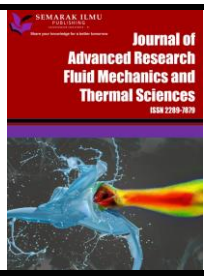
SEMARAK ILMU PUBLISHING

Journal of Advanced Research in Fluid Mechanics and Thermal Sciences

Journal homepage:
https://semarakilmu.com.my/journals/index.php/fluid_mechanics_thermal_sciences/index
ISSN: 2289-7879



The Thematic Review on Convective Heat Transfer of Nanofluid over Horizontal Circular Cylinder

Farahanie Fauzi[1,2], Abdul Rahman Mohd Kasim[1,4,*], Hussein Ali Mohammed Al-Sharifi[3], Siti Farah Haryatie Mohd Kanafiah[1,2]

[1] Centre for Mathematical Sciences, Universiti Malaysia Pahang Al-Sultan Abdullah (UMPSA), 26300, Gambang, Pahang, Malaysia
[2] College of Computing, Informatics and Mathematics, Universiti Teknologi MARA (UiTM) Kelantan Branch, Kelantan, Malaysia
[3] Department of Mathematics, College of Education for Pure Sciences, University of Kerbala, 1125, Karbala, Iraq
[4] Centre for Research in Advanced Fluid and Processes, Universiti Malaysia Pahang Al-Sultan Abdullah (UMPSA), 26300, Gambang, Kuantan, Pahang, Malaysia

ARTICLE INFO

Article history:
Received 11 August 2023
Received in revised form 23 October 2023
Accepted 1 November 2023
Available online 15 November 2023

Keywords:
Circular cylinder; convective heat transfer; nanofluid

ABSTRACT

Convective heat transfer refers to thermal energy transfer from one place to another due to the movement of fluid. To increase the performance of thermal energy transfer, nanoparticles are diluted into the fluid resulting nanofluid. Even though there are lots of studies have been conducted on the convection heat transfer of nanofluid, there are scarce studies that review the patterns of mainly used mathematical model, boundary conditions, surface geometry and method of solution. Therefore, this paper aims to review the studies on convective heat transfer of nanofluid over horizontal circular cylinder. The focus is to review published articles in the year 2014 until 2023. The reviewed articles were extracted using the advanced documents search function in SCOPUS and WOS databases. Of 67 identified articles, only 37 were selected after undergoing screening process. The result of this thematic review identifies that besides Buongiorno and Tiwari and Das models, mathematical models for non-Newtonian fluid like Viscoelastic, Casson, Jeffrey and Williamson models are also used in modeling convection heat transfer of nanofluid.

1. Introduction

Heat transfer is the exchange of thermal energy due to a difference in temperature. Convection is considered one of the methods of heat transfer that is very common in many industrial and engineering fields. According to Bergman [1], convection is the transfer of thermal energy from one place to another due to the movement of fluid. As for the fluid, the scientists have classified fluids into two types: Newtonian, which follows Newton's law of viscosity, and non-Newtonian, which does not and each type has its own characteristics [2]. To enhance thermal energy transfer, diluting or adding particles to the fluid has been identified as a helpful approach. Researchers have identified two types of models for particles in fluids. One is the two-phase model which assumes particles have

* *Corresponding author.*
E-mail address: rahmanmohd@umpsa.edu.my

https://doi.org/10.37934/arfmts.111.1.122134

a similar shape and do not change, while the other one is nanofluid model which involves nano-sized particles [2]. The term nanofluid was first used by Choi and Eastman [3] in the year 1995 and the concept of nanofluid was then manifested by a series of research at Argonne National Laboratory [4]. If multiple nano-sized particles are diluted in a base fluid, a hybrid nanofluid is formed and the use of hybrid nanofluid results in significantly higher heat transfer rates compared to conventional nanofluid [5]. Engineers and researchers are using hybrid nanofluids to improve the performance of their products, research and technology. There are many mathematical models have been introduced and used to formulate convection heat transfer in fluids. For the regular fluid, some of the models are Viscoelastic, Casson, Brinkman, Jeffrey and Williamson while for the nanofluid, the models are Buongiorno and Tiwari and Das. But through the years, researchers have integrated the models of fluid with nanofluid to improve the fluid's characteristics and heat transfer rate.

There are three types of convection mechanisms, namely free, forced and mixed. Free or natural convection is caused solely by the buoyancy force, while forced convection is induced by external sources such as pumps and fans. Mixed convection happens when both free and forced convection occur simultaneously [6]. There are a few aspects to be considered in analyzing convection process which are the boundary conditions (BC) and surface geometry. Boundary conditions (BC) tell what the solutions of a model would be on the boundaries whereas surface geometry is the shape and condition of where the movement of analysed fluid is. There are four types of boundary conditions that are commonly used which are convective boundary condition (CBC), constant wall temperature (CWT), constant heat flux (CHF) and Newtonian Heating (NH) [7]. As for the geometry, flat plate, stretching/shrinking sheet, thin needle, rotating disk, vertical plate, sphere and horizontal circular cylinder are several of the geometries that interest the researchers which lead to an increasing number of publications every year [5]. Previous researchers have found several methods of solving the mathematical model of convection heat transfer and the methods can be either analytical, semi-analytical or numerical such as homotopy perturbation method (HPM), Runge-Kutta-Fehlberg method, shooting method, Akbari–Ganji method (AGM), finite element method, Keller-Box method and BVP4C [8-11]. All in all, it can be said that several models subject to different boundary conditions and different surface geometry solved using one of many discovered numerical methods have been studied by many researchers. But the pattern of which mostly used model, with boundary conditions and geometry being solved with which method is scarcely reviewed.

