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REGULAR ARTICLE

Exploring Thermodynamic Process in Hybrid Nanofluid Flow through Porous Materials Using Multi-Objective Support Vector Machine

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Thermodynamic processes in the location of hybrid Nano fluid flow through porous materials. It probably appears the way Nano fluids behave and interact in porous structures while consuming thermodynamics. The fluid dynamics and heat transfer, as well as possibly improving the system for particular applications. The purpose of this research is to clarify the behavior and interactions of nanofluidsin porous structures by examining the thermodynamic processes of hybrid nanofluid flow through porous materials. In this paper, we proposed multi-objective support vector machine (MSVM) techniques for thermodynamic processes in Nano fluid through porous materials. The technique's predictions were thoroughly examined and verified against the computational data. Then, shear stress across the cylinder, nusselt and bejan number, and thermal field behaviors were estimated using the validated prediction method. Our method delivers a huge efficiency improvement by reducing processing time over 92 %. We effectively present correlations in numerical order of accuracy when faced with a growing set of variables. This emphasizes the way of useful and powerful created predictive technique. It is noteworthy that it is a strong alternative that outperforms classical statistical techniques in the field of equipment for processing design. In the final analysis, our proposed method is a unique and useful way to handle challenging layout circumstances.

Keywords: Thermodynamic, Nanofluid, Shear stress, Nusselt, Porous structures.

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1. INTRODUCTION

In thermal engineering, hybrid nanofluids have shown great promise since they have greater heat transfer characteristics than conventional fluids [1]. The investigation of thermodynamic phenomena as it relates to hybrid nanofluid flow across porous media. Because theyare synthetic of particles scattered throughout a base fluid, nanofluids have special thermal properties that can be used to increase the effectiveness of heat transfer. Conversely, porous substances offer a well-organized medium with a variety of uses, including purification and thermal exchange. The combination of pore-filled substances and composite nanofluids works synergistically to optimize heat transport in a variety of engineering applications [2].

Particles influence the thermophysical attributes of the fundamental fluiddue to their enhanced surface area and heat conductivity. The modification affects the conduction and convection heat transfer processes, which in turn affects the heating procedure's overall effectiveness. Understanding these subtleties of thermodynamics allows to customize the composition of the nanofluid to maximize the transmission of heat in mediums that are porous, increasing the effectiveness of thermal systems [3].

Considering porous materials are used extensively in applications related to engineering, they are essential [4]. The fluid movement and transfer of heat processes are made more complex by the linked pore structure of these materials. Designing effective and dependable thermal systems requires a understanding of hybrid nanofluids interface move through media that is porous. Advances

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the theoretical comprehension of the aforementioned procedures and has applications in the field of enhanced warmth exchange, battery backup, and filtering technology development [5-7].

The remaining portion of this article as follows: Part 2 discusses the methodology. Part 3 provide the result and discussion. The concluding segment of this article, Part 4, summarizes the key findings and contributions of our research.

2. RELATED WORKS

The mechanical convection of copper aluminum oxide in the presence of water nanofluid into a permeable chamber was examined in study [8-9]. The volume control technique has been employed to tackle the analysis numerically, and the field of magnets was applied to the flowing sector. A wide range of characteristics, including Nano fluid hybrids, parts, Lorenz numerals, Hartman numbers, and permeability factors, were added to the analysis of hybrid nanofluid energy as part of its transfer flux. The main results show that convection heat transport inside the protective structure improves with a rise in the darcy amount as well as the Rayleigh amount.

Study [10] examinedthe properties of axisymmetric homann and agarwal flows at the point of stagnant flow over a stretched and spiraling surface. In addition to the use of mixed nanofluids, the consequences of homogeneous rotating and longitudinal, radial stretch of the disc are taken into consideration. To be more precise, motor oil was mixed with multi-walled cellulose nanotubes and titanium oxide to create the nanofluid. Important findings from the experiment can be used for a variety of technical applications, such as fluid flow systems, cooling equipment, and heating exchangers.

