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Thermophysical Correlation of Hybrid Nanofluids (HNFs) : A Thematic Review

Masyfu'ah Mokhtar[1,2], Abdul Rahman Mohd Kasim[1,3,*], Iskandar Waini[4], Nur Syahidah Nordin[1,2], Hussein Ali Mohammed Al-Sharifi[5]

[1] Centre for Mathematical Sciences, Universiti Malaysia Pahang Al-Sultan Abdullah, Gambang, 26300 Kuantan, Pahang, Malaysia
[2] College of Computing, Informatics and Media, Universiti Teknologi MARA, Johor Branch, Segamat Campus, Johor, Segamat, 85000, Malaysia
[3] Centre for Research in Advanced Fluid and Process, Universiti Malaysia Pahang Al-Sultan Abdullah, Lebuhraya Tun Razak, Pahang, Gambang, 26300, Malaysia
[4] Fakulti Teknologi dan Kejuruteraan Industri dan Pembuatan, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia
[5] Department of Mathematics, College of Education for Pure Sciences, University of KerbalaThe institution will open in a new tab, Karbala, 1125, Iraq

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ABSTRACT

Hybrid nanofluids represent innovative fluid class that combine the advantages of nanoparticles with base fluid to enhance the heat transfer capabilities. It exhibits higher heat transfer capabilities compared to traditional nanofluids. Researchers have seized abundant opportunity to further investigate the unknown behaviour of hybrid nanofluids over different geometries and physical parameters numerically by implementing a certain model of correlation. However, from the literature, these correlation models sometimes underestimate the experimental data of thermal performance. Thus, it is crucial for this review paper to discuss these models for advancing research in this field. Utilizing keyword search and filtering parameters, 354 journal articles from the Scopus and Web of Science (WoS) databases were found. Following the application of the inclusion and exclusion criteria process, only 60 papers were evaluated as final articles. These studies were further classified into seven types of correlations: Devi, Modified Devi Type A, Modified Devi Type B, Modified Devi Type C, Takabi, Modified Takabi and Xue model. It is found that Xue model is widely used for solving hybrid nanofluids flow problem which dealing with carbon nanotube particle. While Devi and Takabi-based model are extensively used for non-carbon nanotube particle. This study provides valuable insights for future research to further study the hybrid nanofluid flow precisely and increase the heat transfer performance.

1. Introduction

Heat transfer is the process of exchanging thermal energy between physical systems through the dissipation of heat. Across the dynamics of nanofluids (NFs), it is a property which could be controlled and influenced using magnetic flux density, thermo-migration and haphazard motion of

* *Corresponding author.*
E-mail address: rahmanmohd@umpsa.edu.my (Abdul Rahman Mohd Kasim)

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nanoparticles as shown by several authors [1-3]. Because of its importance in applications of industries, it is crucial to have the best heat transfer material. Hybrid nanofluids (HNFs) are then developed and found to have great thermophysical properties and thermal performance compared to mono-NFs. HNFs consist of two elements of nanoparticle immersed in a base fluid. Through this technology, the heat transfer performance has been improved and their advantages had led to numerous researches to further investigate the unknown behavior of HNFs over different body geometries and physical parameters.

Referring to Huminic & Huminic [4], heat transfer characteristics of HNFs were investigated through numerous experimental and numerical studies. Based on experimental findings, numerous empirical correlations have been proposed through curve fitting process which are in good accuracy. These correlations represent the thermophysical properties including viscosity, density, heat capacitance and thermal conductivity. Yıldız *et al.,* [5] state that employing the theoretical models for thermal conductivity underestimates the heat performance of both NFs and HNFs. The study also in line with findings from Esfe *et al.,* [6] that state the presented theoretical models lower predicted that experimental data.

The most significant element of thermophysical correlation is thermal conductivity. HNFs are preferred due to their higher thermal conductivity compared to regular NFs. Researchers have extensively studied the thermal conductivity of both NFs and HNFs in recent years. Sarviya and Fuskele [7] reviewed NFs thermal conductivity, while Sajid and Ali [8] focused on HNFs. Another significant element of thermophysical correlation is viscosity as it also can influence flow behavior and heat transfer characteristics. However, there have been fewer studies specifically addressing viscosity element in NFs. Besides viscosity, with the changing of nanoparticles concentration will also change other elements of thermophysical correlation including density, heat capacity and electrical conductivity. Thus, these elements have also been investigated by researchers to better understand nanofluid behavior [9].

In recent studies, researchers have extensively investigated the HNFs flow problem numerically with different adoptions of thermophysical correlation models [10-76]. Among the frequently implemented models are Devi model [10,11] and Takabi model [44]. These models were first developed to solve HNFs flow containing Alumina and Copper particles suspended in water (Al_2O_3-Cu/H_2O). Another model known as Xue model [71] has also been found in the literature where it accounts for the unique properties of Carbon nanotubes (CNTs) particle.

The previously mentioned models (Devi, Takabi and Xue) are not only restricted to Newtonian HNFs but also have been adopted by non-Newtonian HNFs as discussed by Gul *et al.,* [77-79]. However, the Takabi model tends to underestimate the heat transfer performance especially at higher volume concentration. This suggests that it might not accurately predict heat transfer behavior in certain scenarios. In addition, although HNFs flow problems have been widely explored numerically by adopting the previously described models, the review paper discussing these models for solving HNFs flow with dissimilar geometry, effects and numerical method has been very scarce.

Therefore, it is crucial for this paper to perform a systematic review of the adopted thermophysical correlation models which then will direct the future research to further study the flow of HNFs precisely and thus improve the heat transfer performance.

According to Petrosino *et al.,* [80], a systematic review can be defined as quantitatively and qualitatively recognizing, combining, and evaluating all accessible data to produce a hearty, observationally determined response to an engaged research question. It offers several advantages compared to the conventional style literature reviews. The reviews can be strengthened via a transparent article retrieving process, a more prominent wider area of research, more significant objectives which can control research bias. Apart from that, this also motivates the researcher to produce quality evidence with more significant results.

Thus, in the development of this review paper, recent articles related to numerical study on HNFs flow are clustered to its type of correlation model. The discussion will be specifically focused on the implementation of available correlation models referring to the following research question; What are the thermophysical correlations that have been adopted for solving the HNFs flow problem with dissimilar type of particle, base fluid, geometry, effects, and numerical method used in publication from 2019-2022?

2. Review Methodology

The details of material and method that have been implemented in this study, are discussed in this section. This study applied the thematic analysis technique which is referring to the thematic review process introduced by Zairul [81]. Thematic analysis is a technique used in literature. Through in-depth reading on the subject, the approach identifies the pattern and creates the themes [82]. For the first step in this study the pattern has been defined and correlation model's category has been constructed to understand the trend from various publications. The research aims to evaluate the outcomes of various types of correlation models of HNFs, which then be recommended for future studies. The literature has been selected based on several criteria, which are 1) publication from 2019-2022, 2) has at least keyword(s) of the HNFs, fluid flow and heat transfer, and focused on a correlation model. The search strings used in the Scopus and WoS databases were used to find the relevant literature, as shown in Table 1.

Table 1
Search strings from Scopus and WoS

Database	Keyword	Result
Scopus	TITLE-ABS-KEY ("Hybrid nanofluid" AND "heat transfer" AND "fluid flow" PUBYEAR (2019-2022)	101 articles
WoS	TITLE-ABS-KEY ("Hybrid nanofluid" AND "heat transfer" AND "fluid flow" PUBYEAR (2019-2022)	253 articles

For this study, a systematic review of papers has been implemented in the Scopus and WoS search engines to determine the correlation model of the HNFs. Figure 1 illustrates the inclusion and exclusion criteria used in the current study. There were 101 (Scopus) and 253 (WoS) items available for the initial search. Nevertheless, some of these articles were lacking, couldn't be viewed, or had a broken connection. Thus, due to a missed match and premature outcome, 281 papers have been removed. Another 13 overlapping articles also have been excluded. Therefore only 60 final articles need to be reviewed, including conference proceedings and journal.