Therefore, this paper aims to review some selected articles and summarize the pattern of research on convective heat transfer of nanofluid over only one surface geometry which is horizontal circular cylinder. The horizontal circular cylinder geometry was chosen in this study is due to its application in many engineering fields and industrial applications such as oil filtration process, electronic device channel, pipeline and many more. The analysis will be focusing on the boundary conditions and methods used in each article.

2. Methodology

In this section, detailed steps of how this study is conducted are explained. The concept of this study is thematic review process where it compiles research that has been published on a specific topic by scholars and experts. This review will tell readers about the development and improvement of the selected topic. The process of thematic review consists of several steps which are identification, screening, eligibility, and analysis of data as shown in Figure 1. The first step is to identify relevant keywords that best represent the searched topic. In this study, each article must have keywords of horizontal circular cylinder and nanofluid. Articles are extracted using two search strings which are SCOPUS and WOS databases. After the list is identified, articles must undergo a

screening process. This process involves two elements which are inclusion and exclusion. This study only considers articles with publication years from 2014 until 2023. Books and chapters in a book type of document are also excluded from this study. The third step of the process is eligibility where only accessible articles are considered. The articles are also skimmed to ensure they really represent the keywords and meet the criteria. The last step is analysis of data where articles are read, and analysis is conducted to identify preferred themes. Table 1 shows the number of extracted articles using SCOPUS and WOS search string.

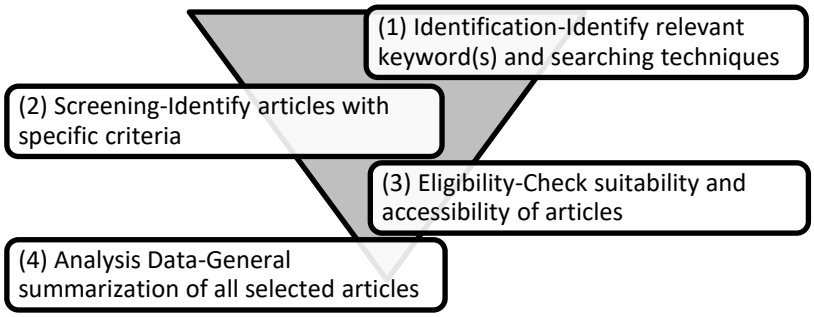


Fig. 1. Thematic review process

Table 1
Research results from SCOPUS and WOS

Database	Keyword	Result
Scopus	Advanced document search TITLE-ABS-KEY ("Horizontal Circular Cylinder" AND nanofluid) Limit to year (2014 – 2023)	43
WOS	Documents search "Horizontal Circular Cylinder" AND nanofluid Limit to year (2014 – 2023)	24

Out of 67 articles extracted from SCOPUS (43) and WOS (24), 14 of them are overlapping articles and 16 do not meet the keywords and criteria that have been set or the full articles are not accessible. So, the number of selected articles for this review is 37. Figure 2 shows the process of reviewed articles.

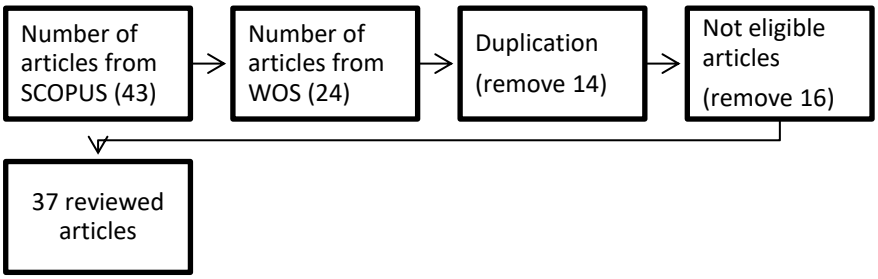


Fig. 2. Total reviewed articles

3. Results

3.1 Thematic Review Results

In this subsection, the findings of the review of 37 articles are summarized. While in the subsequent subsection, the detailed summary for each model is explained. Table 2 shows the models that have been used in the 37 articles. It is identified that besides Tiwari and Das and Buongiorno model, non-Newtonian models are also used in formulating convection heat transfer of nanofluid over horizontal circular cylinder. These models are either based on Buongiorno model or Tiwari and Das model. There are researchers who used Casson, Jeffrey and Williamson models based on either Tiwari and Das model or Buongiorno model. But if it is Viscoelastic model, this study finds that it is only based on Tiwari and Das model. Buongiorno model is best used in analysing Brownian motion and thermophoresis mechanisms while Tiwari and Das model is best used to analyse volume fraction [12]. Brownian motion refers to the continuous collision of nanoparticles of the base fluid while thermophoresis means the movement of nanoparticles in a temperature gradient [13]. The most used model is Buongiorno model where 14 out of 37 articles (38%) used this model to formulate their problems.

Table 2
Number of articles based on nanofluid model

Model	∑
Tiwari and Das	8 (22%)
Viscoelastic Nanofluid (Tiwari and Das)	5 (13%)
Casson Nanofluid (Tiwari and Das)	3 (8%)
Jeffrey Nanofluid (Tiwari and Das)	1 (3%)
Williamson Nanofluid (Tiwari and Das)	1 (3%)
Buongiorno	14 (38%)
Casson Nanofluid (Buongiorno)	2 (5%)
Jeffrey Nanofluid (Buongiorno)	2 (5%)
Williamson Nanofluid (Buongiorno)	1 (3%)
Total	37

In terms of boundary conditions, it has been observed that 20 out of the total 37 articles (54%) are subjected to Constant Wall Temperature boundary conditions (Table 3). Researchers have shown less interest in both CBC and CHF, with CBC being used in 8 articles and CHF in 9 articles. As for the method, 87% of reviewed articles used the Keller-Box method in solving the model to analyse convective heat transfer as shown in Table 4.

