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Highlights

- \checkmark Ferrofluid exergy behavior is investigated within porous media.
- ✓ CVFEM is implemented to model MHD effect on nanofluid.
- \checkmark Entropy generation augments with rise of Hartmann number.
- ✓ Bejan number has direct relationship with magnetic field.

Ferrofluid irreversibility and heat transfer simulation inside a permeable space

including Lorentz forces

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Abstract

In current paper, exergy (mulation of free convection is scrutinized. In current mathematical framework, uniform r agretic field is adopted. In order to save the time, single phase model has been involved for nanofluid. Trend of Darcy, Hartmann and Rayleigh numbers on Bejan number, exergy loss and Nusselt number are captured through figures. Obtained outputs have indicated the growth of Nu_{ave} with the Darcy and Rayleigh numbers. A growth of Lorenz horders reflects greater exergy loss. To get the desired outcomes for application prospective, lower Hartmann number should be selected.

Keywords: C . 'FEM, Exergy; Nanofluid; Heat transfer; Lorentz force.

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1. Introduction

Mixing of nanoparticles in a pure carrier fluid significantly augment the thermal conductivity, consequently improve heat transfer rate which can be helpful in various industrial process. Common used coolant, like water for illustration, 15 (bout three orders magnitude lower in the heat conduction when compared with models. Recent decades, nanofluids are utilized in numerous areas [1-9]. Rashid et al. [10]; carr. 4 out the macroscopic modeling for wavy porous duct including second grade fluid. They imposed both magnetic and electric fields. Non-Newtonian flow due to Lorentz forms and imposed chemical reaction was investigated by Roy and Gorla [11]. They reported 1 wer skin friction with rise of magnetic forces. Their outputs indicated that Schmidt number has direct relation with Sherwood number.

New modeling approach for analyzing entropy generation of nanofluid has been offered by Sheikholeslami [12]. He displayed that permeability has reverse relation with Bejan number. Third grad nanoflui a movement within non stationary domain was simulated by Shah et al. [13]. They supposed that bottom wall is stretched. They incorporated thermophoresis impact on energy transportation. Impact of chemical reaction on Eyring-Powell fluid motion has been scrutinized by Hayat and Nadeem [14]. They evidenced that concentration decline: with rise of reaction parameter. Thermal radiation impact on nanoparticle thermal to hav or was explained by Nasir et al. [15]. They imposed MHD and reported Sherwood nur ber to describe concentration of nanofluid. Various nanoparticles have been te ted by Rehman and Nadeem [16] for nanofluid transport along stretching forces. Maximur Muscelt number has been obtained with selecting copper. Two magnetic sources' impacts on thermal treatment of ferrofluid were investigated by Muhammad et al. [17]. They demonstrated that temperature profile augments with rise of ferrohydrodynamic parameter.

thermo diffusion impacts. They concluded that Sherwood number declines with augment of Dufour number. Nanofluid layer behavior in existence of EHD has been analyzed by Moatimid and Hassan [19]. They provided instability analysis for two pure fluids. Numerical developments for thermal analysis have been presented by various reserrch as [20-28].

In current study, we discuss the new model for magnetic force impact on nanomaterial convection by including homogenous model for ferrofluid. Exercy and ysis was examined in view of second law approach. Last equations with considering pon-Darcy law was simulated via innovative approach namely CVFEM which is lear employed for computations of nonlinear systems.