3. Previous research on HNFs flow problem

This section displays tables related to the number of final articles published according to 1) authors and correlation model 2) year and correlation model 3) hybrid nanofluids and correlation model and 4) numerical method and correlation model. Firstly, Table 2 listed the number of identified 60 final articles according to the various authors and type of correlation. Notably, Waini, Ishak, & Pop are the top authors who utilized Devi & Takabi-based correlation model.

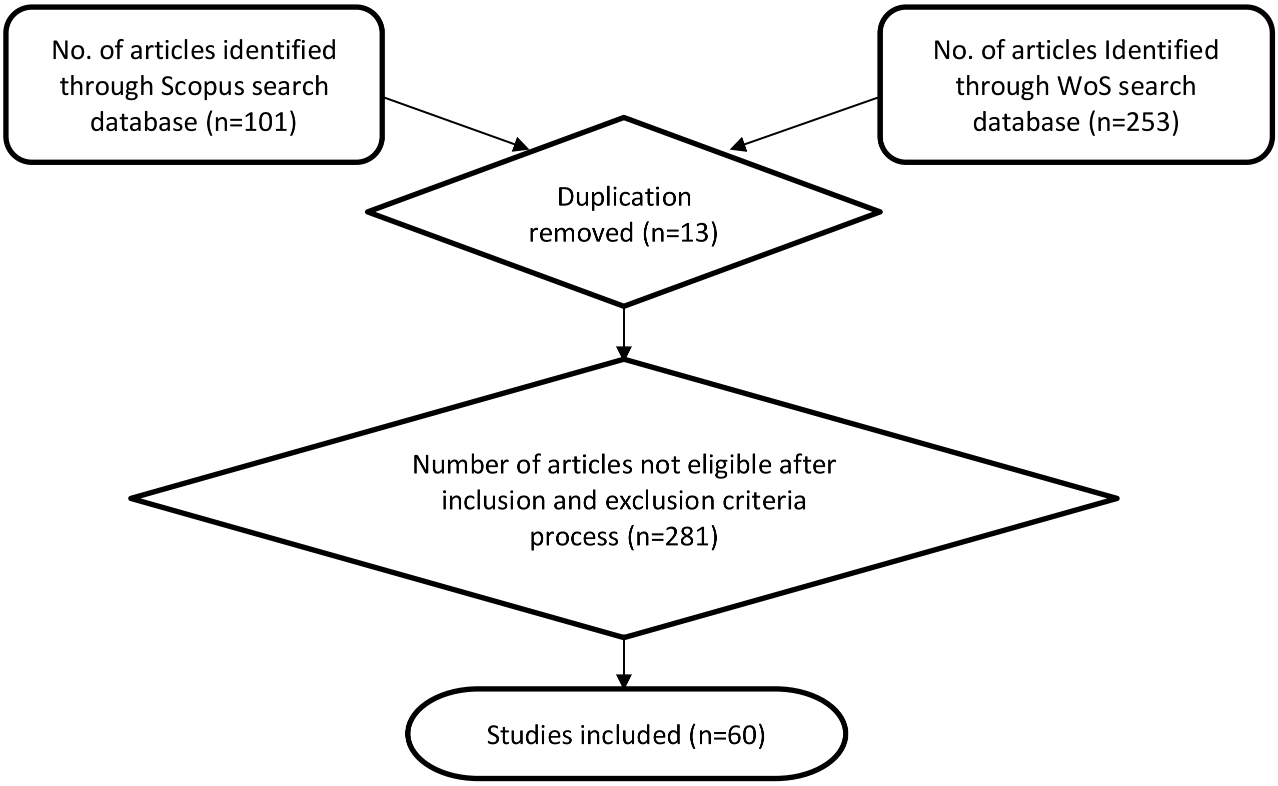

Fig. 1. Inclusion and exclusion criteria in the thematic review

Table 2
The classification of authors based on type of correlation

Author	Correlation						
	Devi	Modified Devi Type A	Modified Devi Type B	Modified Devi Type C	Takabi	Modified Takabi	Xue
Abu Bakar *et al.,* [12]	1						
Acharya *et al.,* [60]						1	
Alabdulhadi *et al.,* [34]		1					
Aladdin *et al.,* [13]	1						
Aladdin & Bachok [14]	1						
Anuar *et al.,* [35]		1					
Anuar & Bachok [15]	1						
Aziz *et al.,* [16]	1						
Dinarvand [39]			1				
Dinarvand *et al.,* [40]			1				
Gangadhar *et al.,* [41]			1				
Ghalambaz *et al.,* [45]					1		
Jamaludin *et al.,* [42]				1			
Jamaludin *et al.,* [43]				1			
Khan *et al.,* [17]	1						
Khan *et al.,* [46]					1		
Khashi'ie *et al.,* [18]	1						
Khashi'ie *et al.,* [19]	1						
Khashi'ie *et al.,* [47]					1		
Khashi'ie *et al.,* [48]					1		
Khashi'ie, Arifin, & Pop		1 [36]			1 [49]	1 [61]	
Khashi'ie *et al.,* [50]					1		

Lund *et al.,* [20]	1						
Manjunatha *et al.,* [21]	1						
Prashar *et al.,* [22]	1						
Wahid *et al.*, [51]					1		
Wahid *et al.,* [62]						1	
Wahid *et al.,* [52]					1		
Wahid *et al.,* [63]						1	
Wahid *et al.,* [23]	1						
Waini, Ishak, & Pop	6 [24-29]	1 [37]			3 [53-55]	3 [64-66]	
Waini *et al.,* [67]						1	
Waini *et al.,* [68]						1	
Yashkun *et al.,* [38]		1					
Zainal *et al.,*	3 [30-32]				2 [56-57]	2 [69-70]	
Abbas *et al.,* [72]							1
Bilal *et al.,* [73]							1
Bilal *et al.,* [74]							1
Saba *et al.,* [75]							1
Saeed *et al.,* [76]							1
Total	21	5	3	2	13	11	5

Next, the same process is repeated for another category and the results are tabulated in Table 3, Table 4 and Table 5. To ensure the consistency in the resulting sub-categories, the evaluation was based on their resemblance and variations. Note that, the number of articles for each category remains the same across all table (Table 2, Table 3, Table 4, and Table 5), demonstrating consistency.

Referring to Table 3, the Devi model [10,11] was popular among article researchers during the early years (2019-2020). However, in recent years (2021-2022), the Takabi model [44] has become more preferred. This is due to their capabilities in solving HNFs flow problem well.

Moving on to Table 4, Al_2O_3-Cu/H_2O is recognised as the most investigated hybrid nanofluids. Although carbon nanotubes (CNTs) are intriguing due to their high thermal conductivity compared to other nanoparticles, it has been established that Copper nanoparticles could provide a great heat transfer performance in the combination with Alumina while water as their base fluid.

Table 5 presents the number of final articles based on the numerical methods used and the type of correlation. The bvp4c MATLAB numerical method has been commonly employed to compute the governing equation of HNFs flow problem. This illustrates that this method is less complex compared to other method. Bvp4c MATLAB was programmed with a finite difference scheme known as 3-stage Lobatto IIIa. Correct results are obtained within the specified accuracy when the far-field boundary conditions are asymptotically satisfied, and no errors are generated from the MATLAB software.

