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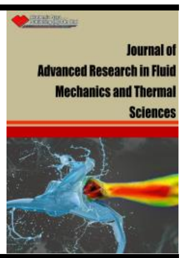

A Thematic Review on Mathematical Model for Convective Boundary Layer Flow

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ABSTRACT

Convection refers to the heat transfer that occurs between moving fluid and surface at a different temperature. Nowadays, there has been a great deal of interest in the convective boundary layer fluid flow problems. Despite its popularity, the review paper discussing the mathematical model for various fluid types regarding various geometry and boundary conditions has been observed to fall short. This review paper adopts a thematic review based on the mathematical model captured in published fluid flow problems from 2015 until 2020. The articles were analysed using thematic analysis ATLAS.ti 8 software. Using keyword search and filtering criteria from Scopus and Web of Science (WOS) databases, 198 peer-reviewed journal articles were identified. However, after the exclusion and inclusion processes, only 50 articles were reviewed as final articles. The thematic review of these articles has further identified 120 initial codes characterising the mathematical model, grouped into 7 clusters: Viscoelastic, Williamson, Casson, Brinkman, Jeffrey, Nanofluid and hybrid Nanofluid. The report from the code-to-document in ATLAS.ti 8 found that the boundary condition, geometry and method were highlighted in the literature. The outcomes of this study will benefit the future research direction to identify the gap for future studies, specifically in extending the mathematical model for fluid flow problems as well as choosing the suitable geometry and boundary condition.

1. Introduction

Convection refers to the heat transfer generated by the random motion of molecules and the energy transmitted by fluid's motion. Additionally, the boundary condition and surface geometry are the dual elements that influence the heat transfer process. Due to its significance in many industrial

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and technical applications, interest in convective boundary layer flow problems has increased substantially over the year.

About a dozen articles have been published on convective boundary layer problems in various fluid types with different surface geometry. For example, the fluid flow problem along a flat plate [1-4], fluid flow over the circular cylinder [5-7], fluid flow over a stretching sheet [8-12], fluid flow over a sphere [13-15] and fluid flow over an inclined stretching sheet [16-18].

The theoretical investigations in non-Newtonian fluids are more challenging due to the complexity of their constitutive equations. A non-Newtonian fluid is a fluid that does not obey Newton's law in which the viscosity will change to either liquid or more solid under stress. The most frequently highlighted mathematical model for non-Newtonian in the literature comprehend the Jeffrey fluid [19-22], Nanofluid [23-25], Viscoelastic fluid[26-28], Brinkman fluid [29-31], Casson fluid [32-34] and Williamson fluid models [35-36]. Even though the convective boundary layer flow has been widely explored, the review paper on different mathematical models with dissimilar boundary conditions, surface geometry, and method has been very scarce.

Therefore, the underpinning of this paper is to perform a systematic review of the mathematical model discussed in convective boundary layer flow. The discussion will be specifically directed to boundary condition, surface geometry and methods used in each problem based on the following research question; What are the mathematical models of the non-Newtonian fluid on convective boundary layer flow being discussed in the publication from 2015 to 2020?

2. Thematic Review Process

This section discusses in detail the materials and methods used in this study. The main concept of this study is the thematic review process introduced by [37], implemented using ATLAS.ti 8 software. He applied the thematic analysis technique in the literature review. The thematic analysis identifies the trend and constructs the themes through detailed reading on the topic [38]. In this study, the first step is defining the pattern and constructing a mathematical model category to understand the trend of publication in various countries. The research concept is to analyse and interpret the findings on the types of a mathematical model in the convective boundary layer for recommendations of future study. Literature selection was carried out according to different selection criteria, which are 1) publication from 2015- 2020, 2) has at least keyword(s) of the convective boundary layer or fluid flow, and 3) focus on a mathematical model. The decision to limit the fluid type was made to help define the model used in fluid flow problems. The literature discovery was conducted using the search strings in the Scopus and WOS database, as illustrated in Table 1.

Table 1
Search strings from Scopus and WOS

Database	Keyword	Result
Scopus	TITLE-ABS-KEY ("Convective Boundary Layer" AND fluid flow) PUBYEAR (2015-2020)	129 articles
WOS	TITLE-ABS-KEY ("Convective Boundary Layer" AND fluid flow) PUBYEAR (2015-2020)	69 articles

In this study, the systematic review of articles was performed in the Scopus and WOS search to identify the mathematical model of the convective boundary layer. The inclusion and exclusion criteria are carried out in the current study, as displayed in Figure 1. The initial search was made with 129 (Scopus) and 69 (WOS) articles. However, 125 papers have been removed and not matched due to their premature outcomes, while 23 overlapping articles also have been excluded. Some of these articles were incomplete, or the full articles cannot be accessed and have a broken link. Therefore, the final paper to be reviewed is 50 articles, including conference proceeding and journals.

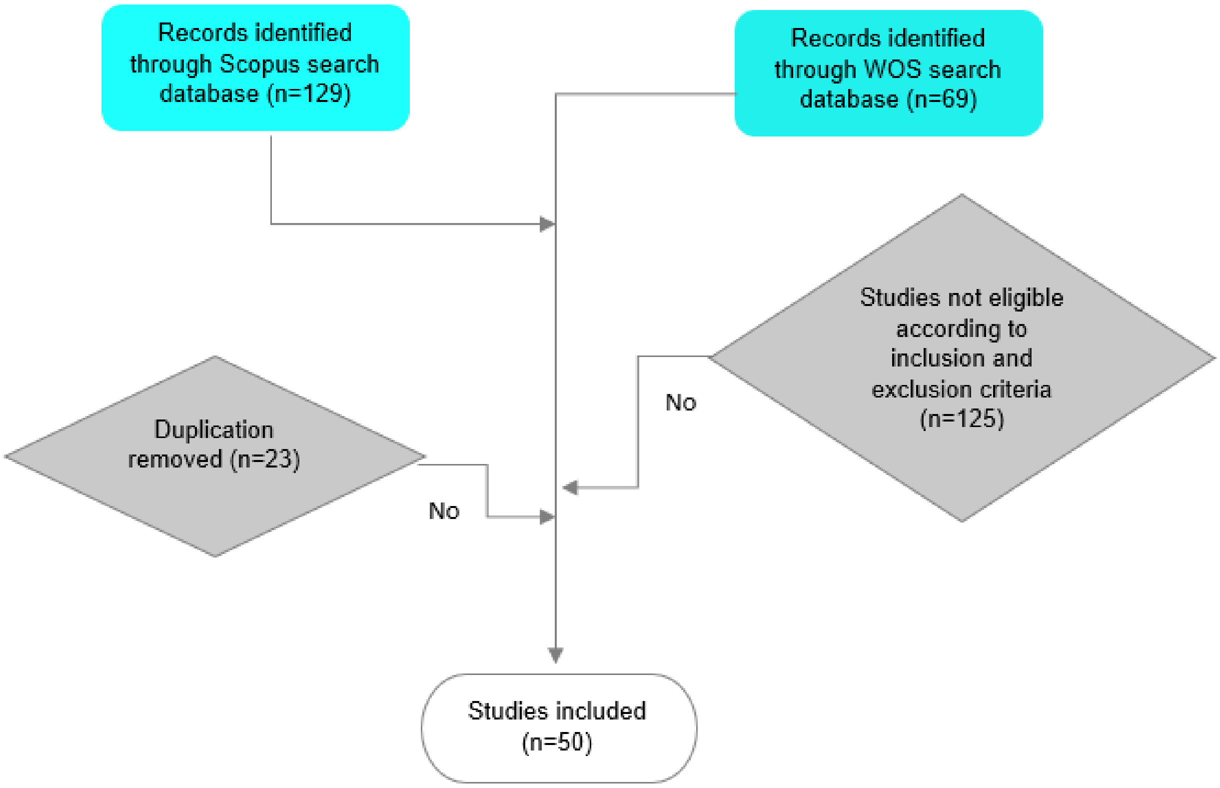

Fig. 1. Inclusion and exclusion criteria in the thematic review

The articles were uploaded in the ATLAS.ti 8 as primary documents, grouped into author, issue number, periodical, publisher and year of publication. In the first round, the initial coding resulted in 120 codings and later was categorised into seven main categories: Viscoelastic, Williamson, Casson, Brinkman, Jeffrey, Nanofluid, and hybrid Nanofluid models. In a thematic review, clustering the initial coding into the group classifies a common code under a similar category. However, it is also common for a code to belong to several categories, namely code group.

3. Past Studies on Convective Boundary Layer Flow

In this section, the tables and figures are displayed based on the following subject: journals and year, authors and fluid models, country and year as well as fluid models and year. Firstly, these research strings are directly referenced in the identified 50 articles through several journals listed in Table 2. As can be seen from the table, many publications highlighted the convective boundary layer fluid flow problems in 2017. The trends of publication are shown in a normal distribution. It is also noted that the involved journals are not necessarily heat and fluid-related journals such as Advanced Powder Technology, AIP Conference Proceedings and Journal of Symmetry.