Table 3
Number of articles based on model and boundary condition

Model	CWT	CBC	CHF	∑
Tiwari and Das	3	3	2	8
Viscoelastic Nanofluid (Tiwari and Das)	1	1	3	5
Casson Nanofluid (Tiwari and Das)	2	-	1	3
Jeffrey Nanofluid (Tiwari and Das)	-	1	-	1
Williamson Nanofluid (Tiwari and Das)	1	-	-	1
Buongiorno	9	2	3	14
Casson Nanofluid (Buongiorno)	1	1	-	2
Jeffrey Nanofluid (Buongiorno)	2	-	-	2
Williamson Nanofluid (Buongiorno)	1	-	-	1
Total	20 (54%)	8 (22%)	9 (24%)	37

Table 4
Number of articles based on model and method

Model	Keller-Box	RKF45	FEM	HLCSM	∑
Tiwari and Das	6	1	-	1	8
Viscoelastic Nanofluid (Tiwari and Das)	5	-	-	-	5
Casson Nanofluid (Tiwari and Das)	3	-	-	-	3
Jeffrey Nanofluid (Tiwari and Das)	-	1	-	-	1
Williamson Nanofluid (Tiwari and Das)	1	-	-	-	1
Buongiorno	12	-	2	-	14
Casson Nanofluid (Buongiorno)	2	-	-	-	2
Jeffrey Nanofluid (Buongiorno)	2	-	-	-	2
Williamson Nanofluid (Buongiorno)	1	-	-	-	1
Total	32 (87%)	2 (5%)	2 (5%)	1 (3%)	

From a better understanding of all 37 articles, some of them analysed how changes happen to convective heat transfer if small effect factors such as viscous dissipation, magnetohydrodynamics and radiation are added to the model. So, this discovery is also discussed in the findings of this study. From Table 5, it is identified that this topic of research is popular among Malaysian researchers followed by Indian and Saudi Arabian researchers with number of articles 16, 7 and 6 respectively. Publications of researchers from other countries are also identified such as Bangladesh, Jordan, Pakistan, Romania, Tunisia, and Vietnam. It is identified that the selected articles are from several journals as stated in Table 6. From the table, in 10 years' time, research on convection heat transfer of nanofluid over horizontal circular cylinder is starting to be popular in 2019. But the year with the most published articles is 2020 with 8 articles. There are 30 journals involved in publishing the 37 reviewed articles. CFD Letters, Journal of Nanofluids, Mathematics, Sains Malaysiana and Proceedings of The Institution of Mechanical Engineers Part C-Journal of Mechanical Engineering Science published more than one article on convective heat transfer of nanofluid over horizontal circular cylinder.

Table 5
Number of reviewed articles according to country and year

Country	Year										Total
	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	
Bangladesh								1			1
India		1		1	2	1		2			7
Jordan						1				1	2
Malaysia	1		3	1	3	1	4	1	2		16
Pakistan			1								1
Romania									1		1
Saudi Arabia							3		3		6
Tunisia						1					1
Vietnam						2					2

Table 6
Reviewed articles journals and year

Journal	Year (20**)									
	14	15	16	17	18	19	20	21	22	23
Ain Shams Engineering Journal						1				
AIP Conference Proceedings								1		
ARPN Journal of Engineering and Applied Sciences			1							
CFD Letters							1		2	
Coatings									1	
Heat Mass Transfer			1							
IAENG International Journal of Applied Mathematics						1				
International Journal of Mechanical Engineering and Robotics Research						1				
International Journal of Numerical Methods for Heat & Fluid Flow								1		
International Journal of Thermal Sciences	1									
IOP Conf. Series: Journal of Physics: Conf. Series				1						
IOP Conf. Series: Materials Science and Engineering							1			
Jordan Journal of Mechanical and Industrial Engineering										1
Journal Of Advanced Research in Dynamical and Control Systems							1			
Journal Of Advanced Research in Fluid Mechanics and Thermal Sciences							1			
Journal Of Molecular Liquids			1							
Journal Of Nanofluids				1	1	1				
Journal Of Physics: Conference Series						1				
Journal Of Thermal Analysis and Calorimetry							1			
Journal Of Thermophysics and Heat Transfer		1								
MATEC Web Of Conferences					1					
Mathematics									2	
MJFAS								1		
Nonlinear Engineering						1				
Proceedings of The Institution of Mechanical Engineers Part C-Journal of Mechanical Engineering Science							1		1	
Processes							1			
Sains Malaysiana			1		1					
Scientific Reports									1	
Theoretical And Applied Mechanics						1				
Thermal Science							1			
Total	1	1	4	2	3	7	8	3	7	1

3.2 Tiwari and Das Model

Tiwari and Das nanofluid model is developed by Raj Kamal Tiwari and Manab Kumar Das in their 2007 published research. The model is developed to analyse the behaviour of nanofluids considering the solid volume fraction [14]. For this review, it is identified that 8 studies used Tiwari and Das model in their research and 6 of them solved the model using Keller-Box method. Articles by Zokri *et al.,* [9] applied Runge Kutta-Fehlberg Method (RKF45) while El-Zahar *et al.,* [15] applied Hybrid Linearization-Chebyshev Spectral Method (HLCSM) method in their research. Table 7 shows the details of all 8 researches conducted using Tiwari and Das model. Research by Mohamed *et al.,* [10] and Yasin *et al.,* [16] analysed convective heat transfer in ferrofluid. Ferrofluid is one type of nanofluid that is formed by magnetic nanoparticles such as magnetite (Fe_3O_4), hematite (Fe_2O_3) and cobalt ferrite ($CoFe_2O_4$)

[16]. Like nanofluids, ferrofluids have high thermal conductivity and excellent heat transfer, making them valuable in device manufacturing [5].