2. Explanation of problem and method

Consider the laminar, steady free convection of H₂O based ferrofluid in a permeable region with involving Lorentz for cs. Fig. 1 describes the domain in which inner side imposed the constant heat flux. We as the domain and joule heating were negligible. To add the pernead lith in momentum equations, Non-Darcy model was incorporated. To simplify the governing equations, pressure source terms were discarded with involving Ψ - ω formulatery CVFEM was implemented to solve the equations. This approach is very powerful due to this fact that it uses not only the advantage of FVM but also it uses the benefits of FEM fo. discretization [29]. To save time in simulation single phase model was employ d for nanomaterial. Considering two dimensional problem leads to below equations [29]:

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

$$\begin{pmatrix} B_{y}, B_{x} \end{pmatrix} = B_{o} \left(\sin \gamma, \cos \gamma \right),$$

$$(2)$$

$$\begin{pmatrix} \rho_{nf} \end{pmatrix} \left(\frac{\partial u}{\partial y} v + u \frac{\partial u}{\partial x} \right) = \left[B_{y} v \sigma_{nf} B_{x} - B_{y}^{2} \sigma_{nf} u + \left(\frac{\partial^{2} u}{\partial y^{2}} + \frac{\partial^{2} u}{\partial x^{2}} \right) \mu_{nf} - \frac{\partial P}{\partial x} - u \frac{\mu_{nf}}{K} \right],$$

$$g \left(T - T_{c} \right) \beta_{nf} \rho_{nf} - \frac{\partial P}{\partial y} + \mu_{nf} \left(\frac{\partial^{2} v}{\partial y^{2}} + \frac{\partial^{2} v}{\partial x^{2}} \right) - \frac{\mu_{nf}}{K} v$$

$$- B_{x} v B_{x} \sigma_{nf} + B_{x} u \sigma_{nf} B_{y} = \left(v \frac{\partial v}{\partial y} + \frac{\partial v}{\partial x} u \right) \rho_{nf},$$

$$\left(u \frac{\partial T}{\partial x} + \frac{\partial T}{\partial y} v \right) = k_{nf} \left(\frac{\partial^{2} T}{\partial x^{2}} + \frac{\partial^{2} T}{\partial y^{2}} \right) / \left(\rho C_{p} \right)_{nf}$$

$$(4)$$

As we mentioned, to estimate the properties of cz is find, homogenous model with

following formulas was employed:

$$CC = (1-\phi) + \left(\rho C_p\right)_s \phi / \left(\rho C_p\right)_f, CC = \left(\rho C_p\right)_{t_s} / \left(\rho C_p\right)_t, CC = \left(\rho C_p\right)_{t_s} / \left(\rho C_p\right)_t, CC = \left(\rho C_p\right)_{t_s} / \left(\rho C_p\right)_t, CC = \left(\rho C_p\right)_t, CC =$$

$$BB = \phi(\rho\beta)_{s} / (\rho\beta)_{f} + (1-\phi), BB = (\rho\beta)_{nf} / (\rho_{F})_{f}$$
(6)

$$\rho_s \phi + (1 - \phi)\rho_f = \rho_{nf} \tag{7}$$

$$\frac{\sigma_{nf}}{\sigma_f} = 1 + \frac{3(-1+\Delta)\phi}{(2+\Delta) - (-1+\Delta)\phi}$$

$$\sigma_s / \sigma_f = \Delta$$
(8)

$$kk = \left(\frac{2k_f + 2\phi kd}{2k_f - kd\phi} + \frac{\kappa_s}{k_s}\right), k\kappa = k_{nf} / k_f, kd = k_s - k_f$$
(9)

$$\mu_{nf} = e^{-0.01T} \left(-\frac{278}{6} 6.4807 \phi^2 + 3.1B + 4263.02\phi + 316.0629 + 0.035B^2 \right)$$
(10)

Features of nanomaterial were portrayed in table 1. To simplify the above equations, Eq. (11) was implemented and then Eq. (12) was employed to reach last equations:

$$\psi_x = -v, v_x - u_y = -\omega, \frac{\partial \psi}{\partial y} = u,$$
(11)

$$(X,Y) = (x,y)L^{-1}, \Delta T = q''L / k_f, V \alpha_f L^{-1} = v, \Theta = \frac{T - T_c}{\Delta T}, \alpha_f U L^{-1} = u, \qquad (12)$$