Table 3
Review articles based on year and correlation

Year	Correlation							
	Devi	Modified Devi Type A	Modified Devi Type B	Modified Devi Type C	Takabi	Modified Takabi	Xue	Total
2019	2		2				1	5
2020	10	1		1	3	1	1	17
2021	8	4	1	1	5	3	3	21
2022	1				5	7		13
Total	21	5	3	2	13	11	5	60

Table 4
Review articles based on nano particles used and correlation

Nanoparticles / Base fluid	Correlation							
	Devi	Modified Devi Type A	Modified Devi Type B	Modified Devi Type C	Takabi	Modified Takabi	Xue	Total
Al_2O_3-Cu/H_2O	21	3		2	12	9	1	48
Ag-MgO/H_2O		2			1			3
MgO-Au/H_2O			1					1
TiO_2-CuO/H_2O			1					1
CuO-Ag/H_2O			1					1
TiO_2-$CoFe_2O_4$/H_2O						2		2
SWCNTs/MWCNTs-Fe_3O_4/H_2O							4	4
Total	21	5	3	2	13	11	5	60

Table 5
Review articles based on numerical method used and correlation

Numerical method	Correlation							
	Devi	Modified Devi Type A	Modified Devi Type B	Modified devi Type C	Takabi	Modified Takabi	Xue	Total
bvp4c MATLAB / MATLAB	17	5	2	2	12	10	2	50
Maple	1							1
RK4	1					1		2
Keller Box	1							1
RKF45	1		1				1	3
Finite difference solver					1			1
HAM							2	2
Total	21	5	3	2	13	11	5	60

Finally, in this section, the final articles are summarized according to its type of nanoparticles, base fluids, effects, geometry, numerical method, and all the elements of correlation involved for each models below:

3.1 Devi Model

A new special correlation known as Devi model for analyzing the HNFs boundary layer equations have been introduced in 2016 [10,11]. The required HNFs have been prepared by taking the mixture of Cu nanoparticles into 0.1 vol. of Al_2O_3/water. The mathematical formulation for the boundary layer equations is given as follows [10]:

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}=0 \tag{1}$$

$$u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}=\frac{\mu_{hnf}}{\rho_{hnf}}\frac{\partial^2 u}{\partial y^2}-\frac{\sigma_{hnf}}{\rho_{hnf}}\beta_0{}^2 u \tag{2}$$

$$u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}=\frac{k_{hnf}}{\left(\rho C_p\right)_{hnf}}\frac{\partial^2 T}{\partial y^2} \tag{3}$$

subject to:

$$\begin{aligned}
&u\left(x,0\right)=u_w(x)=cx,\\
&v\left(x,0\right)=-v_0,\quad T\left(x,0\right)=T_w,\\
&u\left(x,\infty\right)\to 0,\quad T\left(x,\infty\right)\to T_\infty,
\end{aligned} \tag{4}$$

where (u,v) are the velocity components in (x,y) direction respectively, c is constant; μ_{hnf} , ρ_{hnf} , k_{hnf} , σ_{hnf} and $c_{p_{hnf}}$ a are the dynamic viscosity, density, thermal conductivity , electrical conductivity, and specific heat at constant pressure of hybrid nanofluid respectively, B_0 is uniform magnetic field, v_0 is the suction velocity (where $v_0 > 0$). T is the fluid temperature, T_w is the wall temperature, T_∞ is the temperature far away from the sheet.

The correlation model for thermophysical properties of both NFs and HNFs from Devi model are given in Table 6. Referring to the table, this model consists of five elements of thermophysical properties: viscosity, density, heat capacity, thermal conductivity, and electrical conductivity.

The thermal conductivity of Devi model is originated from Hamilton-crosser model [83]. The resulted data using the Devi model have been validated with experimental data obtained by Suresh *et al.,* [78]. In particular, the Devi model's thermal conductivity for an HNFS (Al_2O_3-Cu/water with 90:10 ratio of concentrations) showed an excellent correlation with existing experimental data. Due to its accuracy, the Devi model has been widely adopted by previous researchers in solving various HNFs flow problem numerically with dissimilar geometries and effects [12-32].

The related articles using the Devi model are summarized in Table 7. Out of 21 articles using the Devi model, five adopted all five elements of correlation [18,19,23,26,28], while the remaining articles uses only four elements of correlation (excluding electrical conductivity) [12-17,20-22,24,25,27,29-32].

Most articles dealing with boundary layer problems and incorporating magnetic effects consider the electrical conductivity element [19,23,26,28]. For instance, Waini, Ishak, & Pop [26] studied steady HNFs over a permeable stretching/shrinking wedge with magnetohydrodynamic (MHD) and radiation effects. In another research, Wahid *et al.,* [23] investigated HNFs flow past a permeable stretching sheet, considering MHD, velocity slip and thermal radiation. Waini *et al.,* [28] examined squeezed HNFs flow past a permeable sensor surface with MHD and radiation effects. While Khashi'ie *et al.,* [19] explored axisymmetric HNFs flow characteristics and heat transfer on a stretching/shrinking surface accounting for MHD, suction and Joule heating.

3.2 Modified Devi Model

Rostami *et al.,* [33] extended the previous Devi model by incorporating two additional elements: thermal expansion and diffusivity. These modifications enhance the thermophysical properties of HNFs resulting in three new types of correlation which can be name as Modified Devi Model Type A (Includes an additional thermal expansion element), Modified Devi Model Type B (Includes an additional diffusivity element) and Modified Devi Model Type C (Includes both thermal expansion and diffusivity elements). Researchers have recently adopted these modified models in various studies [34-43]. The thermal expansion and diffusivity elements of correlation for both NFs and HNFs are shown in Table 8. The summary of related articles using Modified Devi Type A, B and C are displayed in Table 9, Table 10, and Table 11 respectively.

Table 6
Effective thermophysical properties of NFs and HNFs from Devi model

Element	NFs	HNFs
Viscosity	$\frac{\mu_{nf}}{\mu_f}=\frac{1}{(1-\phi)^{2.5}}$	$\frac{\mu_{hnf}}{\mu_f}=\frac{1}{(1-\phi_1)^{2.5}(1-\phi_2)^{2.5}}$
Density	$\rho_{nf}=(1-\phi)\rho_f+\phi\rho_s$	$\rho_{hnf}=(1-\phi_2)\left[(1-\phi_1)\rho_f+\phi_1\rho_{s1}\right]+\phi_2\rho_{s2}$
Heat Capacity	$\left(\rho C_p\right)_{nf}=(1-\phi)\left(\rho C_p\right)_f+\phi\left(\rho C_p\right)_s$	$\left(\rho C_p\right)_{hnf}=\left(1-\phi_{hnf}\right)\left(\rho C_p\right)_f+\phi_1\left(\rho C_p\right)_{s1}+\phi_2\left(\rho C_p\right)_{s2}$
Thermal Conductivity	$\frac{k_{nf}}{k_f}=\frac{k_s+2k_f-2\phi\left(k_f-k_s\right)}{k_s+2k_f+\phi\left(k_f-k_s\right)}$	$\frac{k_{hnf}}{k_{bf}}=\frac{k_{s2}+2k_{bf}-2\phi_2\left(k_{bf}-k_{s2}\right)}{k_{s2}+2k_{bf}+\phi_2\left(k_{bf}-k_{s2}\right)}$ where $\frac{k_{bf}}{k_f}=\frac{k_{s1}+2k_f-2\phi_1\left(k_f-k_{s1}\right)}{k_{s1}+2k_f+\phi_1\left(k_f-k_{s1}\right)}$
Electrical Conductivity	$\frac{\sigma_{nf}}{\sigma_f}=\frac{\sigma_s+2\sigma_f-2\phi\left(\sigma_f-\sigma_s\right)}{\sigma_s+2\sigma_f+\phi\left(\sigma_f-\sigma_s\right)}$	$\frac{\sigma_{hnf}}{\sigma_{bf}}=\frac{\sigma_{s2}+2\sigma_{bf}-2\phi_2\left(\sigma_{bf}-\sigma_{s2}\right)}{\sigma_{s2}+2\sigma_{bf}+\phi_2\left(\sigma_{bf}-\sigma_{s2}\right)}$ where $\frac{\sigma_{bf}}{\sigma_f}=\frac{\sigma_{s1}+2\sigma_f-2\phi_1\left(\sigma_f-\sigma_{s1}\right)}{\sigma_{s1}+2\sigma_f+\phi_1\left(\sigma_f-\sigma_{s1}\right)}$