Table 7
Tiwari and Das model

Authors	BC	Method	Effect
El-Zahar *et al.,* [15]	CBC	HLCSM	Magnetohydrodynamics (MHD)
Zokri *et al.,* [9]	CBC	RKF45	-
Sarif *et al.,* [17]	CBC	Keller-Box	-
Afsana *et al.,* [18]	CHF	Keller-Box	-
Alkasasbeh *et al.,* [19]	CHF	Keller-Box	-
Mohamed *et al.,* [10]	CWT	Keller-Box	Viscous Dissipation
Yasin *et al.,* [16]	CWT	Keller-Box	Magnetohydrodynamics (MHD)
Swalmeh *et al.,* [12]	CWT	Keller-Box	-

3.3 Buongiorno Model

Buongiorno nanofluid model is developed and introduced by Jacopo Buongiorno in his 2006 published research. It has been identified that Buongiorno model is employed to incorporate the effects of Brownian motion and thermophoresis. Buongiorno model is a two-component four-equation nonhomogeneous equilibrium model for mass, momentum, and heat transport in nanofluids [20]. Since it can enhance the efficiency in modeling convective heat transfer in nanofluid, this model is then has been widely used in many applications. Table 8 shows the details of the articles. Out of 14, 9 of them examined the model subject to constant wall temperature boundary conditions, 3 were subject to constant heat flux and 2 were subject to convective boundary conditions. Keller-Box method is used in 12 articles and only two of them used Finite Element Method which are research by Reddy *et al.,* [11] and Reddy and Chamkha [21].

Table 8
Buongiorno model

Authors	BC	Method	Effect
Reddy and Chamkha [21]	CWT	Finite Element Method	-
Basha *et al.,* [22]	CWT	Keller-Box	-
Akram *et al.,* [23]	CWT	Keller-Box	MHD, thermal radiation, heat generation
Alwawi *et al.,* [24]	CWT	Keller-Box	-
Damseh [25]	CWT	Keller-Box	The presence of chemical reaction
Reddy *et al.,* [11]	CWT	Finite Element Method	-
Mohamed *et al.,* [26]	CWT	Keller-Box	Viscous Dissipation
Prasad *et al.,* [27]	CWT	Keller-Box	-
Tham *et al.,* [28]	CWT	Keller-Box	-
Swalmeh *et al.,* [29]	CHF	Keller-Box	-
Tlili *et al.,* [30]	CHF	Keller-Box	Magnetohydrodynamics (MHD)
Tham *et al.,* [31]	CHF	Keller-Box	-
Sarif *et al.,* [32]	CBC	Keller-Box	-
Mabood *et al.,* [33]	CBC	Keller-Box	-

3.4 Viscoelastic Nanofluid (Tiwari and Das)

Viscoelastic fluid is a type of non-Newtonian fluid with materials that have the behaviour of viscous and elastic properties at the same time. For Viscoelastic nanofluid model, all 5 identified articles are produced by the same authors. They used Keller-Box method in all 5 articles. The

differences are in the boundary conditions and effect. Mahat *et al.,* [34] focused on solving the model using Keller-Box method with constant heat flux boundary conditions. Mahat *et al.,* [35] solved the model using the same method but with different boundary conditions which is constant wall temperature and analysed the effect of viscous dissipation. Table 9 shows all the articles using Viscoelastic Nanofluid based on Tiwari and Das model.

Table 9
Viscoelastic Nanofluid (Tiwari and Das)

Authors	BC	Method	Effect
Mahat *et al.,* [34]	CHF	Keller-Box	-
Mahat *et al.,* [35]	CWT	Keller-Box	Viscous dissipation
Mahat *et al.,* [36]	CBC	Keller-Box	-
Mahat *et al.,* [37]	CHF	Keller-Box	Viscous dissipation
Mahat *et al.,* [38]	CHF	Keller-Box	MHD

3.5 Casson Nanofluid (Tiwari and Das)

A Casson model is one of the most effective and efficient models for predicting the behaviour of Casson fluids [39]. Casson fluid is an independent of time non-Newtonian liquid that behaves similarly to an elastic material in which no motion occurs with low yield stress [40]. Only 3 articles used Casson model based on Tiwari and Das nanofluid and two of them are from Alwawi *et al.,* [41,42]. They used Keller-Box method and constant wall temperature boundary conditions in both of their research. The difference is in 2020 research, Alwawi *et al.,* [41] analysed the effect of magnetohydrodynamics while in 2022 research, Alwawi *et al.,* [42] analysed the effect of magneto micropolar. The other article is written by Hamarsheh *et al.,* [39] where they used Keller-Box method to solve the model hence examining heat transfer improvement in magnetohydrodynamics natural convection flow of nanofluid with methanol as the base and graphite oxide and carbon nanotubes as nanoparticles past a horizontal curricular cylinder. Table 10 shows the details of the three articles.