Thus, the last equations have following forms:

$$\left(\frac{\partial\Theta}{\partial X}\right) \Pr Ra\left(A_{2}^{2}\frac{A_{3}}{A_{4}^{2}A_{1}}\right) + \Pr\left(\frac{A_{2}A_{5}}{A_{4}A_{1}}\right) \left(\frac{\partial^{2}\Omega}{\partial Y^{2}} + \frac{\partial^{2}\Omega}{\partial X^{2}}\right) + \Pr Ha^{2}\left[\frac{A_{2}A_{6}}{A_{4}A_{1}}\right] \left(-(\sin\gamma)\frac{\partial V}{\partial Y}(\cos\gamma) + (\cos\gamma)\frac{\partial U}{\partial X}(\sin\gamma)\right) + \Pr Ha^{2}\left[\frac{A_{2}A_{6}}{A_{4}A_{1}}\right] \left((\sin\gamma)^{2}\frac{\partial U}{\partial Y} - (\cos\gamma)^{2}\frac{\partial V}{\partial X}\right) - \left(\frac{A_{5}}{A_{4}A_{1}}\right)\Omega\frac{\Pr}{Da}A_{2} = U\frac{\partial\Omega}{\partial X} + \frac{\partial\Omega}{\partial Y}V$$
(13)

$$V \frac{\partial \Theta}{\partial Y} + U \frac{\partial \Theta}{\partial X} = \left(\frac{\partial^2 \Theta}{\partial Y^2} + \frac{\partial^2 \Theta}{\partial X^2}\right)$$
(14)

$$\frac{\partial^2 \Psi}{\partial Y^2} + \frac{\partial^2 \Psi}{\partial X^2} = -\Omega$$
⁽¹⁵⁾

Dimensionless parameters which are used above equations and boundary conditions are as follows:

$$Da = \frac{K}{L^{2}}, Ra = \beta_{f} g g'' L^{4} / (\epsilon_{f} \upsilon_{f} - f),$$

$$A_{6} = \frac{\sigma_{nf}}{\sigma_{f}}, A_{2} = \frac{(\rho C_{P})_{nf}}{(\rho C_{P})_{f}},$$

$$A_{5} = \frac{\mu_{nf}}{\mu_{f}}, \Pr = \upsilon_{f} / x_{f}, A_{1} - \frac{\nu_{nf}}{\rho_{f}}, A_{4} = \frac{k_{nf}}{k_{f}},$$

$$Ha = \sqrt{\sigma_{f} / \mu} B_{0}L, A_{2} = \frac{(\rho \beta)_{nf}}{(\rho \beta)_{f}}$$

$$\frac{\partial \Theta}{\partial n}\Big|_{inner} = 1.0, |\Psi|_{all} = 0.0, \Theta|_{outer} = 0.0$$

$$(17)$$

 Nu_{loc} and Nu_{ave} are determined from:

$$Nu_{loc} = A_{4} \left(Rd \frac{4}{3A_{4}} + 1 \right) \frac{1}{\Theta}$$

$$(18)$$

$$Nu_{ave} = \frac{1}{S} \int_{0}^{s} Nu_{loc} ds$$

$$(19)$$

$$S_{gen, soud}, Be \text{ and } X_{d} \text{ were calculated according to below formulas:}$$

$$S_{gt} = \frac{\mu_{uf}}{IK} \left(u^{2} + v^{2} \right)$$

$$+ \frac{v^{2} \sigma_{uf} B_{0}^{2} T^{-2}}{S_{gon, k}} + \frac{1}{2} \left[\left(\frac{\partial T}{\partial x} \right)^{2} + \left(\frac{\partial T}{\partial y} \right)^{2} \right] k_{uf}}{S_{gon, k}}$$

$$+ \left[2 \left(\frac{\partial u}{\partial x} \right)^{2} + 2 \left(\frac{\partial v}{\partial y} \right)^{2} + \left(\frac{\partial v}{\partial x} + \frac{\partial u}{\partial y} \right)^{2} \right] \mu_{uf} T^{-2}}{S_{gon, k}}$$