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Table 7
Summary of authors based on particle, base fluid, geometry, effects, numerical method and elements of correlation involved in Devi model

No.	Authors	Particle	Base fluid	Geometry	Effects	Numerical method	DV	DS	HC	TC	EC	TE	DF
1	Waini *et al.*, [26]	Al_2O_3-Cu	Water	Permeable stretching/ shrinking wedge	MHD and radiation	bvp4c MATLAB	√	√	√	√	√		
2	Wahid *et al.*, [23]	Al_2O_3-Cu	Water	Permeable stretching sheet	MHD, thermal radiation and velocity slip	Maple program	√	√	√	√	√		
3	Abu Bakar *et al.*, [12]	Al_2O_3-Cu	Water	Permeable shrinking sheet in Darcy porous medium	Radiation and slip	bvp4c MATLAB	√	√	√	√			
4	Waini *et al.*, [29]	Al_2O_3-Cu	Water	Stagnation point region of stretching/shrinking surface	Second-order slip and melting heat transfer	bvp4c MATLAB	√	√	√	√			
5	Zainal *et al.*, [30]	Al_2O_3-Cu	Water	Stagnation point flow of stretching/shrinking surface	Anisotropic slip	bvp4c MATLAB	√	√	√	√			
6	Zainal *et al.*, [32]	Al_2O_3-Cu	Water	Permeable moving surface	MHD and thermal radiation	bvp4c MATLAB	√	√	√	√			
7	Anuar & Bachok [15]	Al_2O_3-Cu	Water	Unsteady stagnation point flow of deformable sheet	Thermal radiation	bvp4c MATLAB	√	√	√	√			
8	Waini *et al.*, [28]	Al_2O_3-Cu	Water	Permeable sensor surface	MHD and radiation	bvp4c MATLAB	√	√	√	√	√		
9	Waini *et al.*, [25]	Al_2O_3-Cu	Water	Nonlinear permeable stretching/ shrinking surface	Radiation	bvp4c MATLAB	√	√	√	√			
10	Waini *et al.*, [27]	Al_2O_3-Cu	Water	Permeable moving thin needle	Thermophoresis and brownian motion	bvp4c MATLAB	√	√	√	√			
11	Khashi'ie *et al.*, [19]	Al_2O_3-Cu	Water	Radially stretching/ shrinking surface	MHD, suction and joule heating	bvp4c MATLAB	√	√	√	√	√		
12	Khan *et al.*, [17]	Al_2O_3-Cu	Water	Thin horizontally moving needle	Bio-convective, chemical reaction and viscous dissipation	MATLAB	√	√	√	√			
13	Waini *et al.*, [24]	Al_2O_3-Cu	Water	Stretching/ shrinking curved surface	Mass suction	bvp4c MATLAB	√	√	√	√			
14	Lund *et al.*, [20]	Al_2O_3-Cu	Water	Non-linear shrinking sheet	Viscous dissipation and suction/ injection	bvp4c MATLAB	√	√	√	√			
15	Prashar *et al.*, [22]	Ag–CuO	Water	Parabolically shaped thin heated needle	None	RK-4 method with shoooting strategy	√	√	√	√			

16	Aladdin *et al.*, [13]	Al_2O_3-Cu	Water	Horizontally and vertically slender (thin) needle	Hydromagnetic and slip	bvp4c MATLAB	√	√	√	√			
17	Zainal *et al.,* [31]	Al_2O_3-Cu	Water	Permeable stretching/ shrinking	MHD and quadratic velocity	bvp4c MATLAB	√	√	√	√			
18	Aziz *et al.,* [16]	Al_2O_3-Cu	Water	Uniform horizontal porous stretching surface	Viscous dissipation and linear thermal radiation	Keller box finite difference scheme	√	√	√	√			
19	Manjunatha *et al.,* [21]	Ag-CuO	Water	Exponentially stretching surface	None	Runge-Kutta-Fehlberg method (RKF 45)	√	√	√	√			
20	Aladdin & Bachok [14]	Al_2O_3-Cu	Water	Permeable moving plate	None	bvp4c MATLAB	√	√	√	√			
21	Khashi'ie *et al.,* [18]	Al_2O_3-Cu	Water	Shrinking cylinder	Joule heating	bvp4c MATLAB	√	√	√	√	√		

DV=Dynamic Viscosity, DS=Density, HC=Heat Capacity, TC=Thermal Conductivity, EC=Electrical Conductivity, TE=Thermal Expansion, DF=Diffusivity

Table 8
Additional effective thermophysical properties of NFs and HNFs to existing Devi model

Element	NFs	HNFs
Thermal expansion	$(\rho\beta)_{nf}=(1-\phi)(\rho\beta)_f+\phi(\rho\beta)_s$	$(\rho\beta)_{hnf}=\left[(1-\phi_2)\left\{(1-\phi_1)(\rho\beta)_f+\phi_1(\rho\beta)_{s1}\right\}\right]+\phi_2(\rho\beta)_{s2}$
Diffusivity	$\alpha=\dfrac{k_{nf}}{(\rho C_p)_{nf}}$	$\alpha=\dfrac{k_{hnf}}{(\rho C_p)_{hnf}}$

3.2.1 Modified Devi type A

Referring to Table 9, most studies involved mixed convection problem of HNFs. It is noteworthy that the addition of the thermal expansion element to the existing Devi model accounts for this factor. However, some studies consider only the four elements of the Devi model (excluding the electrical conductivity element) and an additional thermal expansion element includes Anuar *et al.,* [35], Khashi'ie *et al.,* [36], and Waini *et al.,* [37]. Anuar *et al.,* [35] explored the boundary layer flow and heat transfer of HNFs over an inclined stretching/shrinking sheet, considering suction and buoyancy force effects. Khashi'ie *et al.,* [36] investigated the stagnation point flow of HNFs with mixed convection induced by a Riga plate and electromagnetohydrodynamic (EMHD) effects. Waini *et al.,* [37] studied a stagnation region of HNFs flow over a vertical plate accounting for mixed convection and radiation effects.

While Alabdulhadi *et al.,* [34] and Yashkun *et al.,* [38] adopted Devi model with all five elements (including electrical conductivity) and an additional thermal expansion element. Alabdulhadi *et al.,* [34] examined mixed convection boundary layer flow and heat transfer of HNFs over an inclined shrinking-stretching surface, considering the presence of magnetic field. While Yashkun *et al.,* [38] investigated mixed convection HNFs flow and heat transfer past an exponentially stretching/shrinking sheet, incorporating Joule heating.