Study [11] examined the use of"hamilton crosser (HMC) and yamadaota(YMO)"hybrid forms of nanofluids to provide optimal thermal improvement in a variety of applications, including temperature therapy, engines for airplanes, solar panels, gadgets, and refrigeration processes. Based on connections related to the improvement of hybrid nanofluid heat exchange, the HMC model and YMO model were selected predominantly. By applying the notion of similarity factors, an ordinary differential equation (ODE)-related system was created, and the technique of finite elements numerically simulates the evolving flow model.

Study [12] investigated the effects of the synthetic nanofluid in a medium that was porous, covering melting portions of a bipolar biochemical reaction and an arrhenius stimulating frequency. The water-based nanoparticle was expected to include gyrotactic microorganisms. The resulting dimensional quadratic boundary-layer model was reduced and transformed into an undefined form by applying the proper similarity factors. The rapid adoption of the approach was further illustrated by the plot of remaining error. They suggest by increasing the melted temperature.

The fluid flow zone was exposed to the Buongiorno model in study [13]. The impact on energy production has been examined using the concept of mass and heat transport phenomenon. Using flow presumptions, that resemble border barrier estimates expressed in terms of equations with partial differentials, the controlling model has been created. Further solution of without dimensions system was achieved via a numerical technique with Matlab software tools. The findings from the analysis of physical variables were discussed through the use of graphs and tables. Higher heat production values led to an improvement in the temperature curves.

3. METHODOLOGY

The methodology contains the problem statement, an in-depth exploration of nanofluid hybridization, and outlines the proposed method of this research. This section provides a comprehensive overview of this research objectives and the approach.

3.1 Problem Description

An illustration of the process and thermal transfer issue in this research. This applies to a nanofluid flowing under radial heat transfer around an embedded cylinders in a porous media. We consider one stage, laminar in nature steady-state, Newtonian, the nanofluid flow. A homogeneous and isotropic porous media and an infinitely long cylinder are considered to be in a state of local thermal non-equilibrium. The unevenness of evaporation is the cause of the non-axisymmetric features of the flow through the cylindrical object. Furthermore, it is presumable that gravity acts along with the cylinder's axis.

Regardless, the cylinder is surrounded by an exterior axisymmetric circular SPF. Due to the moderate variety of Reynolds values in the pore-scale, non-linear effects in transferring momentum might be regarded as minor. Finally, because of constant particular heat, porosity, heat conductivity, and weight, the thermal dispersal effects and flow movement energy dissipation phenomena are disregarded. The equations that govern can be solved as follows to get the accomplishments.
The consistency of substance:

$$\frac{\partial(rn)}{\partial r} + r\frac{\partial v}{\partial y} = 0 \tag{1}$$

The direction of radial energy equations:

$$\frac{\rho_{hnf}}{\varepsilon^2}\left(v\frac{\partial v}{\partial r} + V\frac{\partial v}{\partial z}\right) = - \\ -\frac{\partial s}{\partial r} + \frac{\mu_{hnf}}{\varepsilon}\left(\frac{\partial^2 V}{\partial r^2} + \frac{1}{r}\frac{\partial v}{\partial r} - \frac{v}{r^2} + \frac{\partial^2 v}{\partial y^2}\right) - \frac{\mu_{hnf}}{D_1} \tag{2}$$

The buoyant pressure and axial direction of energy transport:

$$\frac{\rho_{hnf}}{\varepsilon^2}\left(v\frac{\partial V}{\partial r} + V\frac{\partial V}{\partial y}\right) = -\frac{\partial s}{\partial y} + \frac{\mu_{hnf}}{\varepsilon}\left(\frac{\partial^2 V}{\partial r^2} + \frac{1\partial V}{r\,\partial r} + \frac{\partial^2 V}{\partial y^2}\right) \pm \\ (\rho\beta)_{hnf}\, h\left(D_{hnf} - D_{\infty}\right) - \frac{\mu_{hnf}}{T_1} \tag{3}$$

Equations (4) and (5) give the amount of thermal energy flow in the fluid with pores.