Table 2
Reviewed articles based on journals and year

Journals	Year					
	2015	2016	2017	2018	2019	2020
Advanced Powder Technology	1		1	1		
Ain Shams Engineering Journal		1				
AIP Conference Proceedings		1	1			
American Journal of Heat and Mass Transfer			1		1	
Archives of Thermodynamics					1	
ARPN Journal of Engineering and Applied Sciences		1				
Canadian Journal of Physics	1					
Chemical Engineering Science			1			
Engineering Computations (Swansea, Wales)			1			
Engineering Science and Technology, an International Journal			1			
Frontiers in Heat and Mass Transfer			1			
International Journal of Ambient Energy				1		
International Journal of Applied and Computational Mathematics			1			
International Journal of Numerical Methods for Heat and Fluid Flow		1	2	1	1	
IOP Conference Series: Materials Science and Engineering			1			
Journal of Aerospace Engineering	1					
Journal of Applied Fluid Mechanics		1				
Journal of Engineering Physics and Thermophysics	1					
Journal of King Saud University – Science					1	
Journal of the Brazilian Society of Mechanical Sciences and Engineering			1			
Journal of Thermal Analysis and Calorimetry				1		
MATEC Web of Conferences				1		
Materials Today: Proceedings			1	1		
Mathematical Modelling of Engineering Problems						1
Physics Letters, Section A: General, Atomic and Solid State Physics				1		
PloS ONE	1					
Procedia Engineering	1	1				
Proceedings of the Institution of Mechanical Engineers, Part N: Journal of Nanomaterials, Nanoengineering and Nanosystems			1			
Sains Malaysiana				1		
Scientia Iranica			1	1		
Symmetry					1	
Thermal Science	1			1		
Water						1
Journal of Mechanical Engineering Science						1
Case Studies in Thermal Engineering						1
Mathematics						1
Heliyon					1	
Chinese Journal of Physics				1		
Totals	7	6	15	11	6	5

Next, research articles were analysed in an iterative process as tabulated in Table 3. The comparison was made according to its similarity and differences to ensure consistency in the resulting sub-categories. These articles were assigned to the types of fluid models. It was noticed that the Nanofluid model, which is Buongiorno and Tiwari and Das, are very popular models among the considered articles. Recently, the hybrid Nanofluid model has been extensively explored by researchers.

Table 3
The classification of authors based on a fluid model

Author	Model							
	Brink-man	Buongi-orno	Cas-son	Jeff-rey	Tiwari das	Visco-elastic	William-son	Hybrid Nanofluid
Thumma *et al.*, [39]					1			
Thumma *et al.*, [40]					1			
Sravanthi [41]					1			
Kumar & Kumar [42]					1			
Sohail *et al.*, [3]		1						
Reddy [43]			1					
Rajesh *et al.*, [44]					1			
Narahari *et al.*, [45]		1						
Narahari *et al.*, [46]		1						
Metri *et al.*, [47]						1		
Makinde *et al.*, [48]		1						
Krishna & Reddy [49]	1							
Izani & Ali [50]				1				
Devi & Suriyakumar [51]					1			
Aziz *et al.*, [26]						1		
Archana *et al.*, [52]		1						
Akbar *et al.*, [53]		1						
Ahmed *et al.*, [54]			1					
Ahmed *et al.*, [55]		1						
Reddy & Shankar [56]		1						
Uddin *et al.*, [57]		1						
Al-Sharifi *et al.*, [22]				1				
Kumar & Kumar [58]					1			
Saranya *et al.*, [59]			1					
Reddy [60]			1					
Parmar [61]							1	
Nayak *et al.*, [62]		1						
Maleque [63]			1					
Khan *et al.*, [64]		1						
Isa *et al.*, [65]			1					
Hashim *et al.*, [66]							1	
Eswaramoorthi *et al.*, [67]						1		
Dinarvand *et al.*, [68]					1			
Dinarvand *et al.*, [69]		1						
Basir *et al.*, [70]		1						
Arifin *et al.*, [36]							1	
Zokri *et al.*, [20]				1				
Gangadhar *et al.*, [71]		1						
Tlili [72]				1				
Siyal *et al.*, [73]	1							
Chu *et al.*, [74]								1
Suganya *et al.*, [75]								1
U. Khan *et al.*, [76]								1
Waini *et al.*, [77]								1
Waini *et al.*, [78]								1
Manjunata *et al.*, [79]								1
Junoh *et al.*, [80]								1
Rostaimi *et al.*, [25]								1
Yousefi *et al.*, [81]								1
Mehryan *et al.*, [82]								1
Totals	2	14	6	4	8	3	3	10

After that, the trends were analysed following the country and year of the conducted study, as exhibited in Table 4. The trend was seen as rather popular in India and Malaysia. The publications from other countries are also reported, such as Bangladesh, Egypt, Iran, Pakistan, Saudi Arabia, South Africa, Sweden and China. This shows that trends of convective boundary layer have increased over the varying country with different types of the fluid model.

Table 4
Reviewed articles based on country and year

Country	Year						
	2015	2016	2017	2018	2019	2020	Totals
Bangladesh	0	0	1	0	0	0	1
Egypt	0	0	1	0	1	0	2
India	2	2	7	4	2	2	19
Iran	2	0	1	2	0	0	5
Malaysia	1	2	5	2	2	1	13
Pakistan	2	1	0	2	0	1	6
Saudi Arabia	0	0	0	0	1	0	1
South Africa	0	0	0	1	0	0	1
Sweden	0	1	0	0	0	0	1
China	0	0	0	0	0	1	1

Lastly, in this paper, the mathematical model for convective boundary layer flow problems is discussed over various fluid types. As can be seen from the Table 5, the most popular mathematical model is the Nanofluid model, which is Buongiorno (28%), and Tiwari and Das (16%). These two models have attracted more attention in engineering applications for the Nanofluid type over the years. Besides, the Hybrid nanofluid model (20%) has gained much attraction from 2017 to 2020. It is then followed by Casson (12%), Jeffrey (8%), Williamson (6%), Viscoelastic (6%) and Brinkman (4%). The pattern of the mathematical model shows that there is limited work focusing on Williamson, Viscoelastic and Brinkman Models.

Table 5
Reviewed articles based on fluid models and year

Models		Year						
		2015	2016	2017	2018	2019	2020	Totals
Brinkman		0	0	0	2	0	0	2
Nanofluid	Buongiorno	4	1	4	2	2	1	14
	Tiwari and Das	1	1	5	1	0	0	8
Casson		1	1	3	1	0	0	6
Jeffrey		0	2	0	1	1	0	4
Viscoelastic		1	1	1	0	0	0	3
Williamson		0	0	1	2	0	0	3
Hybrid Nanofluid		0	0	1	2	3	4	10

This final section discusses the mathematical models with the related boundary condition, surface geometry, and method illustrated in figures and tables for every section below.

3.1 Viscoelastic Model

Viscoelasticity is the property of materials that exhibit both viscous and elastic properties deformation. Some examples of viscoelastic materials include biopolymers, metals at very high temperatures, and bitumen materials. Cracking happens when the pressure is strongly applied and beyond the elastic limit. The study of boundary layer flow and heat transfer of viscoelastic fluid has been addressed in many engineering applications. Figure 2 shows the network diagram of the Viscoelastic model, while the summary of previous research topic based on boundary condition, surface geometry and method are listed in Table 6. Eswaramoorthi *et al.,* [67] studied the problem of unsteady three-dimensional magnetohydrodynamic (MHD) in stretching surface with constant wall temperature (CWT) boundary condition. They derived the analytical solutions using Homotopy Analysis Method (HAM). In another study of MHD mixed convection boundary layer embedded in a porous medium over a similar geometry, Metri *et al.,* [47] used two types of the heating process, namely the constant heat flux (CHF) and constant wall temperature (CWT). The numerical solutions were then solved using Runge Kutta Fehlberg Method with shooting technique. Meanwhile, Aziz *et al.,* [26] investigated the effect of aligned MHD on a mixed convective boundary layer past a circular cylinder for the case of Newtonian Heating (NH). They used the Keller Box method to solve the numerical solution.

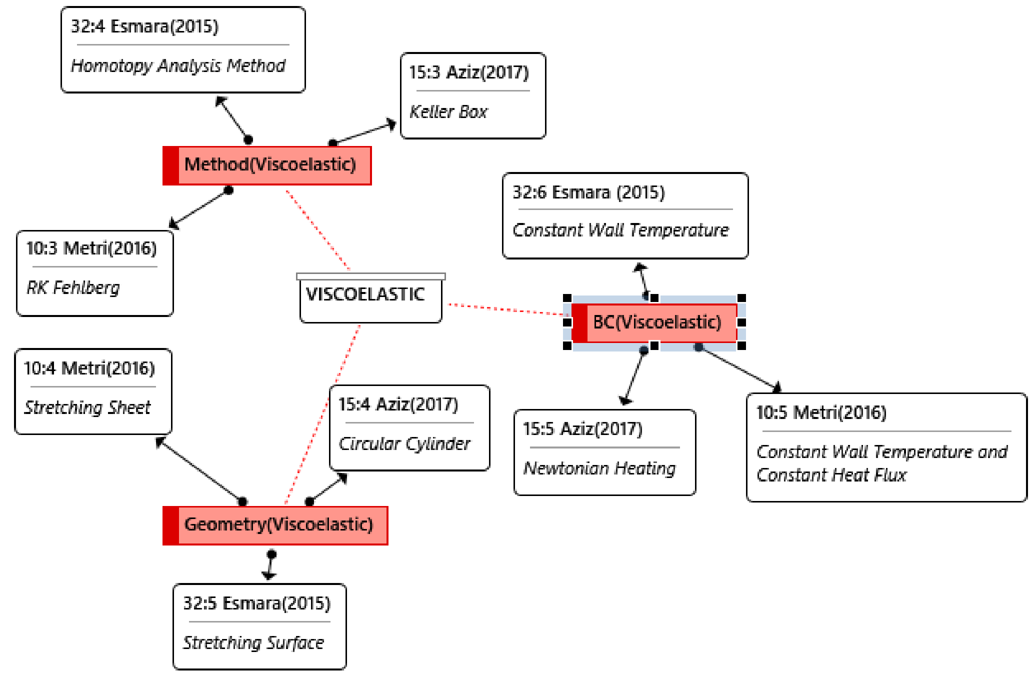

Fig. 2. A network of Viscoelastic model

Table 6
Summary of authors based on boundary condition, geometry, and method

Authors	Boundary Condition	Geometry	Method
Eswaramoorthi *et al.,* [67]	CWT	Stretching Surface	Homotopy Analysis Method
Metri *et al.,* [47]	CHF & CWT	Stretching Surface	Runge Kutta Fehlberg
Aziz *et al.,* [26]	NH	Circular Cylinder	Keller Box

3.2 Casson Model

Casson fluid can be described as a shear-thinning liquid having infinite viscosity at zero shear rate, yield stress below regions with no flow, and zero viscosity at an infinite shear rate Mehta and Dash [83]. Numerous researchers have studied on Casson fluid model owing to its special yield stress characteristic. The overall network diagram of the Casson model is shown in Figure 3, while Table 7 shows the summary of authors based on boundary condition, geometry and method. The investigation involving flow over a stretching sheet with constant wall temperature was conducted by many researchers ([54,60,65]). They used the "built-in" Matlab program (BVP4C), the Shooting method and Runge Kutta 4th order integration, respectively, to solve the numerical solution. In other theoretical studies, Reddy [43]and Maleque [63] investigated the MHD convective boundary layer flow over the inclined stretching surface and vertical plate in the presence of thermal radiation and chemical reaction, respectively. It was noticed that the CBC is rarely used in the recent study. Therefore, Saranya *et al.,* [59]considered the convective boundary condition to investigate steady convective boundary layer flow and heat transfer of base fluids with magnetic/non-magnetic nanoparticles over a flat plate, incorporating non-linear thermal radiation slip effects.