Table 10
Casson Nanofluid (Tiwari and Das)

Authors	BC	Method	Effect
Alwawi *et al.,* [41]	CWT	Keller-Box	MHD
Alwawi *et al.,* [42]	CWT	Keller-Box	Magneto micropolar
Hamarsheh *et al.,* [39]	CHF	Keller-Box	MHD

3.6 Casson Nanofluid (Buongiorno)

There are only 2 articles that use Casson model based on Buongiorno nanofluid model. Both articles used Keller-Box method in solving the model. The study by Bég *et al.,* [43] analysed the steady-state transport phenomena in magnetohydrodynamic Casson nanofluid flow from a horizontal cylinder with thermal slip. While the study by Prasad *et al.,* [13] examined the convection flow of isothermal horizontal circular cylinder in non-Darcy porous media. Isothermal is a term for thermodynamics process in a system where the temperature is constant. Table 11 shows the details of the two articles.

Table 11
Casson Nanofluid (Buongiorno)

Authors	BC	Method	Effect
Bég *et al.,* [43]	CBC	Keller-Box	MHD
Prasad *et al.,* [13]	CWT	Keller-Box	-

3.7 Jeffrey Nanofluid (Buongiorno & Tiwari and Das)

The model of non-Newtonian Jeffrey fluid is known for its ability to describe viscoelastic property, namely the dual components of retardation and relaxation times [44]. There are three articles that used Jeffrey Nanofluid and all of them are produced by Zokri *et al.,* [44-46]. Two of them are based on Buongiorno model and the other one is based on Tiwari and Das model. The ones using Buongiorno were both with constant wall temperature boundary conditions and analysed viscous dissipation's effect by applying the Keller-Box method in solving the model. The difference is, Zokri *et al.,* [44] focus on the problem of mixed convection flow while Zokri *et al.,* [45] focus on free convection flow. On the other hand, the article with Tiwari and Das nanofluid model used RKF45 method subject to convective boundary conditions [46]. Table 12 shows the articles that discuss Jeffrey Nanofluid model.

Table 12
Jeffrey Nanofluid (Buongiorno & Tiwari and Das)

Authors	BC	Method	Effect
Jeffrey (Buongiorno)			
Zokri *et al.*, [44]	CWT	Keller-Box	Viscous dissipation
Zokri *et al.*, [45]	CWT	Keller-Box	Viscous dissipation
Jeffrey (Tiwari and Das)			
Zokri *et al.*, [46]	CBC	RKF45	-

3.8 Williamson Nanofluid (Buongiorno & Tiwari and Das)

Williamson model that has been introduced by Williamson in 1929 is best for formulating the convection heat transfer involving shear-thinning fluid [47]. Shear-thinning fluid refers to fluid that becomes thinner as the rate of shear increases, which means the more stress is applied the thinner the fluid becomes. There are only two articles using the Williamson model as shown in Table 13. Alwawi *et al.,* [47] used Williamson nanofluid based on Tiwari and Das while Hayath *et al.,* [48] used Williamson nanofluid based on Buongiorno model, and both are subject to constant wall temperature boundary conditions and use Keller-Box method in solving the model. Alwawi *et al.,* [47] analysed the effect of magnetic and radiation impressions on convective heat transfer.

Table 13
Williamson Nanofluid (Buongiorno & Tiwari and Das)

Authors	BC	Method	Effect
Williamson (Tiwari and Das)			
Alwawi *et al.*, [47]	CWT	Keller-Box	Magnetic and radiation impressions
Williamson (Buongiorno)			
Hayath *et al.*, [48]	CWT	Keller-Box	-

4. Conclusions

As mentioned in the introduction, the mathematical models to formulate convective heat transfer of non-Newtonian fluid are Viscoelastic, Casson, Brinkman, Jeffrey and Williamson while Buongiorno and Tiwari and Das models are used for nanofluid. From this review paper, it can be summarized that the two main models of nanofluid which are Buongiorno model and Tiwari and Das are widely used by researchers. But over the years, researchers modified non-Newtonian models based on Buongiorno and Tiwari and Das models to study convective heat transfer of nanofluid. It is identified that there is limited research conducted using combination of two non-Newtonian models in analyzing convective heat transfer of nanofluid over horizontal circular cylinder. To expand and improve this area of study, future researchers have the option to use a combination of two non-Newtonian models. As for the method and boundary condition, the keller-Box method and Contant Wall Temperature boundary conditions are researchers' choice in solving their models.

Acknowledgement

The authors want to acknowledge Universiti Malaysia Pahang Al-Sultan Abdullah for providing financial support under UIC221518. A deep appreciation also goes to Universiti Teknologi MARA Cawangan Kelantan (UiTMCK) and University of Kerbala for guidance and support.

References

[1] Bergman, Theodore L. *Fundamentals of heat and mass transfer*. John Wiley & Sons, 2011.

[2] Khashi'ie, Najiyah Safwa, Iskandar Waini, Syazwani Mohd Zokri, Abdul Rahman Mohd Kasim, Norihan Md Arifin, and Ioan Pop. "Stagnation point flow of a second-grade hybrid nanofluid induced by a Riga plate." *International Journal of Numerical Methods for Heat & Fluid Flow* 32, no. 7 (2021): 2221-2239. https://doi.org/10.1108/HFF-08-2021-0534

[3] Choi, S. U. S., and Jeffrey A. Eastman. *Enhancing thermal conductivity of fluids with nanoparticles*. No. ANL/MSD/CP-84938; CONF-951135-29. Argonne National Lab.(ANL), Argonne, IL (United States), 1995.

