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Urmi, W.T.[a] , Shafiqah, A.S.[a] , Rahman, M.M.[a] , Kadirgama, K.[b] , Maleque, M.A.[c]

Preparation Methods and Challenges of Hybrid Nanofluids: A Review
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[a] Department of Mechanical Engineering, College of Engineering, Universiti Malaysia Pahang, Lebuhraya Tun Razak, Kuantan, Pahang 26300, Malaysia
[b] Automotive Engineering Centre, Universiti Malaysia Pahang, Pekan, Pahang 26600, Malaysia
[c] Department of Manufacturing and Materials Engineering, International Islamic University Malaysia, Kulliyah of Engineering, Jalan Gombak, Kuala Lumpur, 53100, Malaysia

Abstract
The recent studies on nanotechnology have reported rapid development of nanofluids in various aspects due to the enhanced thermophysical and heat transfer properties of nanofluids. This paper reviews the preparation methods and some challenging issues of hybrid nanofluids during the Preparation of hybrid nanofluids. One-step and two-step are mainly the preparation methods of hybrid nanofluids. Compared to the one-step method, the two-step method is a widely used technique for preparing nanofluids due to its simplicity, whereas this technique has a complexity of achieving stability of hybrid nanofluids. On the contrary, the one-step is very flexible for achieving uniformity of nanofluids with comparatively high production cost. Some researchers followed various techniques such as surfactant addition, surface treatment, and pH modification for preparing a durable nanofluid. However, these methods also have their limitation, such as degrading the thermal attributes of hybrid nanofluids. So, future studies need to address these challenges along with the cost analysis during preparing the hybrid nanofluids.

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hybrid nanofluid; Nanoparticle; stability; surfactant; thermophysical property

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References
- Esfe, M.H., Esfandeh, S., Amiri, M.K., Afrand, M.
  A novel applicable experimental study on the thermal behavior of SWCNTs (60%)-MgO (40%)/EG hybrid nanofluid by focusing on the thermal conductivity
  (2019) *Powder Technology*, 342, pp. 998-1007.
  [1]

- Nabil, M., Azmi, W., Hamid, K.A., Mamat, R., Hagos, F.Y.
  An experimental study on the thermal conductivity and dynamic viscosity of TiO₂-SiO₂ nanofluids in water: ethylene glycol mixture
  (2017) *International Communications in Heat and Mass Transfer*, 86, pp. 181-189.
  [2]

- Asadi, A., Asadi, M., Rezaniakolaei, A., Rosendahl, L.A., Afrand, M., Wongwises, S.
  Heat transfer efficiency of Al₂O₃-MWCNT/thermal oil hybrid nanofluid as a cooling fluid in thermal and energy management applications: An experimental and theoretical investigation
  (2018) *International Journal of Heat and Mass Transfer*, 117, pp. 474-486.

[3]

- Hamid, K.A., Azmi, W., Nabil, M., Mamat, R., Sharma, K.
Experimental investigation of thermal conductivity and dynamic viscosity on nanoparticle mixture ratios of TiO2-SiO2 nanofluids
(2018) *International Journal of Heat and Mass Transfer*, 116, pp. 1143-1152.
[4]

- Sheikholeslami, M., Gerdroodbary, M.B., Moradi, R., Shafee, A., Li, Z.
Application of Neural Network for estimation of heat transfer treatment of Al₂O₃-H₂O nanofluid through a channel
(2019) *Computer Methods in Applied Mechanics and Engineering*, 344, pp. 1-12.
[5]

- Maleki, H., Safaei, M.R., Togun, H., Dahari, M.
Heat transfer and fluid flow of pseudo-plastic nanofluid over a moving permeable plate with viscous dissipation and heat absorption/generation
(2019) *Journal of Thermal Analysis and Calorimetry*, 135 (3), pp. 1643-1654.
[6]

- Choi, S.U., Eastman, J.A.
(1995) *Enhancing thermal conductivity of fluids with nanoparticles*,
[7] Argonne National Lab., IL (United States)