$$Be = S_{uon, th} / S_{ut}$$

$$(21)$$

$$Be = S_{gen,th} / S_{gt}$$

$$X_d = S_{gt}T_0$$

3. Results and discussion

Simulations vere excuted to illustrate the new concept of energy and exergy treatment of convective flow of nanomaterial within a permeable region. Non Darcy and single phase modules were incorporated considering Ψ - ω formulation. The governing non dimensional system has been figure out numerically by means of CVFEM. Influences of buoyancy no Lorentz forces were accounted in view of entropy analysis.

(22)

Prior to the validation and presenting outputs, the mesh sensitivity analysis has been examined. As displayed in table 2, Nu_{ave} has no changes after 3rd mesh, so this grid can

guarantee a grid independent output. The computational outputs for the special case have been verified by comparisons with current outputs in existing studies [30] in table 3 and the outputs were in nice agreement. Figs. 2, 3, 4 and 5 portray various comportent of entropy, Be and X_d as well as nanomaterial hydrothermal behavior. At low values $c \in Dc$ and Ra, contours expounded that the isotherms forms a pack of straight lines along the boundaries which indicates conduction mode. By augmenting Rayleigh number, na. Juid transport boosts up and convection develops but it has an inverse correlation with Bejan number. Thermal plume can be progressed easily in greater values of Ra. When perreadility of region augments, it improves the convection. Also, thinner boundary layer was reported as a result of augmenting Rayleigh number. Thermal boundary thickness grows when Ha augments. Entropy generation reinforces with augment of magnetic forces. One can perceived that nanofluid transportation enhances with rise of Darcy numery. So, exergy loss declines with augment of Da. Be and X_d have inverse relation with permability and buoyancy force. So, with augment of *Ra* and *Da*, entropy generation become weaker and as an outputs less resistance has been affected the domain. Boundary lay, " thick ess becomes thicker for greater Hartmann number due to reduction of flow in a perfance of resisting force. Beside, exergy loss has direct relation with Lorentz forces *Zimilar* trend is reported for Bejan number.

Be, Nu_{ave} , and λ_{av} variations were deliberated in Figs. 6, 7 and 8 for different active parameters. In addition, colle wing formulas can be offered:

$$Nu_{ave} = 1.11 + 0.023Da + 1.21\log(Ra) - 0.41Ha + 0.035Da \log_{-Ra} - 0.22Da Ha - 0.13\log(Ra) Ha$$
(23)

$$Be = 0.95 \cdot 8.5 \times 10^{-3} Da - 0.0931 \log(Ra) + 0.03 Ha$$

-5.38×10⁻³ Da \og(Ra) + 3.25×10⁻³ Da Ha + 0.019 \log(Ra) Ha (24)

(25)

 $X_{d} = 70.64 - 1.34Da - 7.71\log(Ra) + 14.43Ha$ $+0.13Da\log(Ra) + 7.23DaHa + 1.29\log(Ra)Ha$

Temperature distribution augments with greater values of Darcy number. So, free convection proliferates with Da. Stronger resisting force can be obtained with rise of Ha. Thus, Nu_{ave} declines with rise of Ha. There are reductions in $Be \ r \propto X_d$ for higher values of Da and Ra.

4. Conclusions

This paper was focused on nanofluid, laminal, free convection in a porous domain including exergy analysis. Non-Darcy model and Lorentz forces impacts were incorporated. The homogeneous model was utilized to contacterize the features of nanomaterial. Comparison of our outputs with previous outputs was made for various Ra and found to be in nice agreement. The outputs revealed that the exergy loss is in a direction proportion with Hartmann number. For higher values of Da, nanofluid motion enriches and consequently Nu_{ave} augments. Isotherms become curry with rise of permeability

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References

[1] Sivasanka an, S., A. I. Alsabery, and I. Hashim, Internal heat generation effect on transient natural convection in a nanofluid-saturated local thermal non-equilibrium porous inclined cavity, Physica A: Statistical Mechanics and its Applications 509, (2018) 275-293

 [2] GHR Kefayati, NAC Sidik, Simulation of natural convection and entropy generation of non-Newtonian nanofluid in an inclined cavity using Buongiorno's mathematical model (Part II, entropy generation), Powder Technology 305 (2017) 679-703.