[4] Mahat, Rahimah, Noraihan Afiqah Rawi, Abdul Rahman Mohd Kasim, and Sharidan Shafie. "Heat generation effect on mixed convection flow of viscoelastic nanofluid: Convective boundary condition solution." *Malaysian Journal of Fundamental and Applied Sciences* 16, no. 2 (2020): 166-172. https://doi.org/10.11113/mjfas.v16n2.1367

[5] Waini, Iskandar, Najiyah Safwa Khashi'ie, Abdul Rahman Mohd Kasim, Nurul Amira Zainal, Khairum Bin Hamzah, Norihan Md Arifin, and Ioan Pop. "Unsteady magnetohydrodynamics (MHD) flow of hybrid ferrofluid due to a rotating disk." *Mathematics* 10, no. 10 (2022): 1658. https://doi.org/10.3390/math10101658

[6] Mohd Kasim, Abdul Rahman, Nur Syamilah Arifin, Syazwani Mohd Zokri, Mohd Zuki Salleh, Nurul Farahain Mohammad, Dennis Ling Chuan Ching, Sharidan Shafie, and Noor Amalina Nisa Ariffin. "Convective transport of fluid-solid interaction: A study between non-Newtonian Casson model with dust particles." *Crystals* 10, no. 9 (2020): 814. https://doi.org/10.3390/cryst10090814

[7] Kanafiah, Siti Farah Haryatie Mohd, Abdul Rahman Mohd Kasim, Syazwani Zokri, and Nur Syamilah Arifin. "A Thematic Review on Mathematical Model for Convective Boundary Layer Flow." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 86, no. 2 (2021): 107-125. https://doi.org/10.37934/arfmts.86.2.107125

[8] Khashi'ie, Najiyah Safwa, Iskandar Waini, Abdul Rahman Mohd Kasim, Nurul Amira Zainal, Norihan Md Arifin, and Ioan Pop. "Thermal progress of a non-Newtonian hybrid nanofluid flow on a permeable Riga plate with temporal stability analysis." *Chinese Journal of Physics* 77 (2022): 279-290. https://doi.org/10.1016/j.cjph.2022.03.019

[9] Zokri, Syazwani Mohd, Nur Syamilah Arifin, Zanariah Mohd Yusof, Nursyazni Mohd Sukri, Abdul Rahman Mohd Kasim, Nur Atikah Salahudin, and Mohd Zuki Salleh. "Carboxymethyl Cellulose Based Second Grade Nanofluid around a Horizontal Circular Cylinder." *CFD Letters* 14, no. 11 (2022): 119-128. https://doi.org/10.37934/cfdl.14.11.119128

[10] Mohamed, Muhammad Khairul Anuar, Mohd Zuki Salleh, Fadhilah Che Jamil, and Ong Huei. "Free convection boundary layer flow over a horizontal circular cylinder in Al_2O_3-Ag/water hybrid nanofluid with viscous dissipation." *Malaysian Journal of Fundamental and Applied Sciences* 17, no. 1 (2021): 20-25. https://doi.org/10.11113/mjfas.v17n1.1964