3.2.2 Modified Devi type B

Referring to Table 10, most studies adopted Devi model with four elements (excluding electrical conductivity) and an additional diffusivity element includes Gangadhar *et al.,* [41], Dinarvand *et al.,* [40] and Dinarvand [39]. Gangadhar *et al.,* [41] and Dinarvand [39] both studied nodal/saddle stagnation point boundary layer flow and heat transfer of HNFs, but with different types of nanoparticles. Gangadhar *et al.,* [41] focused on MgO-Au/water HNFs, considering the impact of slip and viscous dissipation effects. Whereas Dinarvand [39] investigated CuO-Ag/water HNFs. In another study, Dinarvand *et al.,* [40] explored boundary layer flow of TiO_2-CuO/water HNFs over a static/moving wedge or corner, known as the Falkner-Skan problem.

3.2.3 Modified Devi type C

Referring to Table 11, Jamaludin *et al.,* [43] adopted Devi model with four elements (excluding electrical conductivity element) and additional elements of both thermal expansion and diffusivity. They proposed a theoretical model for HNFs boundary layer flow and heat transfer with mixed convection over an exponentially stretching/shrinking sheet. On the other hand, Jamaludin *et al.,* [42] used Devi model with all five elements (including electrical conductivity) and additional elements of both thermal expansion and diffusivity. Their study addressed stagnation-point flow and heat transfer over a permeable stretching/shrinking sheet, considering mixed convection, magnetic field, and heat source/sink effects. This study stands out as the only identified study that incorporate all available elements of correlation.

3.3 Takabi Model

In 2014, Takabi & Salehi [44] proposed a special correlation for thermophysical properties in solving the HNFs flow problem. Their study examined laminar natural convection in a sinusoidal corrugated enclosure with a discrete heat source on the bottom wall. The enclosure was filled with pure water, Al_2O_3/water NFs, and Al_2O_3-Cu/water HNFs. Since classical models for thermal conductivity and viscosity properties underestimate the experimental results found by Suresh *et al.,* [83], especially in high volume concentration, data from the experiment have been adopted to get better results. For all Rayleigh numbers that have been studied, the results showed that, the heat transfer rate can be improved by employing HNFs instead of using NFs and water. The findings of the study also give better results for preservation presentation of the enclosure and lower temperature of the heated surface.

The effective thermophysical properties of NFs and HNFs from Takabi model are given in Table 12. Referring to the table, this model consists of five elements of thermophysical: viscosity, density, heat capacity, thermal conductivity, and thermal expansion. The Takabi model's thermal conductivity and viscosity are originated from the modified Maxwell [85] and the Brinkman model [86], respectively. Although thermal conductivity and viscosity of the Takabi model underestimate the experimental data by Suresh *et al.,* [84], however, the density and heat capacity of this model, originating from Pak *et al.,* [87] align well with experimental data obtained by various researchers [88-90]. Sundar *et al.,* [88,89] investigated the density of MWCNT-Fe_3O_4/water and nano-diamond-Fe_3O_4/water hybrid nanofluids using the Takabi model's density, achieving good agreement with their experimental results. The density and heat capacity of Takabi model also showed a good agreement with the experimental outcomes of Ho *et al.,* [90] for various volume fraction (0%, 4%, 10% and 20%). The comparison of experimental data of Sundar *et al.,* [89] for the specific heat of nanodiamond-Fe_3O_4/water hybrid nanofluid with the results obtained using heat capacity of this model showed good agreement as well. Thus, Takabi model have been adopted rigorously by the researchers in solving HNFs flow problem numerically in recent years [45-57].

The summary of related articles using Takabi model is displayed in Table 13. Out of 13 articles using Takabi model, four adopted all five elements of correlation (including thermal expansion) [45,46,49,51]. Most of these articles involved the mixed convection flow problem. For instance, Wahid *et al.,* [52] modeled and explored the properties of stagnation points of HNFs flow and heat transfer over a vertical plate, considering mixed convection, slip, and suction. Khan *et al.,* [46] also investigated stagnation-point flow of a thermo micropolar HNFs through a vertical surface, accounting for mixed convection and buoyancy effects in a saturated porous medium. Both Khashi'ie *et al.,* [49] and Ghalambaz *et al.,* [45] studied mixed convection flow and heat transfer of HNFs over a vertical plate but in different medium. Khashi'ie *et al.,* [49] numerically analyzed the HNFs problem in a porous medium, while Ghalambaz *et al.,* [45] did not involve the porous medium in their study. The remaining articles adopted only four elements of correlation (excluding thermal expansion) [47,48,50,52- 57,61].

Table 9
Summary of authors based on particle, base fluid, geometry, effects, numerical method and elements of correlation involved in Modified Devi model (Type A)

No.	Authors	Particle	Base fluid	Geometry	Effects	Numerical method	DV	DS	HC	TC	EC	TE	DF
1	Alabdulhadi *et al.,* [34]	Ag-MgO	Water	Inclined shrinking/stretching surface	Magnetic field and mixed convection	bvp4c MATLAB	√	√	√	√	√	√	
2	Waini, Ishak, & Pop [37]	Al_2O_3-Cu	Water	Stagnation region of vertical plate	Radiation and mixed convection	bvp4c MATLAB	√	√	√	√		√	
3	Khashi'ie, Arifin, & Pop [36]	Al_2O_3-Cu	Water	Stagnation point flow of Riga plate	EMHD and mixed convective	bvp4c MATLAB	√	√	√	√		√	
4	Anuar *et al.*, [35]	Ag–MgO	Water	Inclined permeable stretching/ shrinking sheet	Suction and buoyancy force	bvp4c MATLAB	√	√	√	√		√	
5	Yashkun *et al.*, [38]	Al_2O_3-Cu	Water	Exponentially stretching/ shrinking sheet	Mixed convection and joule heating	bvp4c MATLAB	√	√	√	√	√	√	

DV=Dynamic Viscosity, DS=Density, HC=Heat Capacity, TC=Thermal Conductivity, EC=Electrical Conductivity, TE=Thermal Expansion, DF=Diffusivity

Table 10
Summary of authors based on particle, base fluid, geometry, effects, numerical method and elements of correlation involved in Modified Devi model (Type B)

No.	Authors	Particle	Base fluid	Geometry	Effects	Numerical method	DV	DS	HC	TC	EC	TE	DF
1	Gangadhar *et al.,* [41]	MgO-Au	Water	Nodal/saddle stagnation point	Slip and viscous dissipation	Runge-Kutta-Fehlberg method (RKF 45)	√	√	√	√			√
2	Dinarvand *et al.,* [40]	TiO_2-CuO	Water	Static/moving wedge or corner	None	bvp4c MATLAB	√	√	√	√			√
3	Dinarvand [39]	CuO-Ag	Water	Nodal/saddle stagnation-point	None	bvp4c MATLAB	√	√	√	√			√

DV=Dynamic Viscosity, DS=Density, HC=Heat Capacity, TC=Thermal Conductivity, EC=Electrical Conductivity, TE=Thermal Expansion, DF=Diffusivity

Table 11
Summary of authors based on particle, base fluid, geometry, effects, numerical method and elements of correlation involved in Modified Devi model (Type C)

No.	Authors	Particle	Base fluid	Geometry	Effects	Numerical method	DV	DS	HC	TC	EC	TE	DF
1	Jamaludin *et al.,* [42]	Al_2O_3-Cu	Water	Permeable stretching/ shrinking sheet	MHD, mixed convectionand heat source/sink	bvp4c MATLAB	√	√	√	√	√	√	√
2	Jamaludin *et al.,* [43]	Al_2O_3-Cu	Water	An exponentially stretching/ shrinking sheet	Mixed convection, viscous dissipation and suction/injection	bvp4c MATLAB	√	√	√	√		√	√

DV=Dynamic Viscosity, DS=Density, HC=Heat Capacity, TC=Thermal Conductivity, EC=Electrical Conductivity, TE=Thermal Expansion, DF=Diffusivity