- Akhtar, A.Z., Rahman, M., Kadirgama, K., Maleque, M.
Effect of TiO₂ and Al₂O₃-ethylene glycol-based nanofluids on cutting temperature and surface roughness during turning process of AISI 1018
(2020) *IOP Conference Series: Materials Science and Engineering*, 736, p. 052033.
[8]

- Farhana, K., Kadirgama, K., Rahman, M., Noor, M., Ramasamy, D., Samykano, M., Najafi, G., Tarlochan, F.
Significance of alumina in nanofluid technology
(2019) *Journal of Thermal Analysis and Calorimetry*, 138 (2), pp. 1107-1126.
[9]

- Safiei, W., Rahman, M., Musfirah, A., Maleque, M., Singh, R.
Experimental study on dynamic viscosity of aqueous-based nanofluids with an addition of ethylene glycol
(2020) *IOP Conference Series: Materials Science and Engineering*, 788, p. 012094.
[10]

- Farhana, K., Kadirgama, K., Ramasamy, D., Samykano, M., Najafi, G.
Experimental Studies on Thermo-Physical Properties of Nanocellulose–Aqueous Ethylene Glycol Nanofluids
(2020) *Renewable Energy*, 69 (1), pp. 1-15.
[11]

- Kadirgama, K., Anamalai, K., Ramachandran, K., Ramasamy, D., Samykano, M., Kottasamy, A., Rahman, M.
Thermal analysis of SUS 304 stainless steel using ethylene glycol/nanocellulose-based nanofluid coolant
(2018) *The International Journal of Advanced Manufacturing*

Technology, 97 (5-8), pp. 2061-2076.
[12]

- Hussein, A.M., Noor, M., Kadirgama, K., Ramasamy, D., Rahman, M.
Heat transfer enhancement using hybrid nanoparticles in ethylene glycol through a horizontal heated tube
(2017) *International Journal of Automotive & Mechanical Engineering*, 14, p. 2.
[13]

- Keblinski, P., Eastman, J.A., Cahill, D.G.
Nanofluids for thermal transport
(2005) *Materials Today*, 8 (6), pp. 36-44.
[14]

- Mahian, O., Kianifar, A., Kalogirou, S.A., Pop, I., Wongwises, S.
A review of the applications of nanofluids in solar energy
(2013) *International Journal of Heat and Mass Transfer*, 57 (2), pp. 582-594.
[15]

- Sarkar, J.
A critical review on convective heat transfer correlations of nanofluids
(2011) *Renewable and Sustainable Energy Reviews*, 15 (6), pp. 3271-3277.
[16]

- Samylingam, L., Anamalai, K., Kadirgama, K., Samykano, M., Ramasamy, D., Noor, M., Najafi, G., Sidik, N.A.C.
Thermal analysis of cellulose nanocrystal-ethylene glycol nanofluid coolant
(2018) *International Journal of Heat and Mass Transfer*, 127, pp. 173-181.
[17]

- Daungthongsuk, W., Wongwises, S.
A critical review of convective heat transfer of nanofluids
(2007) *Renewable and Sustainable Energy Reviews*, 11 (5), pp. 797-817.
[18]

- Chen, H., Ding, Y.
Heat transfer and rheological behaviour of nanofluids–a review
(2009) *Advances in Transport Phenomena*, pp. 135-177.
[19]

- Esfe, M.H., Esfandeh, S., Rejvani, M.
Modeling of thermal conductivity of MWCNT-SiO₂ (30: 70%)/EG hybrid nanofluid, sensitivity analyzing and cost performance for industrial applications
(2018) *Journal of Thermal Analysis and Calorimetry*, 131 (2), pp. 1437-1447.
[20]

- Srikant, R., Prasad, M., Amrita, M., Sitaramaraju, A., Krishna, P.V.
Nanofluids as potential solution for Minimum Quantity Lubrication: A review
(2013) *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture*, pp. 1-19.
[21]

- Esfe, M.H., Raki, H.R., Emami, M.R.S., Afrand, M.
Viscosity and rheological properties of antifreeze based nanofluid containing hybrid

nano-powders of MWCNTs and TiO₂ under different temperature conditions
(2019) *Powder Technology*, 342, pp. 808-816.
[22]