[11] Reddy, Y., M. Suryanarayana Reddy, P. Sudarsana Reddy, and Ali J. Chamkha. "Effect of Brownian motion and thermophoresis on heat and mass transfer flow over a horizontal circular cylinder filled with nanofluid." *Journal of Nanofluids* 6, no. 4 (2017): 702-710. https://doi.org/10.1166/jon.2017.1365
[12] Swalmeh, Mohammed Z., Hamzeh T. Alkasasbeh, Abid Hussanan, and Mustafa Mamat. "Influence of micro-rotation and micro-inertia on nanofluid flow over a heated horizontal circular cylinder with free convection." *Theoretical and Applied Mechanics* 46, no. 2 (2019): 125-145. https://doi.org/10.2298/TAM181120008S
[13] Prasad, V. Ramachandra, S. Abdul Gaffar, and B. Rushi Kumar. "Non-similar comutational solutions for double-diffusive MHD transport phenomena for non-newtnian nanofluid from a horizontal circular cylinder." *Nonlinear Engineering* 8, no. 1 (2019): 470-485. https://doi.org/10.1515/nleng-2018-0035
[14] Tiwari, Raj Kamal, and Manab Kumar Das. "Heat transfer augmentation in a two-sided lid-driven differentially heated square cavity utilizing nanofluids." *International Journal of Heat and Mass Transfer* 50, no. 9-10 (2007): 2002-2018. https://doi.org/10.1016/j.ijheatmasstransfer.2006.09.034
[15] El-Zahar, E. R., A. M. Rashad, W. Saad, and L. F. Seddek. "Magneto-hybrid nanofluids flow via mixed convection past a radiative circular cylinder." *Scientific Reports* 10, no. 1 (2020): 10494. https://doi.org/10.1038/s41598-020-66918-6
[16] Yasin, S. H. M., M. K. A. Mohamed, Z. Ismail, and M. Z. Salleh. "MHD free convection boundary layer flow near the lower stagnation point flow of a horizontal circular cylinder in ferrofluid." In *IOP Conference Series: Materials Science and Engineering*, vol. 736, no. 2, p. 022117. IOP Publishing, 2020. https://doi.org/10.1088/1757-899X/736/2/022117
[17] Sarif, Norhafizah Md, Mohd Zuki Salleh, Abdul Rahman Mohd Kasim, Leony Tham, and Roslinda Nazar. "Numerical study of mixed convection boundary layer flow near the lower stagnation point of a horizontal circular cylinder in nanofluids." *ARPN Journal of Engineering and Applied Sciences* 11, no. 11 (2016): 7274-7278.
[18] Afsana, Sadia, Preetom Nag, Md Mamun Molla, and Sharaban Thohura. "Natural convection flow of nanofluids over horizontal circular cylinder with uniform surface heat flux." In *AIP Conference Proceedings*, vol. 2324, no. 1. AIP Publishing, 2021. https://doi.org/10.1063/5.0037580
[19] Alkasasbeh, Hamzeh T., Mohammed Z. Swalmeh, Abid Hussanan, and Mustafa Mamat. "Numerical solution of heat transfer flow in micropolar nanofluids with oxide nanoparticles in water and kerosene oil about a horizontal circular cylinder." *IAENG International Journal of Applied Mathematics* 49, no. 3 (2019): 1-8.
[20] Buongiorno, Jacopo. "Convective transport in nanofluids." *ASME Journal of Heat and Mass Transfer* 128, no. 3 (2006): 240-250. https://doi.org/10.1115/1.2150834
[21] Reddy, P. Sudarsana, and Ali J. Chamkha. "Heat and mass transfer characteristics of nanofluid over horizontal circular cylinder." *Ain Shams Engineering Journal* 9, no. 4 (2018): 707-716. https://doi.org/10.1016/j.asej.2016.03.015
[22] Basha, H. Thameem, R. Sivaraj, V. Ramachandra Prasad, and O. Anwar Beg. "Entropy generation of tangent hyperbolic nanofluid flow over a circular cylinder in the presence of nonlinear Boussinesq approximation: a non-similar solution." *Journal of Thermal Analysis and Calorimetry* 143 (2021): 2273-2289. https://doi.org/10.1007/s10973-020-09981-5
[23] Akram, Javed, Ahmed Zeeshan, Mohammed Sh Alhodaly, and Marin Marin. "Evaluation of magnetohydrodynamics of natural convective heat flow over circular cylinder saturated by nanofluid with thermal radiation and heat generation effects." *Mathematics* 10, no. 11 (2022): 1858. https://doi.org/10.3390/math10111858
[24] Alwawi, Firas A., Abdulkareem Saleh Hamarsheh, Hamzeh T. Alkasasbeh, and Ruwaidiah Idris. "Mixed convection flow of magnetized Casson nanofluid over a cylindrical surface." *Coatings* 12, no. 3 (2022): 296. https://doi.org/10.3390/coatings12030296
[25] Damseh, Rebhi A. "Chemically Reactive Nanofluid Flowing across Horizontal Cylinder." *Jordan Journal of Mechanical & Industrial Engineering* 17, no. 1 (2023). https://doi.org/10.59038/jjmie/170108
[26] Mohamed, Muhammad Khairul Anuar, N. A. Z. M. Noar, Mohd Zuki Salleh, and Anuar Ishak. "Free convection boundary layer flow on a horizontal circular cylinder in a nanofluid with viscous dissipation." *Sains Malaysiana* 45, no. 2 (2016): 289-296.
[27] Prasad, V. Ramachandra, S. Abdul Gaffar, and O. Anwar Bég. "Heat and mass transfer of nanofluid from horizontal cylinder to micropolar fluid." *Journal of Thermophysics and Heat Transfer* 29, no. 1 (2015): 127-139. https://doi.org/10.2514/1.T4396
[28] Tham, Leony, Roslinda Nazar, and Ioan Pop. "Mixed convection flow from a horizontal circular cylinder embedded in a porous medium filled by a nanofluid: Buongiorno-Darcy model." *International Journal of Thermal Sciences* 84 (2014): 21-33. https://doi.org/10.1016/j.ijthermalsci.2014.04.020
[29] Swalmeh, M. Z., H. T. Alkasasbeh, A. Hussanan, and M. Mamat. "Numerical study of mixed convection heat transfer in methanol based micropolar nanofluid about a horizontal circular cylinder." In *Journal of Physics: Conference Series*, vol. 1366, no. 1, p. 012003. IOP Publishing, 2019. https://doi.org/10.1088/1742-6596/1366/1/012003

[30] Tlili, I., W. A. Khan, and K. Ramadan. "MHD flow of nanofluid flow across horizontal circular cylinder: steady forced convection." *Journal of Nanofluids* 8, no. 1 (2019): 179-186. https://doi.org/10.1166/jon.2019.1574

[31] Tham, Leony, Roslinda Nazar, and Ioan Pop. "Mixed convection flow over a horizontal circular cylinder with constant heat flux embedded in a porous medium filled by a nanofluid: Buongiorno-Darcy model." *Heat and Mass Transfer* 52 (2016): 1983-1991. https://doi.org/10.1007/s00231-015-1720-2

[32] Sarif, Norhafizah Md, Sallhe Mohd Zuki, and Roslinda Nazar. "Mixed convection over a horizontal circular cylinder embedded in porous medium immersed in a nanofluid with convective boundary conditions at lower stagnation point: A numerical solution." In *MATEC Web of Conferences*, vol. 189, p. 02004. EDP Sciences, 2018. https://doi.org/10.1051/matecconf/201818902004

[33] Mabood, F., W. A. Khan, and M. M. Yovanovich. "Forced convection of nanofluid flow across horizontal circular cylinder with convective boundary condition." *Journal of Molecular Liquids* 222 (2016): 172-180. https://doi.org/10.1016/j.molliq.2016.06.086

[34] Mahat, Rahimah, Noraihan Afiqah Rawi, Abdul Rahman Mohd Kasim, and Sharidan Shafie. "Mixed convection boundary layer flow of viscoelastic nanofluid past a horizontal circular cylinder: Case of constant heat flux." In *Journal of Physics: Conference Series*, vol. 890, no. 1, p. 012052. IOP Publishing, 2017. https://doi.org/10.1088/1742-6596/890/1/012052