The energetic equations of the nanofluid technology phase:

$$\frac{\partial D_{hnf}}{\partial r}+V\frac{\partial D_{hnf}}{\partial y}=\frac{L_{hnf}}{(\rho C_s)_{hnf}}\left(\frac{\partial^2 D_{hnf}}{\partial r^2}+\frac{1}{r}\frac{\partial D_{hnf}}{\partial r}+\frac{\partial^2 D_{hnf}}{\partial y^2}\right)+\frac{h_{sf}\cdot b_{sf}}{(\rho C_s)_{hnf}}\left(D_s-D_{hnf}\right) \quad (4)$$

The thermal power transfer in the solid state phase:

$$L_s\left(\frac{\partial^2 D_s}{\partial r^2}+\frac{1}{r}\frac{\partial D_s}{\partial r}+\frac{\partial^2 D_s}{\partial y^2}\right)-h_{sf}\cdot b_{sf}\left(D_s-D_{hnf}\right)+ +\frac{1}{r}\frac{\partial}{\partial r}(r.cr)=0 \quad (5)$$

Heat flow radiative using the Rosseland model:

$$Cr=-\frac{4\sigma^*}{3L^*}\frac{\partial D_s^4}{\partial r} \quad (6)$$

Applying Eq. (5) again produces in:

$$L_s\left(\frac{\partial^2 D_s}{\partial r^2}+\frac{1}{r}\frac{\partial D_s}{\partial r}+\frac{\partial^2 D_s}{\partial y}\right)-h_{sf}\cdot b_{sf}\left(D_s-D_{hnf}\right)+\frac{1}{r}\frac{\partial}{\partial r}\left(r\cdot\frac{16\sigma^*}{3L^*}T_s^3\frac{\partial D_s}{\partial r}\right)=0 \quad (7)$$

The term D_s^4 in Eq. (6) is produced and linearized about the temperature of the environment D_∞ in the earlier works. But in this work, a linear form of thermal radiation has been considered. The amount of pressure, temperatures, kinematics density, volume, electrical conductivity, and heat capacitor of the nanofluid hybrid are represented by the variables s, D, ρ_{hnf}, L_{hnf}, μ_{hnf}, and $(\rho C_s)_{hnf}$ in the aforementioned equations. The thermal expansion coefficient, thermal radiation flux, acceleration due to gravity, prescribed temperatures at the surface of the wall, mean absorbance coefficient, Stefan-Boltzmann stable, and other terms are represented by the parameters b, c_r, g, D_∞, L^*, and s^*, respectively. These characteristics are calculated close to the stream's friction area and inside the buffer layer.
The hemodynamic boundaries are subject to the following restrictions.

$$r=b,\ V=0,\ v=0 \quad (8)$$

$$r=\infty:\ V=2\bar{L}y,\ v=-\bar{L}\left(r-\frac{b^2}{r}\right) \quad (9)$$

Equation (8) assumes no-slip circumstances for the cylinder's exterior surface, and Equation (9) shows that the viscous flow solutions approach the possibility of flow equation as $r=\infty$. This is verified by incorporating the continuous equations of $-\frac{1}{r}\frac{\partial(rv)}{\partial r}=\frac{\partial V}{\partial y}\ Constant=2\bar{L}y$ in the r and y directions. The integration's boundary values are V = 0 at y = 0 and v = 0 at r = b.

Additionally, the limiting requirements for the energy balance problem in the porous zone are shown by Equation (10):

$$r=b:\ D_{hnf}=D_V=Constant$$
$$D_s=D_V=Constant$$
$$r=\infty:\ D_{hnf}=D_\infty \quad (10)$$
$$D_s=D_\infty$$

Where the free-stream and cylindrical temperatures on the surface are denoted by D_V and D_∞.