[3] M. Sheikholeslami, M. Jafaryar, Ahmad Shafee, Zhixiong Li, Rizwan (Haq, Heat transfer of nanoparticles employing innovative turbulator considering ontropy generation, International Journal of Heat and Mass Transfer 136 (2019) 12² -1240

[4] S. Nadeem, Shafiq Ahmad, Noor Muhammad, Comput aronal study of Falkner-Skan problem for a static and moving wedge Sensors and Actuators, C. Chemical (2018) 263 DOI: 10.1016/j.snb.2018.02.039

[5] Mohsen Sheikholeslami, Ahmad Arabkoohsa, uyas knan, Ahmad Shafee, Zhixiong Li, Impact of Lorentz forces on Fe3O4-water ferro.¹ui chiropy and exergy treatment within a permeable semi annulus, Journal of Cleaner Froduction, 221 (2019) 885-898

[6] S. Ijaz, S. Nadeem, Consequences of blood mediated nano transportation as drug agent to attenuate the atherosclerotic lesions with p^r rmeability impacts, Journal of Molecular Liquids, 262 (2018) 565-575

[7] M. Sheikholeslami, Rizwan-u, Haq, Ahmad Shafee, Zhixiong Li, Yassir G. Elaraki, I. Tlili, Heat transfer simulation of heat storage unit with nanoparticles and fins through a heat exchanger, International Journal of Heat and Mass Transfer 135 (2019) 470–478

[8] Xiaohong Su, Linn an Zheng, Xinxin Zhang, Junhong Zhang, MHD mixed convective heat transfer over a permeable stretching wedge with thermal radiation and ohmic heating, Chemical Lingmeering Science, 78 (2012) 1-8

[9] S. Ijaz, S. Nadeem, A biomedical solicitation examination of nanoparticles as drug agents to minimize the hemodynamics of a stenotic channel, Eur. Phys. J. Plus (2017) 132: 448. https://doi.org/10.1140/epjp/i2017-11703-6

[10] M. Rashid, Iqra Shahzadi, S. Nadeem, Corrugated walls analysis in *m* crochannels through porous medium under Electromagnetohydrodynamic (EM¹1D) effects, Results in Physics 9 (2018) 171-182

[11] Nepal C. Roy, R. S. R. Gorla, Effects of radiation and magnetic field on mixed convection flow of non-Newtonian power-law fluids across a cylinder in the presence of chemical reaction, Heat and Mass Transfer, Vol. 55, No. 2, pp. 341–351 (2019). doi:10.1007/s00231-018-2413-4

[12] M. Sheikholeslami, New computational appoach for exergy and entropy analysis of nanofluid under the impact of Lorentz force through a porous media, Computer Methods in Applied Mechanics and Engineering 344 (2019) 319–333

[13] Zahir Shah, Saeed Islam, Taza Gui, Fonezer Bonyah, Altaf Khan, Three dimensional third grade nanofluid flow in crouting system between parallel plates with Brownian motion and thermophoresis effects, Result in Phys. 10 (2018) 36–45

[14] Tanzila Hayat, S Nade, n, Flow of 3D Eyring-Powell fluid by utilizing Cattaneo-Christov heat flux model and chemical processes over an exponentially stretching surface, Results in Physic 8 (20.8) 397-403

[15] Saleem Yasir, Gaeed Islam, Taza Gul, Zahir Shah, Muhammad Altaf Khan, Waris Khan, Auran, Zeb Khan, Saima Khan, Three dimensional rotating flow of MHD single wall carbon nanotubes over a stretching sheet in presence of thermal radiation, Applied Nanoscience, https://doi.org/10.1007/s13204-018-0766-0.