- Singh, D., Toutbort, J., Chen, G.
Heavy vehicle systems optimization merit review and peer evaluation
(2006) *Annual Report, Argonne National Laboratory*, 23, pp. 405-411.
[23]

- Jang, S.P., Choi, S.U.
Cooling performance of a microchannel heat sink with nanofluids
(2006) *Applied Thermal Engineering*, 26 (17-18), pp. 2457-2463.
[24]

- Zhang, L., Jiang, Y., Ding, Y., Povey, M., York, D.
Investigation into the antibacterial behaviour of suspensions of ZnO nanoparticles (ZnO nanofluids)
(2007) *Journal of Nanoparticle Research*, 9 (3), pp. 479-489.
[25]

- Singh, R., Lillard, J.W.
"Nanoparticle-based targeted drug delivery
(2009) *Experimental and Molecular Pathology*, 86 (3), pp. 215-223.
[26]

- Yu, W., Xie, H.
A review on nanofluids: preparation, stability mechanisms, and applications
(2012) *Journal of Nanomaterials*, 2012, p. 1.
[27]

- Sajid, M.U., Ali, H.M.
Thermal conductivity of hybrid nanofluids: a critical review
(2018) *International Journal of Heat and Mass Transfer*, 126, pp. 211-234.
[28]

- Safiei, W., Rahman, M., Yusoff, A., Radin, M.
Preparation, stability and wettability of nanofluid: A review
(2020) *Journal of Mechanical Engineering and Sciences*, 14 (3), pp. 7244-7257.
[29]

- Hatwar, A.S., Kriplani, V.
A review on heat transfer enhancement with nanofluid
(2014) *Int. J. Adv. Res. Sci. Eng*, 3 (3), pp. 175-183.
[30]

- Zhu, H.-t., Lin, Y.-s., Yin, Y.-s.
A novel one-step chemical method for preparation of copper nanofluids
(2004) *Journal of Colloid and Interface Science*, 277 (1), pp. 100-103.
[31]

- Wang, X.-Q., Mujumdar, A.S.
Heat transfer characteristics of nanofluids: a review
(2007) *International Journal of Thermal Sciences*, 46 (1), pp. 1-19.

[32]

- Zhu, D., Li, X., Wang, N., Wang, X., Gao, J., Li, H.
Dispersion behavior and thermal conductivity characteristics of Al₂O₃–H₂O nanofluids
(2009) *Current Applied Physics*, 9 (1), pp. 131-139.
[33]

- Salehi, J., Heyhat, M., Rajabpour, A.
Enhancement of thermal conductivity of silver nanofluid synthesized by a one-step method with the effect of polyvinylpyrrolidone on thermal behavior
(2013) *Applied Physics Letters*, 102 (23), p. 231907.
[34]

- Li, Y., Tung, S., Schneider, E., Xi, S.
A review on development of nanofluid preparation and characterization
(2009) *Powder Technology*, 196 (2), pp. 89-101.
[35]

- Ghadimi, A., Saidur, R., Metselaar, H.
A review of nanofluid stability properties and characterization in stationary conditions
(2011) *International Journal of Heat and Mass Transfer*, 54 (17), pp. 4051-4068.
[36]

- Das, S.K., Choi, S.U., Yu, W., Pradeep, T.
(2007) *Nanofluids: science and technology*,
[37] John Wiley & Sons

- Geng, Y., Al-Rashed, A.A., Mahmoudi, B., Alsagri, A.S., Shahsavar, A., Talebizadehsardari, P.
Characterization of the nanoparticles, the stability analysis and the evaluation of a new hybrid nano-oil thermal conductivity
(2019) *Journal of Thermal Analysis and Calorimetry*, pp. 1-12.
[38]

- Shahsavar, A., Salimpour, M.R., Saghafian, M., Shafii, M.
Effect of magnetic field on thermal conductivity and viscosity of a magnetic nanofluid loaded with carbon nanotubes
(2016) *Journal of Mechanical Science and Technology*, 30 (2), pp. 809-815.
[39]

- Jaiswal, A.K., Wan, M., Singh, S., Singh, D., Yadav, R., Singh, D., Mishra, G.
Experimental Investigation of Thermal Conduction in Copper-Palladium Nanofluids
(2016) *Journal of Nanofluids*, 5 (4), pp. 496-501.
[40]