3.2 Nanofluid Hybridization

The mixed nanofluid utilized in this investigation was produced by dissolving the Cu nanoparticles mixture into 0.1 volume percent Al_2O_3/water. This hybrid nanofluid's border layer equations were examined using a unique type of thermophysical characteristics. The total solid volumes portion of the Al_2O_3nanoparticles added to the base fluid is represented by the number 1 in this model, while the solid volume percentages of Cu added to create the hybrid the nanofluid $CuAl_2O_3$/Water are indicated by the number 2. The equations required to ascertain the effective thermo-physical properties of hybrid nanofluids and nanofluids are shown in Figure 1. Table 1 shows the base fluid's and the nanoparticles' thermo-physical characteristics at 25 °C. Moreover, where the spherical nanoparticles are represented by m = 2. Furthermore, Figure 2 displays the various nanoparticles forms with respect to the sphericity metrics and configuration factor.

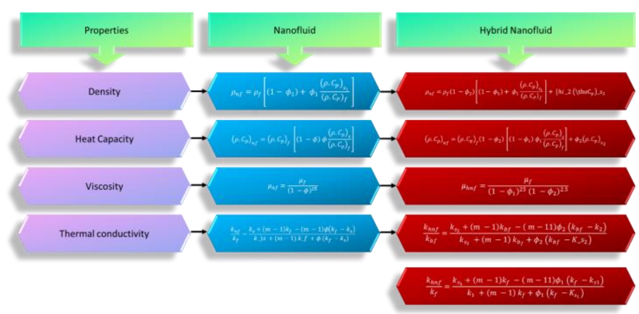

Fig. 1 – Thermophysical characteristics of hybrids and nanofluid technology

Table 1 – The density, particular heat, and electrical conductivity measured for base fluids and nanomaterials

Property	Al_2O_3	Water	Cu
$\rho\ \left(\frac{kg}{m^3}\right)$	3869	990.0	8890
$C_s\frac{J}{kg.L}$	768	4100	379
$L\ \left(\frac{V}{n.L}\right)$	48	0.6056	390

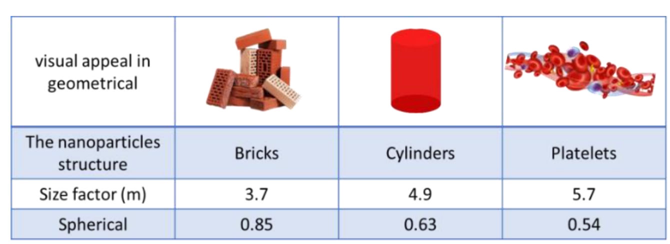

Fig. 2 – The values of different nanoparticles

3.3 Self-Replicating Systems

Equation (11) served as the basis for the similarity translations of the controlling Equations (1–7), which produced the undefined Equations (12) and (13).

$$v = -\frac{\bar{L}\cdot b}{\sqrt{\eta}} f(\eta),\ V = 2\bar{L}f'(\eta)y,\ s = \rho_f \bar{L}^2 b^2 S \quad (11)$$

Where the undefined circumferential component is indicated by $\eta = \left(\frac{r^2}{b}\right)$.

Equation (11) can be substituted into Equations (2), (3), and (4) to obtain:

$$\varepsilon\left[\eta f^{"'} + f^{"}\right] + Re.B_1.B_2[1 + ff' - (f')^2] + \varepsilon^2.\lambda\,[1 - f'] \pm \varepsilon^2.B_s\,.\lambda_1.(\theta_V - 1)\theta_{hnf} = 0 \quad (12)$$

$$S - S_0 = -\frac{1}{2\varepsilon^2}\left(\frac{f^2}{\eta}\right) - \frac{1}{\varepsilon.B_1.B_2}\left[\left(\frac{f'}{Re}\right) + \frac{\lambda}{Re}\int_1^{\eta}\frac{f}{\eta}d\eta\right] - 2\left[\frac{1}{\varepsilon^2} + \frac{1}{B_1.B_2}\frac{\lambda}{Re}\right]\left(\frac{y}{b}\right)^2 \quad (13)$$