Table 12
Effective thermophysical properties of NFs and HNFs from Takabi model

Element	NFs	HNFs
Viscosity	$\frac{\mu_{nf}}{\mu_f}=\frac{1}{(1-\phi)^{2.5}}$	$\frac{\mu_{hnf}}{\mu_f}=\frac{1}{(1-\phi_{hnf})^{2.5}}$
Density	$\rho_{nf}=(1-\phi)\rho_f+\phi\rho_s$	$\rho_{hnf}=(1-\phi_{hnf})\rho_f+\phi_1\rho_{s1}+\phi_2\rho_{s2}$
Heat Capacity	$(\rho C_p)_{nf}=(1-\phi)(\rho C_p)_f+\phi(\rho C_p)_s$	$(\rho C_p)_{hnf}=(1-\phi_{hnf})(\rho C_p)_f+\phi_1(\rho C_p)_{s1}+\phi_2(\rho C_p)_{s2}$
Thermal Conductivity	$\frac{k_{nf}}{k_f}=\frac{k_s+2k_f-2\phi(k_f-k_s)}{k_s+2k_f+\phi(k_f-k_s)}$	$\frac{k_{hnf}}{k_f}=\frac{\left(\frac{\phi_1 k_{s1}+\phi_2 k_{s2}}{\phi_{hnf}}\right)+2k_{bf}+2(\phi_1 k_{s1}+\phi_2 k_{s2})-2\phi_{hnf}k_{bf}}{\left(\frac{\phi_1 k_{s1}+\phi_2 k_{s2}}{\phi_{hnf}}\right)+2k_{bf}-(\phi_1 k_{s1}+\phi_2 k_{s2})+\phi_{hnf}k_{bf}}$
Thermal expansion	$(\rho\beta)_{nf}=(1-\phi)(\rho\beta)_f+\phi(\rho\beta)_s$	$(\rho\beta)_{hnf}=(1-\phi_{hnf})(\rho\beta)_f+\phi_1(\rho\beta)_{s1}+\phi_2(\rho\beta)_{s2}$ where $\phi_{hnf}=\phi_1+\phi_2$

3.4 Modified Takabi Model

Several current studies have adopted the Takabi model with an additional element of electrical conductivity [60-70]. Referring to Hussain *et al.,* [58] and Waini *et al.,* [59], the electrical conductivity element for both NFs and HNFs can be represented in Table 14. The summary of related articles using Modified Takabi model is displayed in Table 15. Out of 11 articles using Takabi model, two adopted all five elements of correlation (viscosity, density, heat capacity, thermal conductivity, and thermal expansion) with an additional element of electrical conductivity [65,62]. Both Waini, Ishak, & Pop [65] and Wahid *et al.,* [62] considered mixed convection HNFs flow with magnetohydrodynamic (MHD) and thermal radiation effects but over different geometries. Waini *et al.,* [65] focused on a shrinking vertical sheet whereas Wahid *et al.,* [62] focused on permeable vertical plate.

The remaining articles adopted the Takabi model with four elements (excluding thermal expansion) and an additional element of electrical conductivity [60,61,63,64,66-70]. For instance, Waini *et al.,* [64] examined HNFs flow and heat transfer over a permeable non-isothermal shrinking surface, considering MHD and radiation effects. Waini *et al.,* [67] also studied HNFs flow past a shrinking sheet in the presence of the magnetic field and dust particles. In another studies, Khashi'ie *et al.,* [61] focused on MHD HNFs flow with heat transfer on a moving plate incorporating Joule heating. While Acharya *et al.,* [60] investigated the TiO_2-$CoFe_2O$/water HNFs over rotating disk with magnetic field effect. Wahid *et al.,* [63] also numerically investigate convective HNFs flow over a permeable stretching/shrinking surface, considering magnetohydrodynamic (MHD) and radiation effects.

3.5 Xue Model

A specific thermal conductivity model for Carbon nanotube (CNT) based composites have been developed by Xue [71] in 2005. The existing model for thermal conductivity such as Maxwell [85] and Hamilton and Crosser [83] only valid for the composites containing the spherical or rotational elliptical particles with small axial ratio. However, CNTs, in fact, can be regarded as rotational elliptical nanoparticles with a very large axial ratio. Thus, Xue model aims to enhance the thermal conductivity of CNTs-based composites beyond what existing models can achieve. The model has been compared with the experimental data and showed a good agreement. Referring to Abbas *et al.,* [72] the thermal conductivity element for NFs and HNFs can be represented in Table 16.

The effective thermophysical properties of NFs and HNFs from Xue model are then, given in Table 17 [73]. Referring to the table, this model consists of five elements of thermophysical properties: viscosity, density, heat capacity, thermal conductivity, and diffusivity.

The summary of related articles using the Xue model is presented in Table 18. Most of these studies involved the CNTs and oxide nanoparticles while water as its base fluid [73-76]. Notably, the thermal conductivity element in the Xue model is specifically for CNTs particle. However, there is a study adopted the Xue model to investigate HNFs which involved non-CNT particles (Alumina and Copper) immersed in the water [72].

Several studies reveal that the thermal conductivity predictions of the Hamilton-Crosser and Maxwell models were better than those of Xue model [91,92]. Since Devi model and Takabi model originated from Hamilton-Crosser and Maxwell model respectively, thus they are much more preferred for solving non-CNTs HNFs flow problem. While Xue model is much more preferred for solving HNFs flow problems involving CNTs. To make it clear, the table comparison of the correlation models of HNFs is given in Table 19.

Table 13
Summary of authors based on particle, base fluid, geometry, effects, numerical method and elements of correlation involved in Takabi model

No.	Authors	Particle	Base fluid	Geometry	Effects	Numerical method	DV	DS	HC	TC	EC	TE	DF
1	Zainal *et al.,* [57]	Al_2O_3-Cu	Water	Unsteady stagnation point flow of permeable stretching/ shrinking riga plate	Thermal radiation	bvp4c MATLAB	√	√	√	√			
2	Wahid *et al.,* [51]	Al_2O_3-Cu	Water	Vertical plate	Mixed convection, slips and suction	bvp4c MATLAB	√	√	√	√		√	
3	Khashi'ie *et al.,* [50]	Al_2O_3-Cu	Water	Permeable stretching/shrinking sheet	Thermal radiation and homogeneous-heterogeneous reactions	bvp4c MATLAB	√	√	√	√			
4	Khan *et al.,* [46]	MgO-Ag	Water	Stagnation point flow of vertical surface	Mixed convection and buoyancy	bvp4c MATLAB	√	√	√	√		√	
5	Waini *et al.,* [53]	Al_2O_3-Cu	Water	Stretching/shrinking sheet	Homogeneous-heterogeneous reactions	bvp4c MATLAB	√	√	√	√			
6	Waini *et al.,* [54]	Al_2O_3-Cu	Water	Shrinking cylinder	Surface heat flux	bvp4c MATLAB	√	√	√	√			
7	Waini *et al.,* [55]	Al_2O_3-Cu	Water	Rotating disk	Suction and deceleration	bvp4c MATLAB	√	√	√	√			
8	Zainal *et al.,* [56]	Al_2O_3-Cu	Water	Moving edge	Activation energy and binary chemical reaction	bvp4c MATLAB	√	√	√	√			
9	Khashi'ie *et al.,* [48]	Al_2O_3-Cu	Water	Moving plate	Viscous dissipation and radiation	bvp4c MATLAB	√	√	√	√			
10	Wahid *et al.,* [52]	Al_2O_3-Cu	Water	Exponentially stretching/shrinking curved surface	None	bvp4c MATLAB	√	√	√	√			
11	Khashi'ie *et al.,* [49]	Al_2O_3-Cu	Water	Vertical plate in non-darcy porous medium	Mixed convection	bvp4c MATLAB	√	√	√	√		√	
12	Khashi'ie *et al.,* [47]	Al_2O_3-Cu	Water	Shrinking cylinder	Surface heat flux	bvp4c MATLAB	√	√	√	√			