- Khairul, M., Shah, K., Doroodchi, E., Azizian, R., Moghtaderi, B.
Effects of surfactant on stability and thermo-physical properties of metal oxide nanofluids
(2016) *International Journal of Heat Mass Transfer*, 98, pp. 778-787.
[41]

- Harandi, S.S., Karimipour, A., Afrand, M., Akbari, M., D’Orazio, A.
An experimental study on thermal conductivity of F-MWCNTs–Fe₃O₄/EG hybrid nanofluid: effects of temperature and concentration
(2016) *International Communications in Heat Mass Transfer*, 76, pp. 171-177.
[42]

- Afrand, M., Toghraie, D., Ruhani, B.J.E.T.
Effects of temperature and nanoparticles concentration on rheological behavior of Fe₃O₄–Ag/EG hybrid nanofluid: an experimental study
(2016) *Experimental Thermal Fluid Science*, 77, pp. 38-44.
[43]

- Ramachandran, R., Ganesan, K., Rajkumar, M., Asirvatham, L., Wongwises, S.
Comparative study of the effect of hybrid nanoparticle on the thermal performance of cylindrical screen mesh heat pipe
(2016) *International Communications in Heat Mass Transfer*, 76, pp. 294-300.
[44]

- Asadi, A., Asadi, M., Rezaniakolaei, A., Rosendahl, L.A., Afrand, M., Wongwises, S.
Heat transfer efficiency of Al₂O₃-MWCNT/thermal oil hybrid nanofluid as a cooling fluid in thermal and energy management applications: An experimental and theoretical investigation
(2018) *International Journal of Heat Mass Transfer*, 117, pp. 474-486.
[45]

- Urmi, W., Rahman, M., Hamzah, W.
An experimental investigation on the thermophysical properties of 40% ethylene glycol based TiO₂-Al₂O₃ hybrid nanofluids
(2020) *International Communications in Heat and Mass Transfer*, 116, p. 104663.
[46]

- Hamid, K.A., Azmi, W., Nabil, M., Mamat, R.
Experimental investigation of nanoparticle mixture ratios on TiO₂–SiO₂ nanofluids heat transfer performance under turbulent flow
(2018) *International Journal of Heat and Mass Transfer*, 118, pp. 617-627.
[47]

- Chai, Y.H., Yusup, S., Chok, V.S., Arpin, M.T., Irawan, S.
Investigation of thermal conductivity of multi walled carbon nanotube dispersed in hydrogenated oil based drilling fluids
(2016) *Applied Thermal Engineering*, 107, pp. 1019-1025.
[48]

- Jabbari, F., Rajabpour, A., Saedodin, S.
Viscosity of carbon nanotube/water nanofluid
(2019) *Journal of Thermal Analysis Calorimetry*, 135 (3), pp. 1787-1796.
[49]

- Singh, N., Chand, G., Kanagaraj, S.
Investigation of thermal conductivity and viscosity of carbon nanotubes–ethylene glycol nanofluids
(2012) *Heat Transfer Engineering*, 33 (9), pp. 821-827.
[50]

- Xing, M., Yu, J., Wang, R.
  Thermo-physical properties of water-based single-walled carbon nanotube nanofluid as advanced coolant
  (2015) *Applied Thermal Engineering*, 87, pp. 344-351.
  [51]

- Esfe, M.H., Arani, A.A.A., Rezaie, M., Yan, W.-M., Karimipour, A.
  Experimental determination of thermal conductivity and dynamic viscosity of Ag–MgO/water hybrid nanofluid
  (2015) *International Communications in Heat Mass Transfer*, 66, pp. 189-195.
  [52]

- Esfe, M.H., Alirezaie, A., Rejvani, M.
  An applicable study on the thermal conductivity of SWCNT-MgO hybrid nanofluid and price-performance analysis for energy management
  (2017) *Applied Thermal Engineering*, 111, pp. 1202-1210.
  [53]

- Asadi, A., Asadi, M., Rezaei, M., Siahmargoi, M., Asadi, F.
  The effect of temperature and solid concentration on dynamic viscosity of MWCNT/MgO (20–80)–SAE50 hybrid nano-lubricant and proposing a new correlation: An experimental study
  (2016) *International Communications in Heat Mass Transfer*, 78, pp. 48-53.
  [54]