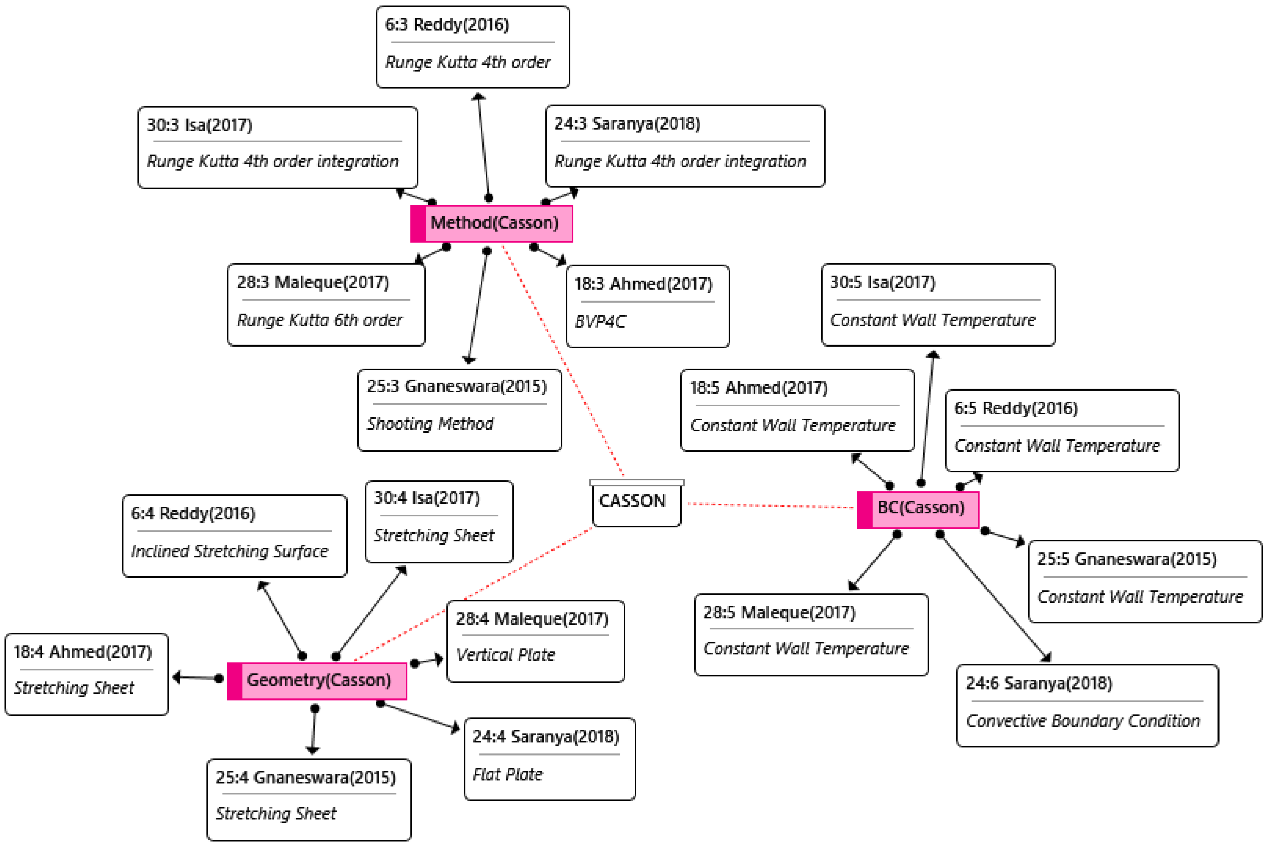

Fig. 3. A network of Casson model

Table 7
Summary of authors based on boundary condition, geometry and method

Authors	Boundary Condition	Geometry	Method
Reddy [60]	CWT	Stretching Sheet	Shooting method
Reddy [43]	CWT	Inclined Stretching Sheet	Runge Kutta 4th
Ahmed *et al.,* [54]	CWT	Stretching Sheet	BVP4C
Maleque [63]	CWT	Vertical Plate	Runge Kutta 6th
Isa *et al.,* [65]	CWT	Stretching Sheet	Runge Kutta 4th Integration
Saranya *et al.,* [59]	CBC	Flat Plate	Runge Kutta 4th Integration

3.3 Williamson Model

Figure 4 shows a network diagram of the Williamson fluid model. It is characterised as a non-Newtonian fluid with a shear-thinning property where the viscosity decreases with an increasing shear stress rate. According to Williamson [84], yield stress does not influence fluid behaviour and cannot be molded. Several studies on the flow behaviour of Williamson fluid under the thermal condition of CBC were considered by Arifin *et al.,* [36], Hashim *et al.,* [61] and Parmar [66], as can be seen in Table 8. They applied different numerical solutions such as Runge Kutta Fehlberg 4th and 5th order and Runge Kutta Integration. Arifin *et al.,* [36] analysed Williamson fluid on the convective boundary layer flow and heat transfer over a horizontal stretching sheet. Meanwhile, Hashim *et al.,* [66] investigated the effect of thermal radiation due to an expanding cylinder. They revealed that friction and heat transfer coefficients are greatly increased by the magnetic parameter for upper branch solutions. In another study, Parmar [61] discussed the effect of MHD Williamson fluid over an inclined stretching sheet. Therefore, it can be concluded that the most used boundary condition in the literature is CBC. Hence, other boundary condition can be considered for future study with different geometry and effect.

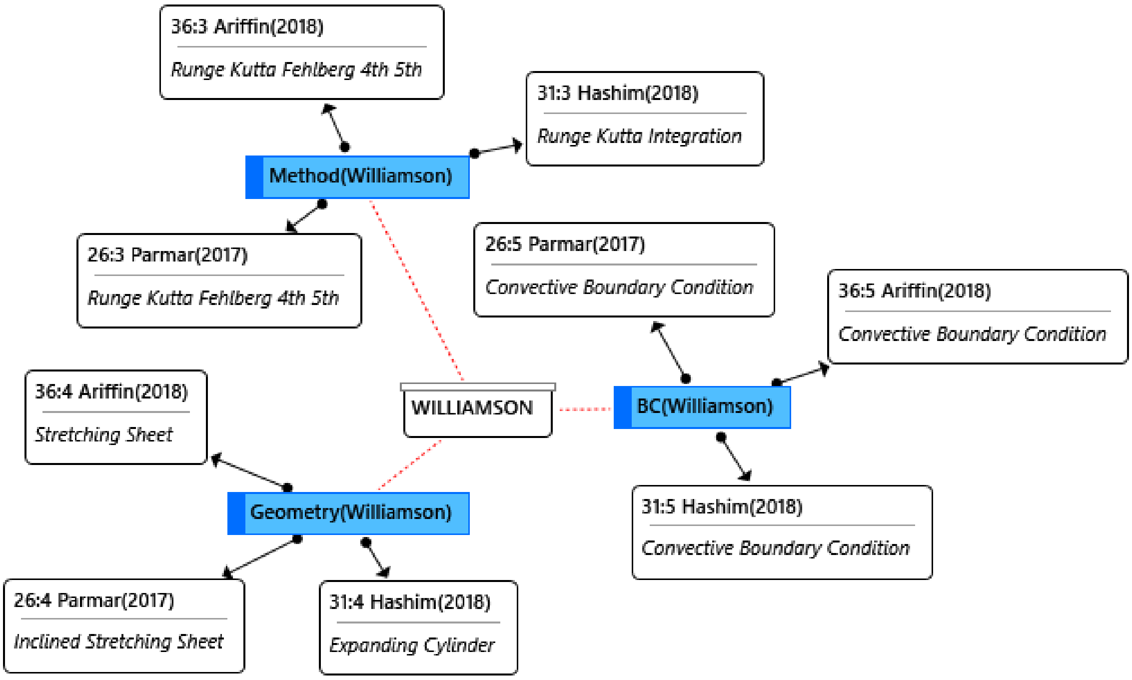

Fig. 4. A network of Williamson model

Table 8
Summary of authors based on boundary condition, geometry and method

Authors	Boundary Condition	Geometry	Method
Parmar [61]	CBC	Inclined Stretching Sheet	Runge Kutta Fehlberg 4th 5th
Hashim *et al.,* [66]	CBC	Expanding Cylinder	Runge Kutta Integration
Arifin *et al.,* [36]	CBC	Stretching Sheet	Runge Kutta Fehlberg 4th 5th

3.4 Jeffrey Model

The Jeffrey fluid model can explain the stress relaxation property of non-Newtonian fluids. It is also known as the relaxation and retardation time which cannot be defined in the normal viscous fluid model. Figure 5 illustrated a network diagram of the Jeffrey Model. The flow induced by various surfaces such as stretching sheet, inclined stretching sheet, exponential stretching and horizontal circular cylinder have been considered by Zokri *et al.,* [20], Al-Sharifi *et al.,* [22], Izani & Ali [50] and Tlili [72], as can be seen in Table 9. The most frequently highlighted boundary condition in the literature is the CWT and was solved using different methods such as Keller Box, Quasi linearisation and Runge Kutta Fehlberg 4th 5th order. Based on this review, it can be observed that very few researchers used CBC in their problems.