13	Ghalambaz *et al.,* [45]	Al_2O_3-Cu	Water	Stagnation point of vertical plate	Mixed convection	finite-difference solver	√	√	√	√		√	

DV=Dynamic Viscosity, DS=Density, HC=Heat Capacity, TC=Thermal Conductivity, EC=Electrical Conductivity, TE=Thermal Expansion, DF=Diffusivity

Table 14
Additional effective thermophysical properties of NFs and HNFs to existing Takabi model

Element	NFs	HNFs
Diffusivity	$\alpha = \dfrac{k_{nf}}{\left(\rho C_p\right)_{nf}}$	$\alpha = \dfrac{k_{hnf}}{\left(\rho C_p\right)_{hnf}}$
Electrical Conductivity	$\dfrac{\sigma_{nf}}{\sigma_f} = \dfrac{\sigma_s + 2\sigma_f - 2\phi\left(\sigma_f - \sigma_s\right)}{\sigma_s + 2\sigma_f + \phi\left(\sigma_f - \sigma_s\right)}$	$\dfrac{\sigma_{hnf}}{\sigma_f} = \dfrac{\left(\dfrac{\phi_1\sigma_{s1} + \phi_2\sigma_{s2}}{\varphi_{hnf}}\right) + 2\sigma_{bf} + 2\left(\phi_1\sigma_{s1} + \phi_2\sigma_{s2}\right) - 2\phi_{hnf}\sigma_{bf}}{\left(\dfrac{\phi_1\sigma_{s1} + \phi_2\sigma_{s2}}{\varphi_{hnf}}\right) + 2\sigma_{bf} - \left(\phi_1\sigma_{s1} + \phi_2\sigma_{s2}\right) + \phi_{hnf}\sigma_{bf}}$

Table 15
Summary of authors based on particle, base fluid, geometry, effects, numerical method and elements of correlation involved in Modified Takabi model

No.	Authors	Particle	Base fluid	Geometry	Effects	Numerical method	DV	DS	HC	TC	EC	TE	DF
1	Waini *et al.,* [64]	Al_2O_3-Cu	Water	Permeable non-isothermal shrinking surface	MHD and radiation	bvp4c MATLAB	√	√	√	√	√		
2	Waini *et al.,* [68].	TiO_2-$CoFe_2O_4$	Water	Moving plate	Thermophoresis particle deposition and viscous dissipation	bvp4c MATLAB	√	√	√	√	√		
3	Waini *et al.,* [65]	Al_2O_3-Cu	Water	Shrinking vertical sheet	MHD, mixed convection and thermal radiation	bvp4c MATLAB	√	√	√	√	√	√	
4	Waini *et al.,* [67]	Al_2O_3-Cu	Water	Shrinking sheet	Magnetic field and dust particle	bvp4c MATLAB	√	√	√	√	√		
5	Khashi'ie *et al.,* [61]	Al_2O_3-Cu	Water	Moving plate	MHD and Joule heating	bvp4c MATLAB	√	√	√	√	√		
6	Acharya *et al.,* [60]	TiO_2-$CoFe_2O_4$	Water	Rotating disk	Magnetic field	RK-4 method	√	√	√	√	√		

7	Wahid *et al.,* [63]	Al_2O_3-Cu	Water	Permeable stretching/shrinking surface	MHD and radiation	bvp4c MATLAB	√	√	√	√	√		
8	Waini *et al.,* [66]	Al_2O_3-Cu	Water	Stretching/shrinking sheet	MHD, Joule heating and viscous dissipation	bvp4c MATLAB	√	√	√	√	√		
9	Wahid *et al.,* [62]	Al_2O_3-Cu	Water	Permeable vertical plate	MHD, mixed convection and thermal radiation	bvp4c MATLAB	√	√	√	√	√	√	
10	Zainal *et al.,* [70]	Al_2O_3-Cu	Water	Exponentially permeable stretching/shrinking sheet	MHD	bvp4c MATLAB	√	√	√	√	√		
11	Zainal *et al.,* [69]	Al_2O_3-Cu	Water	Stretching/shrinking sheet	EMHD	bvp4c MATLAB	√	√	√	√	√		

DV=Dynamic Viscosity, DS=Density, HC=Heat Capacity, TC=Thermal Conductivity, EC=Electrical Conductivity, TE=Thermal Expansion, DF=Diffusivity

Table 16
Effective thermal conductivity element of NFs and HNFs

Fluid	Model
NFs	$\frac{k_{nf}}{k_{bf}}=\frac{1-\phi_1+2\phi_1\left(\frac{k_{s1}}{k_{s1}-k_f}\right)\ln\left(\frac{k_{s1}+k_f}{2k_f}\right)}{1-\phi_1+2\phi_1\left(\frac{k_f}{k_{s1}-k_f}\right)\ln\left(\frac{k_{s1}+k_{nf}}{2k_f}\right)}$
HNFs	$\frac{k_{hnf}}{k_{bf}}=\frac{1-\phi_2+2\phi_2\left(\frac{k_{s2}}{k_{s2}-k_{nf}}\right)\ln\left(\frac{k_{s2}+k_{nf}}{2k_{nf}}\right)}{1-\phi_2+2\phi_2\left(\frac{k_{nf}}{k_{s2}-k_{nf}}\right)\ln\left(\frac{k_{s2}+k_{nf}}{2k_{nf}}\right)}$ where $\frac{k_{bf}}{k_f}=\frac{k_{s1}+(m-1)k_f-(m-1)\phi_1(k_f-k_{s1})}{k_{s1}+(m-1)k_f+\phi_1(k_f-k_{s1})}$

Table 17
Effective thermophysical properties of HNFs from Xue model

Element	HNFs
Viscosity	$\frac{\mu_{hnf}}{\mu_f}=\frac{1}{(1-\phi_1)^{2.5}(1-\phi_2)^{2.5}}$
Density	$\rho_{hnf}=(1-\phi_2)\left[(1-\phi_1)\rho_f+\phi_1\rho_{s1}\right]+\phi_2\rho_{s2}$
Heat Capacity	$(\rho C_p)_{hnf}=(1-\phi_2)\left[(1-\phi_1)(\rho C_p)_f+\phi_1(\rho C_p)_{s1}\right]+\phi_2(\rho C_p)_{s2}$
Thermal Conductivity	$\frac{k_{hnf}}{k_{bf}}=\frac{1-\phi_2+2\phi_2\left(\frac{k_{s2}}{k_{s2}-k_{nf}}\right)\ln\left(\frac{k_{s2}+k_{nf}}{2k_{nf}}\right)}{1-\phi_2+2\phi_2\left(\frac{k_{nf}}{k_{s2}-k_{nf}}\right)\ln\left(\frac{k_{s2}+k_{nf}}{2k_{nf}}\right)}$ where $\frac{k_{bf}}{k_f}=\frac{k_{s1}+(m-1)k_f-(m-1)\phi_1(k_f-k_{s1})}{k_{s1}+(m-1)k_f+\phi_1(k_f-k_{s1})}$
Diffusivity	$v_{hnf}=\frac{\mu_{hnf}}{\rho_{hnf}}$

Table 18
Summary of authors based on particle, base fluid, geometry, effects, numerical method and elements of correlation involved in Xue model