- Hamid, K.A., Azmi, W., Nabil, M., Mamat, R.
  Experimental investigation of nanoparticle mixture ratios on TiO₂–SiO₂ nanofluids heat transfer performance under turbulent flow
  (2018) *International Journal of Heat Mass Transfer*, 118, pp. 617-627.
  [55]

- Senthilraja, S., Vijayakumar, K., Gangadevi, R.
  A comparative study on thermal conductivity of Al₂O₃/water, CuO/water and Al₂O₃–CuO/water nanofluids
  (2015) *Digest Journal of Nanomaterials Biostructures*, 10 (4), pp. 1449-1458.
  [56]

- Urmi, W.T., Rahman, M.M., Hamzah, W.A.W., Kadirgama, K., Ramasamy, D., Maleque, M.A.
  Experimental Investigation on the Stability of 40% Ethylene Glycol Based TiO₂-Al₂O₃ Hybrid Nanofluids
  (2020) *Journal of Advanced Research in Fluid Mechanics and thermal Sciences*, 69 (1), pp. 110-121.
  [57]

- Novoselov, K.S., Geim, A.K., Morozov, S., Jiang, D., Zhang, Y., Dubonos, S.a., Grigorieva, I., Firsov, A.
  Electric field effect in atomically thin carbon films
  (2004) *Science*, 306 (5696), pp. 666-669.
  [58]

- Tung, V.C., Allen, M.J., Yang, Y., Kaner, R.B.
High-throughput solution processing of large-scale graphene
(2009) *Nature Nanotechnology*, 4 (1), pp. 25-29.
[59]

- Kaniyoor, A., Baby, T.T., Ramaprabhu, S.
Graphene synthesis via hydrogen induced low temperature exfoliation of graphite oxide
(2010) *Journal of Materials Chemistry*, 20 (39), pp. 8467-8469.
[60]

- Sridhar, V., Jeon, J.-H., Oh, I.-K.
Synthesis of graphene nano-sheets using eco-friendly chemicals and microwave radiation
(2010) *Carbon*, 48 (10), pp. 2953-2957.
[61]

- Zhang, W., He, W., Jing, X.
Preparation of a stable graphene dispersion with high concentration by ultrasound
(2010) *The Journal of Physical Chemistry B*, 114 (32), pp. 10368-10373.
[62]

- Wen, D., Lin, G., Vafaei, S., Zhang, K.
Review of nanofluids for heat transfer applications
(2009) *Particuology*, 7 (2), pp. 141-150.
[63]

- Yarmand, H., Gharehkhani, S., Ahmadi, G., Shirazi, S.F.S., Baradaran, S., Montazer, E., Zubir, M.N.M., Dahari, M.
Graphene nanoplatelets–silver hybrid nanofluids for enhanced heat transfer
(2015) *Energy Conversion and Management*, 100, pp. 419-428.
[64]

- Zhang, X., Gu, H., Fujii, M.
Effective thermal conductivity and thermal diffusivity of nanofluids containing spherical and cylindrical nanoparticles
(2007) *Experimental Thermal Fluid Science*, 31 (6), pp. 593-599.
[65]

- Sergis, A., Hardalupas, Y.
Anomalous heat transfer modes of nanofluids: a review based on statistical analysis
(2011) *Nanoscale Research Letters*, 6 (1), pp. 1-37.
[66]

- Eastman, J., Choi, S., Li, S., Yu, W., Thompson, L.
Anomalously increased effective thermal conductivities of ethylene glycol-based nanofluids containing copper nanoparticles
(2001) *Applied Physics Letters*, 78 (6), pp. 718-720.
[67]

- Chen, L., Xie, H., Li, Y., Yu, W.
Nanofluids containing carbon nanotubes treated by mechanochemical reaction
(2008) *Thermochimica Acta*, 477 (1-2), pp. 21-24.
[68]

Correspondence Address
Rahman M.M.; Department of Mechanical Engineering, Malaysia; email: mustafizur@ump.edu.my

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