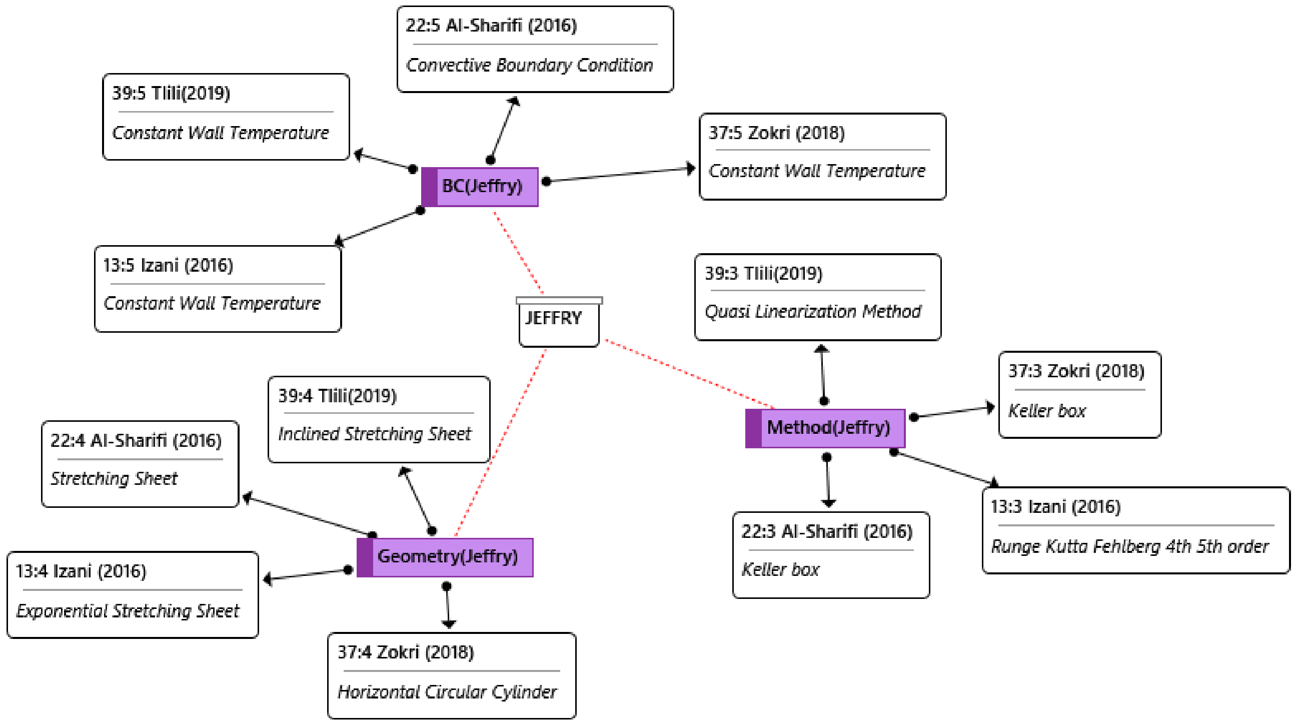

Fig. 5. A network of Jeffrey model

Table 9
Summary of authors based on boundary condition, geometry and method

Authors	Boundary Condition	Geometry	Method
Izani & Ali [50]	CWT	Exponential Stretching Sheet	Runge Kutta Fehlberg 4th 5th
Al-Sharifi *et al.,* [22]	CBC	Stretching Sheet	Keller Box
Zokri *et al.,* [20]	CWT	Horizontal Circular Cylinder	Keller Box
Tlili [72]	CWT	Inclined Stretching Sheet	Quasi Linearization

3.5 Brinkman Model

The overall network diagram of the Brinkman model is illustrated in Figure 6. It describes the incompressible flow in porous media where momentum transport by shear stress in the fluid is crucial. The model considers the viscous transport, momentum balance and introduces velocity in the spatial direction as the dependent variable. Based on Table 10, Krishna & Reddy [49] studied the MHD free convection in a boundary layer fluid flow through a porous medium over a moving infinite vertical plate by considering radiation and mass transfer. They used the CBC and solved the problem numerically using Runge Kutta 4th order. Another study in a porous medium by Siyal *et al.,* [73] discussed how the heat flow changes due to temperature or time on the rheology of magnetohydrodynamic Brinkman fluid over the oscillation heated plate subjected to CWT. They analysed the analytical solution using the Laplace Transform Technique. The Brinkman model is applicable for high porous surface and important in numerous engineering application. However, limited researchers have been working on this Brinkman fluid type.

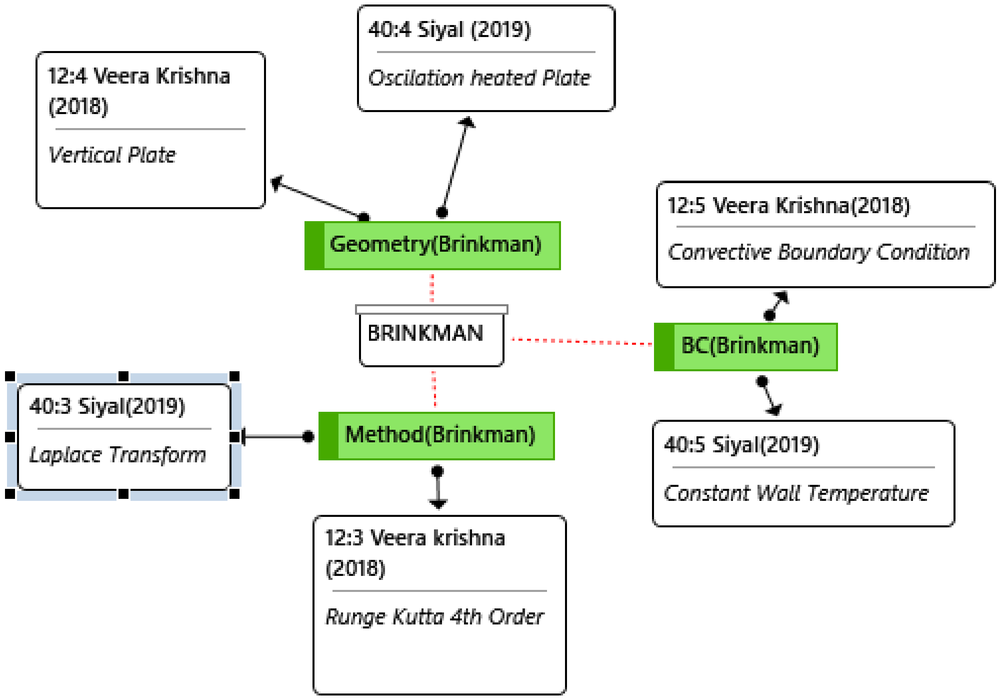

Fig. 6. A network of Brinkman model

Table 10
Summary of authors based on boundary condition, geometry and method

Authors	Boundary Condition	Geometry	Method
Krishna & Reddy [49]	CBC	Vertical Plate	Runge Kutta 4th
Siyal *et al.,* [73]	CWT	Oscillation Heated Plate	Laplace Transform

3.6 Nanofluid Models
3.6.1 Tiwari and Das

Tiwari and Das's model is one of the mathematical models for nanofluid. It takes into consideration the impact of the volume fraction of nanoparticles. The model ignores the velocity slip effect of nanoparticles, which is important in describing the existence of nanoparticles in the base fluid. Several studies in the flow analysis for nanoparticles are based on this model, as portrayed in Figure 7 and listed in Table 11. Thumma *et al.,* [39] considered water-based nanofluids containing metallic nano-particles to investigate the transient dissipative magnetohydrodynamic double diffusive free convective boundary layer flow passing the rotating vertical plate. They used the CWT and solved using the finite element method in numerical computation. Another study by Thumma *et al.,* [40] applied the same boundary condition and method focusing on MHD free convective boundary layer flow of nanofluids but in different geometry. It moves inclined porous plate by considering temperature and concentration gradients with suction effects. These two studies are relevant to high temperature rotating chemical engineering systems. Based on Table 11, most of them are using CWT with various surface geometry and effect. However, Sravanthi [41], used the CHF to study axisymmetric mixed convective boundary layer flow of a nanofluid past a stretching vertical circular cylinder in the presence of non-linear radiative heat flux. The different surface geometry and boundary condition will be among the factors that affect the heat transfer parameter.