No.	Authors	Particle	Base fluid	Geometry	Effects	Numerical method	DV	DS	HC	TC	EC	TE	DF
1	Abbas *et al.,* [72]	Al_2O_3-Cu	Water	Stagnation point, exponential stretching	Thermal slip	bvp4c MATLAB	√	√	√	√			√
2	Bilal *et al.,* [73]	SWCNTs/MWC NTs-Fe_3O_4	Water	Wavy fluctuating spinning disc	MHD	bvp4c MATLAB	√	√	√	√			√
3	Saeed *et al.,* [76]	SWCNTs/MWC NTs-Fe_3O_4	Water	Stretching curved surface	Sundry flow	HAM method	√	√	√	√			√
4	Bilal *et al.,* [74]	SWCNTs/MWC NTs-Fe_3O_4	Water	Two gyrating plates	Magnetic and electrohydrodynamic	HAM method	√	√	√	√			√
5	Saba *et al.,* [75]	SWCNTs/MWCNTs-Fe_3O_4	Water	Asymmetric channel with dilating/squeezing walls	None	Runge–Kutta–Fehlberg	√	√	√	√			√

DV=Dynamic Viscosity, DS=Density, HC=Heat Capacity, TC=Thermal Conductivity, EC=Electrical Conductivity, TE=Thermal Expansion, DF=Diffusivity

Table 19
Table comparison of the correlation models of HNFs

Comparison item	Correlation		
	Devi	Takabi	Xue
The comparison with experimental data	The thermal conductivity of the model gives an excellent correlation with experimental data obtained by Suresh et al., [83].	The density and heat capacity of the model shows a good agreement with experimental results [88,89,90].	The thermal conductivity of the model shows a good agreement with experimental data [71]
The suitability for different type of nano particles	Suitable for non-CNTs particle	Suitable for non-CNTs particle	Suitable for CNTs particle
The applicability for higher concentration	May not be suitable for higher concentration	Not be suitable for higher concentration	May suitable for higher concentration

The latest numerical investigations on hybrid nanofluid flow which does not include in analysis can be found in the works of Azmi *et al.,*, Zainal *et al.,*, Waini *et al.,*, Khashi'ie *et al.,* and Mokhtar *et al.,* [93-97]. These studies explore various nanoparticles and base fluids with the adoption of different correlation models. Additionally, Nordin *et al.,* provides further insights into the recent advancement in hybrid nanofluids [98]. Thus, the studies mentioned earlier can also be referred for future research proposals.

4. Future Recommendations

There is a shortcoming during the collection of potential articles. Problems started to occur when retrieving too many articles and more time and effort were required to download all the articles and screen out all the duplicated articles. For the betterment of future research in the review process, it is recommended to remove the duplicated articles once the screening process (following the inclusion and exclusion process) is completed (refer to Figure 2). It is believed that this process will ease the authors to any duplicated articles as the number of remaining articles should be reduced.

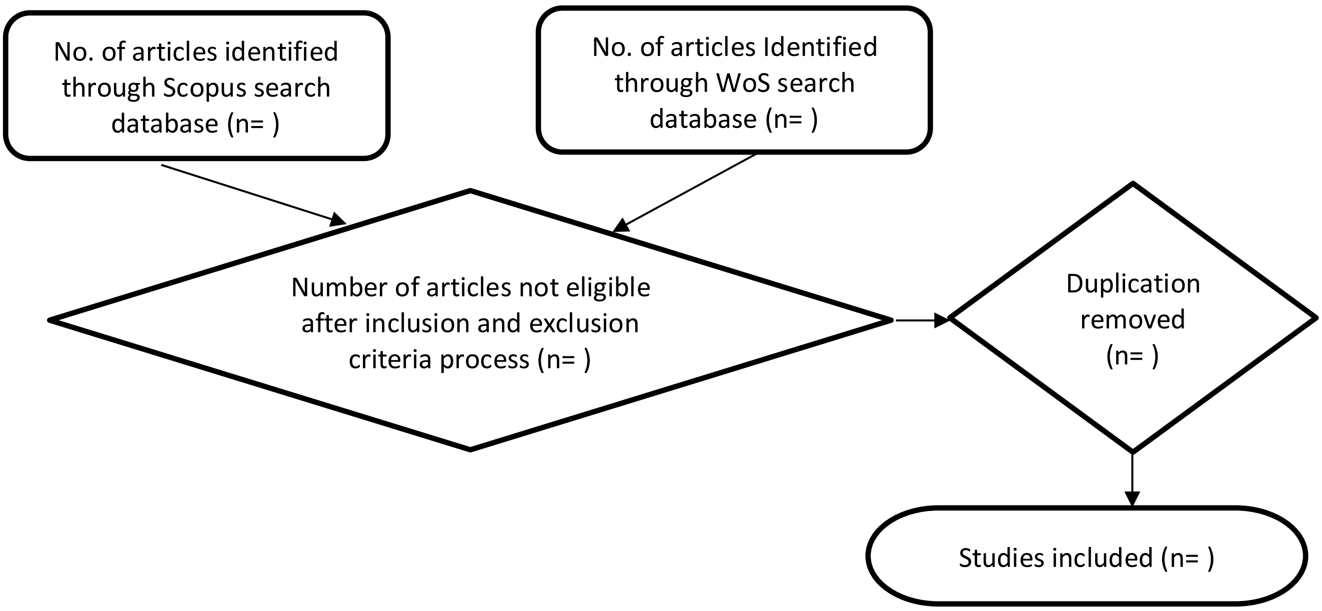

Fig. 2. Suggested flow diagram for the thematic review process

Several recommendations for future research also are made to further study the flow of HNFs precisely and increase the heat transfer rate. The recommendations are as follows:

i) Since Copper and Alumina are the most frequently employed nanoparticles, it is proposed that additional nanoparticles be explored to figure out their application in real world phenomena.
ii) Good and stable base fluid other than water such as oil and ethylene glycol can also be employed.
iii) It is recommended for future study which involved the effect of magnetic field and mixed convection effect to include the electrical conductivity element and the thermal expansion element respectively.
iv) Modified Devi Type C which involved all the elements of correlation is interesting to be adopted due to its capabilities in determining the heat transfer of HNFs.

v) It is also suggested that the hybrid nanofluids flow problems be extended to include medical field applications such as drug delivery for disease treatment purposes.

4. Conclusions

This study examines the patterns and trends of correlations used in numerical HNFs flow problems. The findings from the related recent research articles, seven elements of correlation have been identified including thermal conductivity, viscosity, density, heat capacity, electrical conductivity, thermal expansion, and diffusivity. These elements are considered differently based on the available type of correlation which named as Devi model, Modified Devi Type A, Modified Devi Type B, Modified Devi Type C, Takabi model, and Modified Takabi model. This paper examines each of the type of correlations by further categorizing the available recent research articles into particle type, base fluid, geometry, effects, numerical method, and elements of correlation involved. According to the reviewed literature, the following closing statements are made:

i) Takabi correlation is much more preferred by the authors for recent years.
ii) It is observed that the combination of Alumina and Copper nanoparticles with water as their base fluid, provides better heat transfer rate through the adoption of Devi and Takabi model correlation.
iii) Bvp4c MATLAB is widely used for solving heat transfer and fluid flow of HNFs problem numerically.
iv) The highest possible rate of heat transfer can be achieved through the implementation of various effects and geometry.
v) The Xue model is widely used to study HNFs flow problems which include CNT particles, while Devi and Takabi-based model are extensively used for non-CNT particle.
vi) All correlation models show their strength in different ways (Refer Table 19). At this moment there is no such perfect model that has been introduced to fit the properties from experimental data.

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