Re is the stream that is free in this case. The Reynolds number, λ, represents the inverse of the Darcy number, Gr indicates the Grashof number, and λ_1 indicates the dimensionless mixing convective. In terms of h, the distinction is introduced by the prime.

In regard to Equations (8), (9), and (10), the conditions governing the boundaries for the two equations mentioned above on the following shapes:

$$\eta = 1:\ f'(1) = o,\ f(1) = 0 \quad (14)$$

$$\eta \to \infty:\ f'(\infty) = 0 \quad (15)$$

consequently Equation (4) may not be multidimensional. It is utilizing the conversion of:

$$\theta(\eta) = \frac{D(\eta) - D_\infty}{D_V - D_\infty} \quad (16)$$

Consequently, there is

$$D(\eta) = D_\infty[1 + (\theta_V - 1)\,\theta] \quad (17)$$

Equation (18) can be obtained by replacing Equations (11) and (17) in Equation (4) with the intention of ignoring the modest dissipation factors.

$$\eta\theta^{"}_{hnf} + \theta'_{hnf} + Re.Sr.\frac{B_3}{B_4}.\left(f.\theta'_{hnf}\right) + \frac{Bi.\gamma}{B_3}\left(\theta_s - \theta_{hnf}\right) = 0 \quad (18)$$

The value of the temperature parameter is represented by the parameter $\theta_V = \frac{D_V}{D_\infty}$, the radiative parameter is represented by R_d, and the Biot number is indicated by Bi. Thus, the following can be used to express the thermodynamic boundaries that are fitted to the nanofluid phase.

$$\eta = 1:\ \theta_{hnf}(1) = 1$$

$$\eta_{.}\infty:\ \theta_{hnf}(\infty) = 0 \quad (19)$$

Equations (11) and (17) can be substituted into Equation(7) to yield:

$$\eta\theta^{"}_s + \theta'_s - Bi\left(\theta_s - \theta_{hnf}\right) + R_d.\frac{\partial}{\partial\eta}[\eta.(1 + (\theta_V - 1)\theta_s)^3.\theta'_s] = 0 \quad (20)$$

This indicates the electrical conductivity ratio, which is g ¼ Ls Lf.

4. RESULT AND DISCUSSION

Simulation data for many test scenarios were produced using the mathematical framework created and these were supplied to the proposed technique in the manner mentioned in Section 3, and this section contains the predictions made by the technique.

Precise correlations are provided in this study to estimate the Nusselt and Sherwood numbers. The parameters that were entered are produced as a list. The parameter is chosen by optimizing the exchange of data between it and the output variable and reducing with the chosen variables. Based on Figure 3 and 4, it is possible to analyze the estimation accuracy of the Nusselt and Sherwood values owing to an increase in the number of inputs. Tables 2, 3, and 4 present the experiment's findings.

Table 2 – The analysis's variables' default settings are expressed as numbers

Simulation parameters	
λ_1	2.0
λ	11
η	1.46
Re	6.0
φ_1	0.03
Bi	0.2
Br	3.0
N	4.0
ε	0.10
γ	1.6
φ_2	0.03
Q_c	2.0
θ_x	1.3