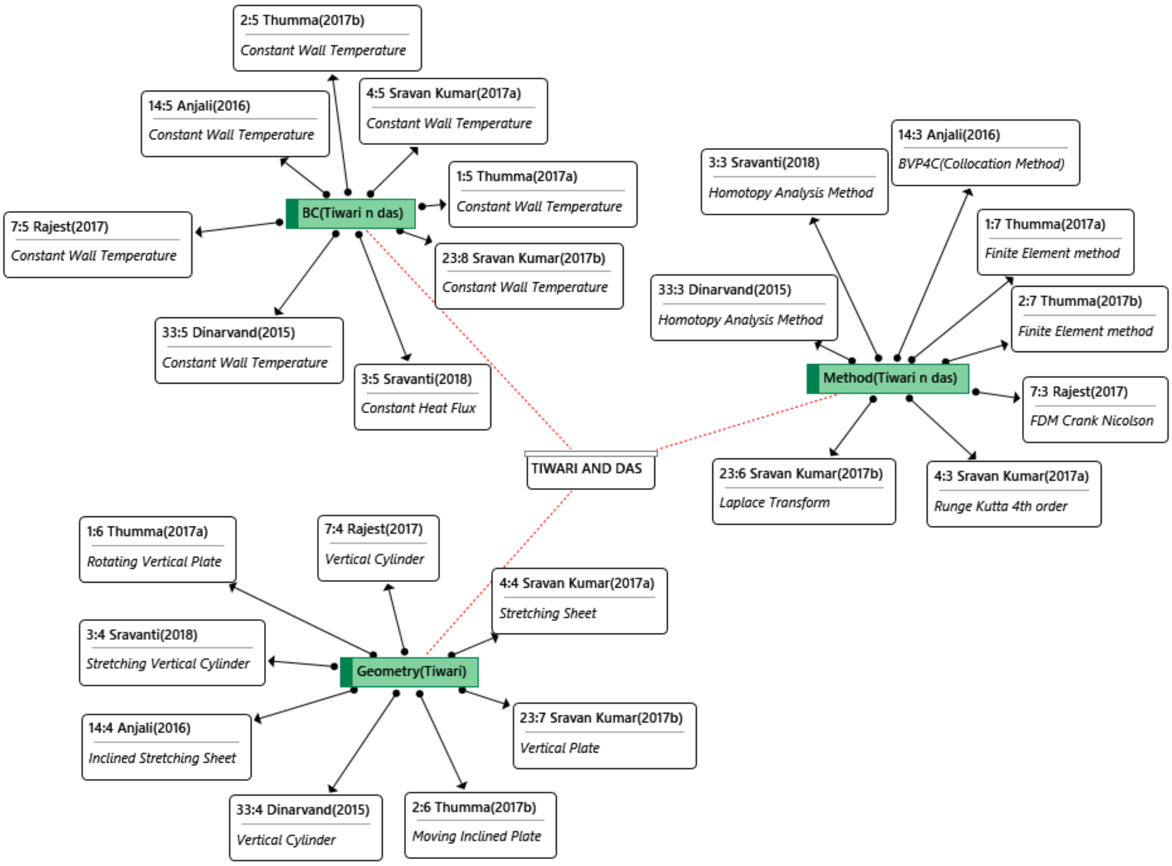

Fig. 7. A network of Tiwari Das model

Table 11
Summary of authors based on boundary condition, geometry and method

Authors	Boundary Condition	Geometry	Method
Dinarvand *et al.,* [68]	CWT	Vertical Cylinder	Homotopy Analysis Method
Devi & Suriyakumar [51]	CWT	Inclined Stretching Sheet	BVP4C (Collocation Method)
Rajesh *et al.,* [44]	CWT	Vertical Cylinder	FDM Crank Nicolson
Thumma *et al.,* [39]	CWT	Rotating Vertical porous plate	Finite Element Method
Thumma *et al.,* [40]	CWT	Moving Inclined porous Plate	Finite Element Method
Kumar & Kumar [42]	CWT	Stretching Sheet	Runge Kutta 4^{th}
Kumar & Kumar [58]	CWT	Vertical Plate	Laplace Transform
Sravanthi [41]	CHF	Stretching Vertical Cylinder	Homotopy Analysis Method

3.6.2 Buongiorno

Buongiorno model is another mathematical model for nanofluid. The network diagram of the Buongiorno model is illustrated in Figure 8. Several papers working on this model are shown in Table 12, which consider the velocity slip that combines Brownian motion and thermophoresis diffusion parameters. The effect of Brownian motion and thermophoresis parameter were examined by Narahari *et al.,* [45] and Narahari *et al.,* [46] with CWT and CHF, respectively. They investigated the two-dimensional transient natural convective boundary-layer flow past a vertical plate using the Finite-Difference Crank Nicolson method. In another study, Uddin *et al.,* [57] and Sohail *et al.,* [3] discussed the numerical solution of nanofluid over a vertical plate using the FDM Quasi Linear method and Collocation method, respectively, subjected to the CBC. Nayak *et al.,* [62] also explored the steady mixed convective boundary layer flow of nanofluid over a stretching sheet with CBC. This model affects the temperature and concentration profile but not the velocity profile. The literature review clearly shows the CWT and CBC considered by many researchers. Nevertheless, the CHF has been given less consideration even this boundary condition is crucial in many industrial and engineering applications.

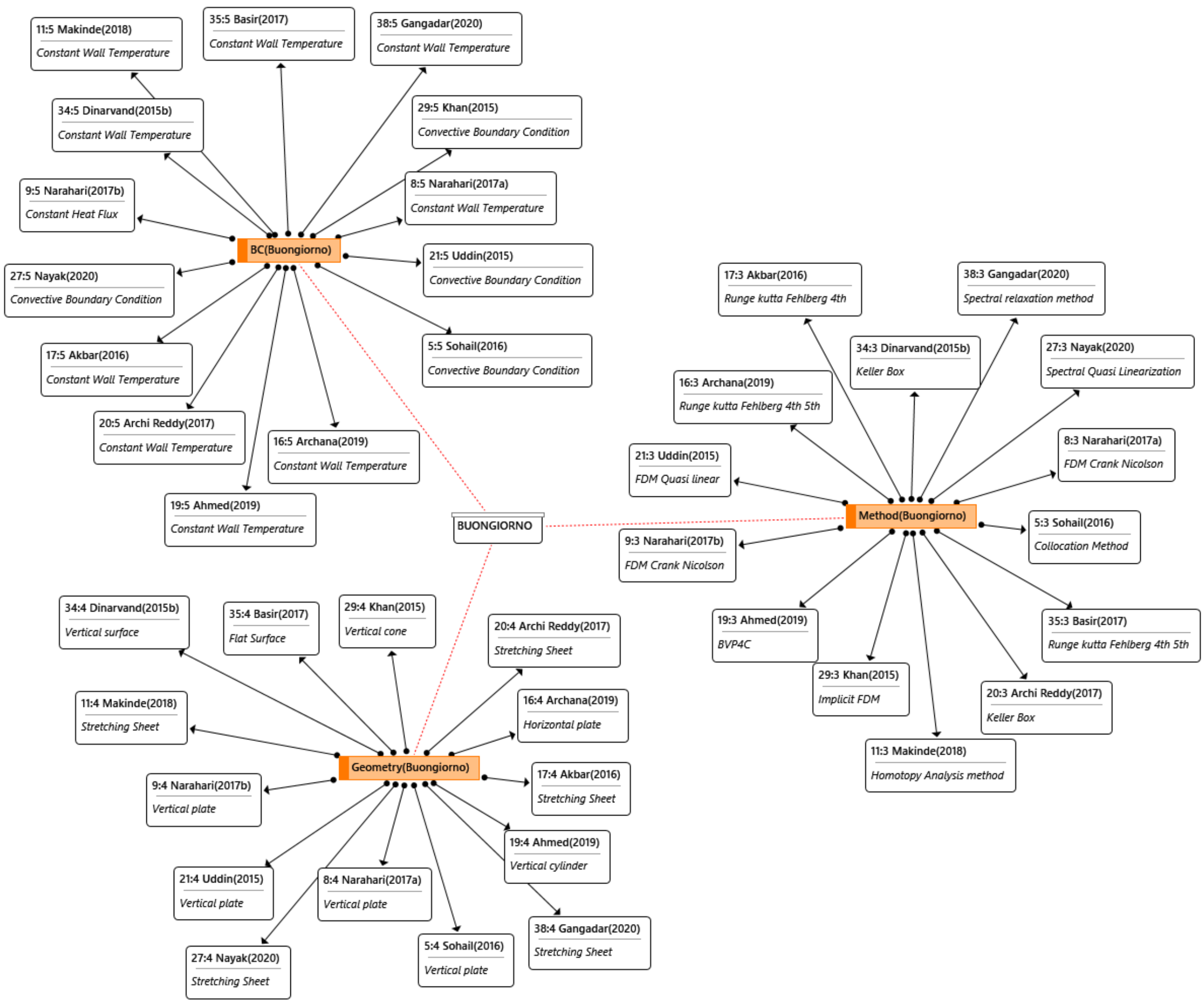

Fig. 8. A Network of Buongiorno model

Table 12
Summary of authors based on boundary condition, geometry and method

Authors	Boundary Condition	Geometry	Method
Dinarvand *et al.*, [69]	CWT	Vertical Surface	Keller Box
Khan *et al.*, [64]	CBC	Vertical Cone	Implicit FDM
Narahari *et al.*, [45]	CWT	Vertical Plate	FDM Crank Nicolson
Uddin *et al.*, [57]	CBC	Vertical Plate	FDM Quasi Linear
Akbar *et al.*, [53]	CWT	Stretching Sheet	Runge Kutta Fehlberg 4^{th}
Sohail *et al.*, [3]	CBC	Vertical Plate	Collocation Method
Basir *et al.*, [70]	CWT	Flat Surface	Runge Kutta Fehlberg 4^{th} 5^{th}
Narahari *et al.*, [46]	CHF	Vertical Plate	FDM Crank Nicolson
Reddy & Shankar [56]	CWT	Stretching Sheet	Keller Box
Gangadhar *et al.*, [71]	CWT	Stretching Sheet	Spectral relaxation Method
Makinde *et al.*, [48]	CWT	Stretching Sheet	Homotopy Analysis method
Ahmed *et al.*, [55]	CWT	Vertical Cylinder	BVP4C
Archana *et al.*, [52]	CWT	Horizontal Plate	Runge Kutta Fehlberg 4^{th} 5^{th}
Nayak *et al.*, [62]	CBC	Stretching Sheet	Spectral QuasiLinear

3.7 Hybrid Nanofluid Models

Recent years have seen a rise in several researches utilising hybrid nanofluid models. When two nanomaterials are suspended into regular fluid, it is known as hybrid nanofluid. Chu *et al.,* [74] studied the hybrid of Molybdenemdisulfide and graphene oxide over an upright cylinder for mixed convection together with thermal radiation effect. The water hybrid nanofluid flow for unsteady natural convection under the radiation and chemical reaction was discussed by [75]. It is found that the heat transfer rate grows by increasing radiation parameter and oscillation frequency. Note that constant wall temperature has been chosen as a preferred boundary condition using the "built-in" bvp4c method to solve the problem. The convective boundary layer problem of hybrid nanofluid has been well described by the researchers, as shown in Table 13.