[35] Mahat, Rahimah, Noraihan Afiqah Rawi, Abdul Rahman Mohd Kasim, and Sharidan Shafie. "Mixed convection flow of viscoelastic nanofluid past a horizontal circular cylinder with viscous dissipation." *Sains Malaysiana* 47, no. 7 (2018): 1617-1623. https://doi.org/10.17576/jsm-2018-4707-33

[36] Mahat, Rahimah, Noraihan Afiqah Rawi, Sharidan Shafie, and Abdul Rahman Mohd Kasim. "Mixed convection boundary layer flow of viscoelastic nanofluid past a horizontal circular cylinder with convective boundary condition." *International Journal of Mechanical Engineering and Robotics Research* 8, no. 1 (2019): 87-91. https://doi.org/10.18178/ijmerr.8.1.87-91

[37] Mahat, Rahimah, Abdul Rahman Mohd Kasim, and Sharidan Shafie. "Numerical simulation of viscoelastic nanofluid past a horizontal circular cylinder with viscous dissipation." *Journal of Advanced Research in Dynamical and Control System* 12, no. 6 (2020): 1851-1858.

[38] Mahat, Rahimah, Muhammad Saqib, Imran Ulah, Sharidan Shafie, and Sharena Mohamad Isa. "Magnetohydrodynamics Mixed Convection of Viscoelastic Nanofluid Past a Circular Cylinder with Constant Heat Flux." *CFD Letters* 14, no. 9 (2022): 52-59. https://doi.org/10.37934/cfdl.14.9.5259

[39] Hamarsheh, Abdulkareem Saleh, Firas A. Alwawi, Hamzeh T. Alkasasbeh, Ahmed M. Rashad, and Ruwaidiah Idris. "Heat transfer improvement in MHD natural convection flow of graphite oxide/carbon nanotubes-methanol based casson nanofluids past a horizontal circular cylinder." *Processes* 8, no. 11 (2020): 1444. https://doi.org/10.3390/pr8111444

[40] Dash, R. K., K. N. Mehta, and G. Jayaraman. "Casson fluid flow in a pipe filled with a homogeneous porous medium." *International Journal of Engineering Science* 34, no. 10 (1996): 1145-1156. https://doi.org/10.1016/0020-7225(96)00012-2

[41] Alwawi, Firas A., Hamzeh T. Alkasasbeh, A. M. Rashad, and Ruwaidiah Idris. "Heat transfer analysis of ethylene glycol-based Casson nanofluid around a horizontal circular cylinder with MHD effect." *Proceedings of the Institution of Mechanical Engineers, Part C: Journal of Mechanical Engineering Science* 234, no. 13 (2020): 2569-2580. https://doi.org/10.1177/0954406220908624

[42] Alwawi, Firas, Ibrahim M. Sulaiman, Mohammed Z. Swalmeh, and Nusayba Yaseen. "Energy transport boosters of magneto micropolar fluid flowing past a cylinder: A case of laminar combined convection." *Proceedings of the Institution of Mechanical Engineers, Part C: Journal of Mechanical Engineering Science* 236, no. 22 (2022): 10902-10913. https://doi.org/10.1177/09544062221111055

[43] Bég, O. Anwar, A. Subba Rao, C. H. Amanulla, N. Nagendra, M. Suryanarayana Reddy, and A. Kadir. "Numerical study of hydromagnetic non-Newtonian nanofluid transport phenomena from a horizontal cylinder with thermal slip: aerospace nanomaterial enrobing simulation." *Journal of Nanofluids* 7, no. 1 (2018): 115-128. https://doi.org/10.1166/jon.2018.1423

[44] Zokri, Syazwani Mohd, Nur Syamilah Arifin, Kasim Abdul Rahman Mohd, and Mohd Zuki Salleh. "Suspended nanoparticles on mixed convection flow of a Jeffrey fluid due to a horizontal circular cylinder with viscous dissipation." *Thermal Science* 24, no. 6 Part A (2020): 3757-3770. https://doi.org/10.2298/TSCI181027106M

[45] Zokri, Syazwani Mohd, Nur Syamilah Arifin, Abdul Rahman Mohd Kasim, and Mohd Zuki Salleh. "Flow of jeffrey fluid over a horizontal circular cylinder with suspended nanoparticles and viscous dissipation effect: Buongiorno model." *CFD Letters* 12, no. 11 (2020): 1-13. https://doi.org/10.37934/cfdl.12.11.113

[46] Zokri, Syazwani Mohd, Mohd Zuki Salleh, Nur Syamilah Arifin, and Abdul Rahman Mohd Kasim. "Lower stagnation point flow of convectively heated horizontal circular cylinder in Jeffrey nanofluid with suction/injection." *Journal of*

Advanced Research in Fluid Mechanics and Thermal Sciences 76, no. 1 (2020): 135-144. https://doi.org/10.37934/arfmts.76.1.135144

[47] Alwawi, Firas A., Feras M. Al Faqih, Mohammed Z. Swalmeh, and Mohd Asrul Hery Ibrahim. "Combined convective energy transmission performance of Williamson hybrid nanofluid over a cylindrical shape with magnetic and radiation impressions." *Mathematics* 10, no. 17 (2022): 3191. https://doi.org/10.3390/math10173191

[48] Hayath, Thameem Basha, Sivaraj Ramachandran, Ramachandra Prasad Vallampati, and O. Anwar Bég. "Computation of non-similar solution for magnetic pseudoplastic nanofluid flow over a circular cylinder with variable thermophysical properties and radiative flux." *International Journal of Numerical Methods for Heat & Fluid Flow* 31, no. 5 (2021): 1475-1519. https://doi.org/10.1108/HFF-04-2020-0236