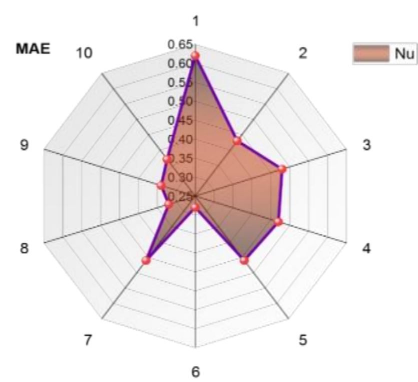

Fig. 3 – The MSVM models mean absolute error (MAE) for estimating Nu

Table 3 – The features applied to Nu

Feature ordering	The quantity of features
1	Bi
2	λ_1
3	ψ_1
4	ψ_2
5	M
6	Pr
7	R_d
8	θ_w
9	Re
10	λ

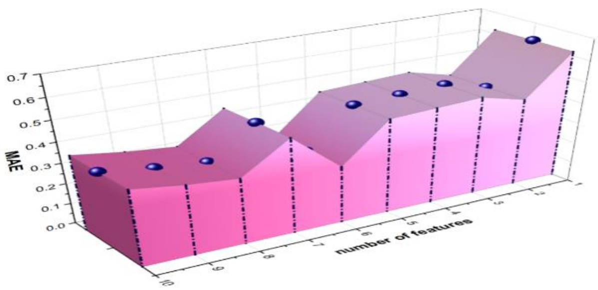

Fig. 4 – The MSVM models mean absolute error (MAE) for estimating shear-stress

Table 4 – The features applied to shear-stress

Feature ordering	The quantity of features
1	λ
2	ψ_2
3	λ_1
4	Re
5	R_d
6	ψ_1
7	Pr
8	θ_w
9	M
10	Bi

5. CONCLUSION

The thermodynamic procedures in the environment of hybrid nanofluid flow through porous materials examine thenanofluids behave and interact with one another inside the porous structures while taking thermodynamic principles. Recognizing the transfer of heat, fluid motion, and even system optimization for particular applications. This paper addressed, a hybrid nanofluid flow passing across a cylinder embedded in porous material. Initially, the problem was modeled computationally using a semi-similarity method. We proposed multi-objective support vector machine (MSVM) techniques through the use of supervised learning techniques was trained to utilize the computational results. It might be applicable in particular situations since it might not into consideration the potential complications seen in the actual world. In order to improve the predicted precision as well as effectiveness for hybrid nanofluid flow via porous materials in the process equipment design, further study may entail improving machine learning techniques and computational techniques.

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Дослідження термодинамічного процесу в гібридному потоці нанофлюїдів через пористі матеріали за допомогою багатоцільової опорної векторної машини

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Термодинамічні процеси в розташуванні гібридної нанотекучої рідини через пористі матеріали. Ймовірно, це виглядає так, як нанорідини поводяться та взаємодіють у пористих структурах, споживаючи термодинаміку. Динаміка рідини та теплопередача, а також, можливо, вдосконалення системи для окремих застосувань. Метою цього дослідження є з'ясування поведінки та взаємодії нанофлюїдів у пористих структурах шляхом вивчення термодинамічних процесів потоку гібридних нанофлюїдів через пористі матеріали. У цій статті ми запропонували методи багатоцільової опорної векторної машини (MSVM) для термодинамічних процесів у нанорідині через пористі матеріали. Прогнози техніки були ретельно вивчені та перевірені на основі обчислювальних даних. Потім було оцінено напругу зсуву в циліндрі, число Нуссельта і Бежана, а також поведінку теплового поля за допомогою перевіреного методу прогнозування. Наш метод забезпечує величезне підвищення ефективності, скорочуючи час обробки більш ніж на 92%. Ми ефективно представляємо кореляції в числовому порядку точності, коли стикаємося зі зростаючим набором змінних. Це підкреслює спосіб корисної та потужної створеної прогностичної техніки. Варто відзначити, що це сильна альтернатива, яка перевершує класичні статистичні методи в області обладнання для проектування обробки. Зрештою, запропонований нами метод є унікальним і корисним способом вирішення складних обставин компонування.

Ключові слова: Термодинаміка, Нанофлюїд, Напруга зсуву, Нуссельт, Пористі структури.