Table 13
Summary of authors based on boundary condition, geometry and method

Authors	Boundary Condition	Geometry	Method
Chu at al. [74]	CWT	Stretching cylinder	bvp4c
Suganya *et al.,* [75]	CWT	Oscillating surface	Laplace Transform
Khan *et al.,* [76]	CWT	Shrinking/Stretching Sheet	bvp4c
Waini *et al.,* [77]	CWT	Moving Thin Needle	bvp4c
Waini *et al.,* [78]	CWT	Shrinking/Stretching Sheet	bvp4c
Manjunata *et al.,* [79]	CWT	Stretching Sheet	Runge Kutta Fehlberg
Junoh *et al.,* [80]	CWT	Shrinking/Stretching Sheet	bvp4c
Rostaimi *et al.,* [25]	CWT	Vertical Plate	bvp4c
Yousefi *et al.,* [81]	CWT	Wavy Cylinder	bvp4c
Mehryan *et al.,* [82]	CWT	The cavity in porous Media	Finite Element Method

4. Conclusion and Recommendation for Future Studies

This article reviews the patterns and trends of the mathematical model used in convective boundary layer problems to give researchers some idea in choosing the fluid model that fits the future study. The findings from the code-to-document analysis in ATLAS.ti 8 indicate that the patterns and trends on the mathematical model highlight the boundary condition, different geometry and methods used in the previous study. This paper examines the trends of fluid models by further defining the thematic codes within the fluid models from 2015 to 2020 to assess the models' trends to date.

Based on the findings of this report, there is a void in the study of Brinkman fluid over bluff body with the highlighted boundary condition. It is interesting to be researched due to its imperative applications in porous medium to enhance understanding of fluid flow phenomena. Furthermore, the research output will improve the development of related industries such as engineering equipment and the manufacturing industry. Therefore, it is also a good move to explore the new fluid flow model. In terms of contribution, this review paper provides potential new research of fluid flow model for researchers to explore the gaps that this paper addresses for future studies.

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References

[1] Tlili, Iskander, Masoud Rabeti, Mostafa Safdari Shadloo, and Zahra Abdelmalek. "Forced convection heat transfer of nanofluids from a horizontal plate with convective boundary condition and a line heat source embedded in porous media." *Journal of Thermal Analysis & Calorimetry* 141, no. 5 (2020). https://doi.org/10.1007/s10973-020-09473-6

[2] Khan, Z. H., W. A. Khan, and I. Pop. "Triple diffusive free convection along a horizontal plate in porous media saturated by a nanofluid with convective boundary condition." *International Journal of Heat and Mass Transfer* 66 (2013): 603-612. https://doi.org/10.1016/j.ijheatmasstransfer.2013.07.074

[3] Sohail, Ayesha, M. J. Uddin, and M. M. Rashidi. "Numerical study of free convective flow of a nanofluid over a chemically reactive porous flat vertical plate with a second-order slip model." *Journal of Aerospace Engineering* 29, no. 2 (2016): 04015047. https://doi.org/10.1061/(ASCE)AS.1943-5525.0000544

[4] Rawi, Noraihan Afiqah, Abdul Rahman Mohd Kasim, Mukheta Isa, and Sharidan Shafie. "g-Jitter induced mixed convection flow of heat and mass transfer past an inclined stretching sheet." *Jurnal Teknologi* 71, no. 1 (2014). https://doi.org/10.11113/jt.v71.3611

[5] 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

[6] 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

[7] Bose, A., N. Nirmalkar, and R. P. Chhabra. "Effect of aiding-buoyancy on mixed-convection from a heated cylinder in Bingham plastic fluids." *Journal of Non-Newtonian Fluid Mechanics* 220 (2015): 3-21. https://doi.org/10.1016/j.jnnfm.2014.06.006

[8] Zaib, Aurang, and Sharidan Shafie. "Thermal diffusion and diffusion thermo effects on unsteady MHD free convection flow over a stretching surface considering Joule heating and viscous dissipation with thermal stratification, chemical reaction and Hall current." *Journal of the Franklin institute* 351, no. 3 (2014): 1268-1287. https://doi.org/10.1016/j.jfranklin.2013.10.011

[9] Faizal, Nur Faizzati Ahmad, Norihan Md Ariffin, Yong Faezah Rahim, Mohd Ezad Hafidz Hafidzuddin, and Nadihah Wahi. "MHD and Slip Effect in Micropolar Hybrid Nanofluid and Heat Transfer over a Stretching Sheet with Thermal Radiation and Non-uniform Heat Source/Sink." *CFD Letters* 12, no. 11 (2020): 121-130. https://doi.org/10.37934/cfdl.12.11.121130

[10] Gireesha, B. J., A. J. Chamkha, S. Manjunatha, and C. S. Bagewadi. "Mixed convective flow of a dusty fluid over a vertical stretching sheet with non-uniform heat source/sink and radiation." *International Journal of Numerical Methods for Heat & Fluid Flow* (2013). https://doi.org/10.1108/09615531311323764

[11] Khan, Ansab Azam, Khairy Zaimi, Suliadi Firdaus Sufahani, and Mohammad Ferdows. "MHD Mixed Convection Flow and Heat Transfer of a Dual Stratified Micropolar Fluid Over a Vertical Stretching/Shrinking Sheet With Suction, Chemical Reaction and Heat Source." *CFD Letters* 12, no. 11 (2020): 106-120. https://doi.org/10.37934/cfdl.12.11.106120

[12] Rawi, Noraihan Afiqah, Abdul Rahman Mohd Kasim, Anati Ali, Mukheta Isa, and Sharidan Shafie. "The effect of g-jitter on double diffusion by mixed convection past an inclined stretching sheet." In *AIP Conference Proceedings*, vol. 1605, no. 1, pp. 392-397. American Institute of Physics, 2014. https://doi.org/10.1063/1.4887621

[13] Mohammad, Nurul Farahain, Iskandar Waini, Abdul Rahman Mohd Kasim, and Nurazleen Abdul Majid. "Unsteady boundary layer flow over a sphere in a porous medium." In *AIP conference proceedings*, vol. 1870, no. 1, p. 040076. AIP Publishing LLC, 2017. https://doi.org/10.1063/1.4995908

[14] Kasim, Abdul Rahman Mohd, Lim Yeou Jiann, N. A. Rawi, A. Ali, and Sharidan Shafie. "Mixed Convection Flow of Viscoelastic Fluid over a Sphere under Convective Boundary Condition Embedded in Porous Medium." In *Defect and Diffusion Forum*, vol. 362, pp. 67-75. Trans Tech Publications Ltd, 2015. https://doi.org/10.4028/www.scientific.net/DDF.362.67

[15] Shalini, J. A. I. N., and Shweta BOHRA. "Soret/Dufour Effects on Radiative Free Convection Flow and Mass Transfer over a Sphere with Velocity Slip and Thermal Jump." *Walailak Journal of Science and Technology (WJST)* 16, no. 9 (2019): 701-721. https://doi.org/10.48048/wjst.2019.3503

[16] Qasim, Muhammad, Tasawar Hayat, and Saleem Obaidat. "Radiation effect on the mixed convection flow of a

