompson LJ, Lee S. Enhanced Thermal Conductivity through the Development of Nanofluids. MRS Proceedings. 1996;457.
3. S. U. S. Choi, Z. George Zhang, W. Yu, Eric A. Grulke, W. Yu-Show, Appl. Physics Lett. 79(14), 2252 (2001). https://doi.org/10.1063/1.1408272.
4. Sh.M.Vanaki, P.Ganesan, H.A.Mohammed, Renewable and Sustainable Energy Reviews 54, 1212(2016). https://doi.org/10.1016/j.rser.2015.10.042.
5. E. Ettefaghi, H. Ahmadi, A. Rashidi, A. Nouralishahi, S.S. Mohtasebi, Int. Commun. Heat Mass Transfer 46, 142(2013).
https: //doi.org/10.1016/j.icheatmasstransfer.2013.05.003.
6. Segal V, Hjortsberg A, Rabinovich A, Nattrass D, Raj K. AC (60 Hz) and impulse breakdown strength of a colloidal fluid based on transformer oil and magnetite nanoparticles. Conference Record of the 1998 IEEE International Symposium on Electrical Insulation (Cat No98CH36239): IEEE.
7. A.A. Nadooshan, R. Kalbasi, M. Afrand, Heat Mass Transfer 54, 3047(2018). https://doi.org/10.1007/s00231-018-2333-3.
8. A.A. Nadooshan, H. Eshgarf, M. Afrand, Powder Technol. 338, 342(2018). https://doi.org/10.1016/j.powtec.2018.07.018.
9. S.M. Hosseini, M.R. Safaei, M. Goodarzi, A.A. Alrashed, T.K. Nguyen, Int. J. Heat Mass Transfer 114, 207(2017). https://doi.org/10.1016/j.ijheatmasstransfer.2017.06.061.
10. R. Ranjbarzadeh, A. Akhgar, S. Musivand, M. Afrand, Powder Technol. 335, 375(2018). https://doi.org/10.1016/j.powtec.2018.05.036.
11. F. Garoosi, Powder Technol., 366, 788(2020) https://doi.org/10.1016/j.powtec.2020.03.032
12. A.N.Omrani, E.Esmaeilzadeh, M.Jafari, A.Behzadmehr, 93, 96(2019). https://doi.org/10.1016/j.diamond.2019.02.002.
13. K. Wusiman, H. Jeong, K. Tulugan, H. Afrianto, H. Chung, Int. Communications in Heat and Mass Transfer 41, 28(2013). https://doi.org/10.1016/j.icheatmasstransfer.2012.12.002
14. E.P. Bandarra Filho, O.S.H. Mendoza, C.L.L. Beicker, A. Menezes, D.Wen, Energy Convers. Manag. 84, 261 (2014). DOI: 10.1016/j.enconman.2014.04.009.
15. L. Chen, H. Xie, Thermochimica Acta 506(1), 62(2010). https://doi.org/10.1016/j.tca.2010.04.016.
16. N. Singh, G. Chand, S. Kanagaraj, Heat Transfer Eng. 33(9), 821(2012). https://doi.org/10.1080/01457632.2012.646922
17. A. Indhuja, K.S. Suganthi, S. Manikandan, K.S. Rajan,J. Taiwan Inst. Chem. Eng. 44(3), 474(2013). https://doi.org/10.1016/j.jtice.2012.11.015.
18. J.P. Meyer, T.J. McKrell, K. Grote, Int. J. Heat Mass Transfer 58(1), 597(2013). https://doi.org/10.1016/j.ijheatmasstransfer.2012.11.074.
19. T. Mare, S. Halelfadl, S. Van Vaerenbergh, P. Estelle, Int. Communications in Heat and Mass Transfer 66, 80(2015). https://doi.org/10.1016/j.icheatmasstransfer. 2015.05.013.
20. P. Garg, J. L. Alvarado, C. Marsh, T.A. Carlson, D. Kessler, K. Annamalai, Int. J. Heat Mass Transfer 52, 5090(2009). https://doi.org/10.1016/j.ijheatmasstransfer.2009.04.029
21. T.X. Phuoc, M. Massoudi, R.H. Chen, International J. Thermal Sci. 50(1), 12(2011). DOI: 10.1016/j.ijthermalsci.2010.09.008.
22. S. Kakac, A. Pramuanjaroenkij, Int J Heat Mass Transfer 52, 3196 (2009). https://doi.org/10.1016/j.ijheatmasstransfer.2009.02.006.