viscoelastic fluid along an inclined stretching sheet." *Zeitschrift für Naturforschung A* 67, no. 3-4 (2012): 195-202. https://doi.org/10.5560/zna.2012-0006
[17] Rafique, Khuram, Muhammad Imran Anwar, Masnita Misiran, Ilyas Khan, Sayer O. Alharbi, Phatiphat Thounthong, and Kottakkaran Sooppy Nisar. "Keller-box analysis of Buongiorno model with Brownian and thermophoretic diffusion for Casson nanofluid over an inclined surface." *Symmetry* 11, no. 11 (2019): 1370. https://doi.org/10.3390/sym11111370
[18] Afridi, Muhammad Idrees, Muhammad Qasim, Ilyas Khan, Sharidan Shafie, and Ali Saleh Alshomrani. "Entropy generation in magnetohydrodynamic mixed convection flow over an inclined stretching sheet." *Entropy* 19, no. 1 (2017): 10. https://doi.org/10.3390/e19010010
[19] Kasim, Abdul Rahman Mohd, Nur Syamilah Arifin, Syazwani Mohd Zokri, and Mohd Zuki Salleh. "Fluid-particle interaction with buoyancy forces on Jeffrey fluid with Newtonian heating." *CFD Letters* 11, no. 1 (2019): 1-16.
[20] Zokri, Syazwani Mohd, Nur Syamilah Arifin, Muhammad Khairul Anuar Mohamed, Abdul Rahman Mohd Kasim, Nurul Farahain Mohammad, and Mohd Zuki Salleh. "Mathematical model of mixed convection boundary layer flow over a horizontal circular cylinder filled in a Jeffrey fluid with viscous dissipation effect." *Sains Malaysiana* 47, no. 7 (2018): 1607-1615. https://doi.org/10.17576/jsm-2018-4707-32
[21] Arifin, Nur Syamilah, Syazwani Mohd Zokri, Abdul Rahman Mohd Kasim, Mohd Zuki Salleh, and Noor Amalina Nisa Arifin. "Jeffrey fluid embedded with dust particles over a shrinking sheet: A numerical investigation." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 74, no. 2 (2020): 196-209. https://doi.org/10.37934/arfmts.74.2.196209
[22] Al-Sharifi, H. A. M., A. R. M. Kasim, M. Z. Salleh, N. Md Sarif, N. F. Mohammad, S. Shafie, and A. Ali. "Influence of slip velocity on convective boundary layer flow of Jeffrey fluid under convective boundary conditions." *ARPN Journal of Engineering and Applied Sciences* 11, no. 18 (2006).
[23] 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
[24] Nagasasikala, Madduleti, and Bommanna Lavanya. "Heat and mass transfer of a MHD flow of a nanofluid through a porous medium in an annular, circular region with outer cylinder maintained at constant heat flux." *CFD Letters* 11, no. 9 (2019): 32-58.
[25] Rostami, Mohammadreza Nademi, Saeed Dinarvand, and Ioan Pop. "Dual solutions for mixed convective stagnation-point flow of an aqueous silica–alumina hybrid nanofluid." *Chinese Journal of Physics* 56, no. 5 (2018): 2465-2478. https://doi.org/10.1016/j.cjph.2018.06.013
[26] Aziz, Laila Amera, Abdul Rahman Mohd Kasim, H. A. M. Al-Sharifi, Mohd Zuki Salleh, Nurul Farahain Mohammad, Sharidan Shafie, and Anati Ali. "Influence of aligned MHD on convective boundary layer flow of viscoelastic fluid." In *AIP Conference Proceedings*, vol. 1842, no. 1, p. 030005. AIP Publishing LLC, 2017. https://doi.org/10.1063/1.4982843
[27] Kasim, Abdul Rahman Mohd, Mohd Ariff Admon, and Sharidan Shafie. "Free convection boundary layer flow of a viscoelastic fluid in the presence of heat generation." *Momentum* 10, no. 6 (2011).
[28] Dasman, Anisah, Abdul Rahman Mohd Kasim, Nurul Farahain Mohammad, Aurangzaib Mangi, and Sharidan Shafie. "Mixed convection boundary layer flow of viscoelastic fluids past a sphere." In *Defect and Diffusion Forum*, vol. 336, pp. 57-63. Trans Tech Publications Ltd, 2013. https://doi.org/10.4028/www.scientific.net/DDF.336.57
[29] Shafie, Sharidan, Muhammad Saqib, Ilyas Khan, and Ahmad Qushairi. "Mixed convection flow of brinkman type hybrid nanofluid based on Atangana-Baleanu fractional model." In *Journal of Physics: Conference Series*, vol. 1366, no. 1, p. 012041. IOP Publishing, 2019. https://doi.org/10.1088/1742-6596/1366/1/012041
[30] Zakaria, Muhamad Najib, Abid Hussanan, Ilyas Khan, and Sharidan Shafie. "The effects of radiation on free convection flow with ramped wall temperature in Brinkman type fluid." *Jurnal Teknologi* 62, no. 3 (2013): 33-39. https://doi.org/10.11113/jt.v62.1886
[31] Yasin, Mohd Hafizi Mat, Norihan Md Arifin, Roslinda Nazar, Fudziah Ismail, and Ioan Pop. "Mixed convection boundary layer flow embedded in a thermally stratified porous medium saturated by a nanofluid." *Advances in Mechanical Engineering* 2013 (2013): 121943. https://doi.org/10.1155/2013/121943
[32] Hayat, T., S. A. Shehzad, A. Alsaedi, and M. S. Alhothuali. "Mixed convection stagnation point flow of Casson fluid with convective boundary conditions." *Chinese Physics Letters* 29, no. 11 (2012): 114704. https://doi.org/10.1088/0256-307X/29/11/114704
[33] Arifin, N. S., S. M. Zokri, A. R. M. Kasim, M. Z. Salleh, N. F. Mohammad, and W. N. S. W. Yusoff. "Aligned magnetic field of two-phase mixed convection flow in dusty Casson fluid over a stretching sheet with Newtonian heating." In *Journal of Physics: Conference Series*, vol. 890, no. 1, p. 012001. IOP Publishing, 2017. https://doi.org/10.1088/1742-6596/890/1/012001
[34] Nadeem, Sohail, Rizwan Ul Haq, Noreen Sher Akbar, and Zafar Hayat Khan. "MHD three-dimensional Casson fluid

flow past a porous linearly stretching sheet." *Alexandria Engineering Journal* 52, no. 4 (2013): 577-582. https://doi.org/10.1016/j.aej.2013.08.005

[35] Rao, A. Subba, C. H. Amanulla, N. Nagendra, O. Anwar Beg, and A. Kadir. "Hydromagnetic flow and heat transfer in a Williamson Non-Newtonian fluid from a Horizontal circular cylinder with Newtonian Heating." *International Journal of Applied and Computational Mathematics* 3, no. 4 (2017): 3389-3409. https://doi.org/10.1007/s40819-017-0304-x

[36] Arifin, N. S., S. M. Zokri, A. R. M. Kasim, M. Z. Salleh, and N. F. Mohammad. "Aligned magnetic field flow of Williamson fluid over a stretching sheet with convective boundary condition." In *MATEC Web of Conferences*, vol. 189, p. 11005. EDP Sciences, 2018. https://doi.org/10.1051/matecconf/201818911005

[37] Zairul, Mohd. "A thematic review on student-centred learning in the studio education." *Journal of Critical Reviews* 7, no. 2 (2020): 504-511. https://doi.org/10.31838/jcr.07.02.95

[38] Clarke, Victoria, and Virginia Braun. "Teaching thematic analysis: Overcoming challenges and developing strategies for effective learning." *The psychologist* 26, no. 2 (2013).

[39] Thumma, Thirupathi, O. Anwar Beg, and Siva Reddy Sheri. "Finite element computation of transient dissipative double diffusive magneto-convective nanofluid flow from a rotating vertical porous surface in porous media." *Proceedings of the Institution of Mechanical Engineers, Part N: Journal of Nanomaterials, Nanoengineering and Nanosystems* 231, no. 2 (2017): 89-108. https://doi.org/10.1177/2397791417712856

[40] Thumma, Thirupathi, A. Chamkha, and Siva Reddy Sheri. "MHD natural convective flow of nanofluids past stationary and moving inclined porous plate considering temperature and concentration gradients with suction." *International Journal of Numerical Methods for Heat & Fluid Flow* (2017). https://doi.org/10.1108/HFF-03-2016-0090

[41] Sravanthi, C. S. "Slip flow of nano fluid over a stretching vertical cylinder in the presence of non-linear thermal radiation and non-uniform heat source/sink." *Scientia Iranica* 25, no. 4 (2018): 2098-2110.

[42] Kumar, B., and T. Kumar. "A comparative study of thermal radiation effects on MHD flow of nanofluids and heat transfer over a stretching sheet." *Frontiers in Heat and Mass Transfer (FHMT)* 9, no. 1 (2017). https://doi.org/10.5098/hmt.9.13

[43] Reddy, P. Bala Anki. "Magnetohydrodynamic flow of a Casson fluid over an exponentially inclined permeable stretching surface with thermal radiation and chemical reaction." *Ain Shams Engineering Journal* 7, no. 2 (2016): 593-602. https://doi.org/10.1016/j.asej.2015.12.010

[44] Rajesh, V., A. J. Chamkha, Ch Sridevi, and A. F. Al-Mudhaf. "A numerical investigation of transient MHD free convective flow of a nanofluid over a moving semi-infinite vertical cylinder." *Engineering Computations* (2017). https://doi.org/10.1108/EC-03-2016-0090

[45] Narahari, Marneni, Suresh Kumar Raju Soorapuraju, Rajashekhar Pendyala, and Ioan Pop. "Transient two-dimensional natural convection flow of a nanofluid past an isothermal vertical plate using Buongiorno's model." *International Journal of Numerical Methods for Heat & Fluid Flow* (2017). https://doi.org/10.1108/HFF-09-2015-0394

[46] Narahari, Marneni, S. Suresh Kumar Raju, and Rajashekhar Pendyala. "Unsteady natural convection flow of multi-phase nanofluid past a vertical plate with constant heat flux." *Chemical Engineering Science* 167 (2017): 229-241. https://doi.org/10.1016/j.ces.2017.04.019

[47] Metri, Prashant G., Pushpanjali G. Metri, Subhas Abel, and Sergei Silvestrov. "Heat transfer in MHD mixed convection viscoelastic fluid flow over a stretching sheet embedded in a porous medium with viscous dissipation and non-uniform heat source/sink." *Procedia Engineering* 157 (2016): 309-316. https://doi.org/10.1016/j.proeng.2016.08.371

[48] Makinde, Oluwole Daniel, Fazle Mabood, and Mohammed S. Ibrahim. "Chemically reacting on MHD boundary-layer flow of nanofluids over a non-linear stretching sheet with heat source/sink and thermal radiation." *Therm. Sci.* 22, no. 1 (2018): 495–506. https://doi.org/10.2298/TSCI151003284M

[49] Krishna, M. Veera, and M. Gangadhar Reddy. "MHD free convective boundary layer flow through porous medium past a moving vertical platewith heat source and chemical reaction." *Materials Today: Proceedings* 5, no. 1 (2018): 91-98. https://doi.org/10.1016/j.matpr.2017.11.058

[50] Izani, Siti Nur Haseela, and Anati Ali. "Mixed convective boundary layer flow of a dusty Jeffrey fluid over an exponentially stretching sheet." In *AIP Conference Proceedings*, vol. 1775, no. 1, p. 030057. AIP Publishing LLC, 2016. https://doi.org/10.1063/1.4965177

[51] Suriyakumar, SP Anjali Deviand P. "Hydromagnetic mixed convective nanofluid slip flow past an inclined stretching plate in the presence of internal heat absorption and suction." *Journal of Applied Fluid Mechanics* 9, no. 3 (2016): 1409-1419. https://doi.org/10.18869/acadpub.jafm.68.228.24194

[52] Archana, Manjappa, Bijjanal Jayanna Gireesha, and Ballajja Chandrappa Prasannakumara. "Triple diffusive flow of Casson nanofluid with buoyancy forces and nonlinear thermal radiation over a horizontal plate." *Archives of*

Thermodynamics 40, no. 1 (2019).
[53] Akbar, Noreen, and S. Nadeem. "Double-diffusive natural convective boundary-layer flow of a nanofluid over a stretching sheet with magnetic field." *International Journal of Numerical Methods for Heat & Fluid Flow* (2016). https://doi.org/10.1108/HFF-01-2015-0019
[54] Ahmed, Sameh E., M. A. Mansour, A. Mahdy, and Shadia S. Mohamed. "Entropy generation due to double diffusive convective flow of Casson fluids over nonlinearity stretching sheets with slip conditions." *Engineering Science and Technology, an International Journal* 20, no. 6 (2017): 1553-1562. https://doi.org/10.1016/j.jestch.2017.10.002
[55] Ahmed, Sameh E., Z. A. S. Raizah, and Abdelraheem M. Aly. "Entropy generation due to mixed convection over vertical permeable cylinders using nanofluids." *Journal of King Saud University-Science* 31, no. 3 (2019): 352-361. https://doi.org/10.1016/j.jksus.2017.07.010
[56] Reddy, Ch Achi, and B. Shankar. "Unsteady convective boundary layer of a Nano fluid over a stretching sheet in the presence of Viscous dissipation, Chemical reaction & Porous Medium." *Materials Today: Proceedings* 4, no. 8 (2017): 7484-7497. https://doi.org/10.1016/j.matpr.2017.07.080
[57] Uddin, Mohammed J., Waqar A. Khan, and Ahmad Izani Md Ismail. "G-jitter induced magnetohydrodynamics flow of nanofluid with constant convective thermal and solutal boundary conditions." *PloS one* 10, no. 5 (2015): e0122663. https://doi.org/10.1371/journal.pone.0122663
[58] Kumar, T. Sravan, and B. Rushi Kumar. "Unsteady MHD free convective boundary layer flow of a nanofluid past a moving vertical plate." In *IOP Conference Series: Materials Science and Engineering*, vol. 263, no. 6, p. 062015. IOP Publishing, 2017. https://doi.org/10.1088/1757-899X/263/6/062015
[59] Saranya, S., P. Ragupathi, B. Ganga, R. P. Sharma, and AK Abdul Hakeem. "Non-linear radiation effects on magnetic/non-magnetic nanoparticles with different base fluids over a flat plate." *Advanced Powder Technology* 29, no. 9 (2018): 1977-1990. https://doi.org/10.1016/j.apt.2018.05.002
[60] Reddy, M. Gnaneswara. "Unsteady radiative-convective boundary-layer flow of a Casson fluid with variable thermal conductivity." *Journal of Engineering Physics and Thermophysics* 88, no. 1 (2015): 240-251. https://doi.org/10.1007/s10891-015-1187-5
[61] Parmar, Amit. "Unsteady convective boundary layer flow for MHD Williamson fluid over an inclined porous stretching sheet with non-linear radiation and heat source." *International Journal of Applied and Computational Mathematics* 3, no. 1 (2017): 859-881. https://doi.org/10.1007/s40819-017-0387-4
[62] R. E. Nayak, M. V. Rao, and K. Gangadhar. "Mixed convection boundary layer flow of non-newtonian nanofluid using the spectral quasi linearization." *Math. Model. Eng. Probl.* 7, no. 1 (2020): 45–54. https://doi.org/10.18280/mmep.070106
[63] Maleque, Kh Abdul. "Temperature dependent suction/injuction and variable properties on non-Newtonian Casson mixed convective MHD laminar fluid flow with viscous dissipation and thermal radiation." *American Journal of heat and Mass transfer* 4 (2017): 104-120. https://doi.org/10.7726/ajhmt.2017.1007
[64] Khan, W. A., M. Jashim Uddin, and A. I. M. Ismail. "Non-similar solution of free convective flow of power law nanofluids in porous medium along a vertical cone and plate with thermal and mass convective boundary conditions." *Canadian Journal of physics* 93, no. 10 (2015): 1144-1155. https://doi.org/10.1139/cjp-2014-0471
[65] Isa, S. S. P. M., N. M. Arifin, R. Nazar, N. Bachok, F. M. Ali, and I. Pop. "MHD mixed convection boundary layer flow of a Casson fluid bounded by permeable shrinking sheet with exponential variation." *Scientia Iranica* 24, no. 2 (2017): 637-647. https://doi.org/10.24200/sci.2017.4048
[66] Hamid, Aamir, Masood Khan, and Umair Khan. "Thermal radiation effects on Williamson fluid flow due to an expanding/contracting cylinder with nanomaterials: dual solutions." *Physics Letters A* 382, no. 30 (2018): 1982-1991. https://doi.org/10.1016/j.physleta.2018.04.057
[67] Eswaramoorthi, S., M. Bhuvaneswari, S. Sivasankaran, and S. Rajan. "Effect of radiation on MHD convective flow and heat transfer of a viscoelastic fluid over a stretching surface." *Procedia Engineering* 127 (2015): 916-923. https://doi.org/10.1016/j.proeng.2015.11.364
[68] Dinarvand, Saeed, Abbas Abbassi, Reza Hosseini, and Ioan Pop. "Homotopy analysis method for mixed convective boundary layer flow of a nanofluid over a vertical circular cylinder." *Thermal science* 19, no. 2 (2015): 549-561. https://doi.org/10.2298/TSCI120225165D
[69] Dinarvand, Saeed, Reza Hosseini, Milad Abulhasansari, and Ioan Pop. "Buongiorno's model for double-diffusive mixed convective stagnation-point flow of a nanofluid considering diffusiophoresis effect of binary base fluid." *Advanced Powder Technology* 26, no. 5 (2015): 1423-1434. https://doi.org/10.1016/j.apt.2015.07.017
[70] Basir, Md Faisal Md, M. J. Uddin, O. Anwar Bég, and AI Md Ismail. "Influence of Stefan blowing on nanofluid flow submerged in microorganisms with leading edge accretion or ablation." *Journal of the Brazilian Society of Mechanical Sciences and Engineering* 39, no. 11 (2017): 4519-4532. https://doi.org/10.1007/s40430-017-0877-7
[71] Gangadhar, K., T. Kannan, G. Sakthivel, and K. DasaradhaRamaiah. "Unsteady free convective boundary layer flow of a nanofluid past a stretching surface using a spectral relaxation method." *International journal of ambient*

energy 41, no. 6 (2020): 609-616. https://doi.org/10.1080/01430750.2018.1472648
[72] Tlili, Iskander. "Effects MHD and heat generation on mixed convection flow of Jeffrey fluid in microgravity environment over an inclined stretching sheet." *Symmetry* 11, no. 3 (2019): 438. https://doi.org/10.3390/sym11030438
[73] Siyal, Ambreen, Kashif Ali Abro, and Muhammad Anwar Solangi. "Thermodynamics of magnetohydrodynamic Brinkman fluid in porous medium." *Journal of Thermal Analysis and Calorimetry* 136, no. 6 (2019): 2295-2304. https://doi.org/10.1007/s10973-018-7897-0
[74] Chu, Yu-Ming, Kottakkaran Sooppy Nisar, Umair Khan, Hamed Daei Kasmaei, Manuel Malaver, Aurang Zaib, and Ilyas Khan. "Mixed convection in MHD water-based molybdenum disulfide-graphene oxide hybrid nanofluid through an upright cylinder with shape factor." *Water* 12, no. 6 (2020): 1723. https://doi.org/10.3390/w12061723
[75] Suganya, S., M. Muthtamilselvan, Fahad Al-Amri, and Bahaaeldin Abdalla. "An exact solution for unsteady free convection flow of chemically reacting A l 2 O 3− S i O 2/water hybrid nanofluid." *Proceedings of the Institution of Mechanical Engineers, Part C: Journal of Mechanical Engineering Science* (2020): 0954406220957710. https://doi.org/10.1177/0954406220957710
[76] Khan, Umair, Anum Shafiq, A. Zaib, and Dumitru Baleanu. "Hybrid nanofluid on mixed convective radiative flow from an irregular variably thick moving surface with convex and concave effects." *Case Studies in Thermal Engineering* 21 (2020): 100660. https://doi.org/10.1016/j.csite.2020.100660
[77] Waini, Iskandar, Anuar Ishak, and Ioan Pop. "Hybrid nanofluid flow past a permeable moving thin needle." *Mathematics* 8, no. 4 (2020): 612. https://doi.org/10.3390/math8040612
[78] Waini, Iskandar, Anuar Ishak, and Ioan Pop. "Unsteady flow and heat transfer past a stretching/shrinking sheet in a hybrid nanofluid." *International Journal of Heat and Mass Transfer* 136 (2019): 288-297. https://doi.org/10.1016/j.ijheatmasstransfer.2019.02.101
[79] Manjunatha, S., B. Ammani Kuttan, S. Jayanthi, Ali Chamkha, and B. J. Gireesha. "Heat transfer enhancement in the boundary layer flow of hybrid nanofluids due to variable viscosity and natural convection." *Heliyon* 5, no. 4 (2019): e01469. https://doi.org/10.1016/j.heliyon.2019.e01469
[80] Junoh, Mohamad Mustaqim, Fadzilah Md Ali, Norihan Md Arifin, Norfifah Bachok, and Ioan Pop. "MHD stagnation-point flow and heat transfer past a stretching/shrinking sheet in a hybrid nanofluid with induced magnetic field." *International Journal of Numerical Methods for Heat & Fluid Flow* (2019). https://doi.org/10.1108/HFF-06-2019-0500
[81] Yousefi, Mohammad, Saeed Dinarvand, Mohammad Eftekhari Yazdi, and Ioan Pop. "Stagnation-point flow of an aqueous titania-copper hybrid nanofluid toward a wavy cylinder." *International Journal of Numerical Methods for Heat & Fluid Flow* (2018). https://doi.org/10.1108/HFF-01-2018-0009
[82] Mehryan, Seyed AM, Farshad M. Kashkooli, Mohammad Ghalambaz, and Ali J. Chamkha. "Free convection of hybrid Al2O3-Cu water nanofluid in a differentially heated porous cavity." *Advanced Powder Technology* 28, no. 9 (2017): 2295-2305. https://doi.org/10.1016/j.apt.2017.06.011
[83] 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
[84] Williamson, R. Vo. "The flow of pseudoplastic materials." *Industrial & Engineering Chemistry* 21, no. 11 (1929): 1108-1111. https://doi.org/10.1021/ie50239a035