[16] Fiaz Ur Rehman, S. Nadeem, Heat Transfer Analysis for Three-Dimensional StagnationPoint Flow of Water-Based Nanofluid over an Exponentially Stretching Surface, Journal of
Heat Transfer (2018) 140(5) HT-17-1037; doi: 10.1115/1.4038359

[17] Noor Muhammad, Sohail Nadeem, MT Mustafa, Impact of magnetic ipole on a thermally stratified ferrofluid past a stretchable surface, Proceedings of the Institution of Mechanical Engineers, Part E: Journal of Process Mechanical Figure (2018) https://doi.org/10.1177/0954408918759244

[18] S. Bilal, K.U. Rehman, M.Y. Malik, A. Hussain, M. A. ais, ¹ affect logs of double diffusion on MHD Prandtl nano fluid adjacent to stretching surface by way of numerical approach, Results in Physics 7 (2017) 470-479.

[19] Galal M. Moatimid and Mohamed A. Hason, Linear Instability of Water–Oil Electrohydrodynamic Nanofluid Layers: Analytical and Numerical Study, Journal of Computational and Theoretical Nanoscience 15 (2018) 1495-1510

[20] Fengrui Sun, Yuedong Yao, X., ngfan J Li, Pengliang Yu, Guanyang Ding, Ming Zou, The flow and heat transfer char one istics of superheated steam in offshore wells and analysis of superheated steam perfor name, Computers & Chemical Engineering, 2017, 100: 80-93.

[21] M. Sheikholeslam, M. Jafaryar, Ahmad Shafee, Zhixiong Li, Simulation of nanoparticles application for expediting melting of PCM inside a finned enclosure, Physica A: Statistical Mechanics and its Applications 523 (2019) 544–556

[22] Fiaz Ur .?ehma I, S. Nadeem, Rizwan Ul Haq, Heat transfer analysis for threedimension. 's agnation-point flow over an exponentially stretching surface, Chinese Journal of Physics 55 (2017) 1552-1560

[23] M. Sheikholeslami, Omid Mahian, Enhancement of PCM solidification using inorganic nanoparticles and an external magnetic field with application in energy storage systems, Journal of Cleaner Production 215 (2019) 963-977

[24] Fengrui Sun, Yuedong Yao, Xiangfang Li, Lin Zhao, Guanyang Ding, Xuejiao Zhang, The Mass and Heat Transfer Characteristics of Superheated Steam Coupled with Noncondensing Gases in Perforated Horizontal Wellbores, Journal of Petroloum Science and Engineering, 2017, 156: 460-467.

[25] M. Sheikholeslami, Rizwan-ul Haq, Ahmad Shafee, "hixining Li, Heat transfer behavior of Nanoparticle enhanced PCM solidification through an enclosure with V shaped fins, International Journal of Heat and Mass Transfer (1997) 1322–1342

[26] Houman B. Rokni, Joshua D. Moore, Ashut n Gupta, Mark A. McHugh, Manolis Gavaises, Entropy scaling based viscosity predictions for hydrocarbon mixtures and diesel fuels up to extreme conditions, Fuel 241 (2019) 1203-1213

[27] M. Sheikholeslami, Numerical appendent for MHD Al2O3-water nanofluid transportation inside a permeable medium using tone vative computer method, Computer Methods in Applied Mechanics and Engineering 344 (2019) 306–318

[28] Xiao-hong Su, Li In-cui. Zheng, Xin-xin Zhang, DTM-BF method and dual solutions for unsteady MHD flow over permeable shrinking sheet with velocity slip, Applied Mathematics and Mechanics, 33 (2012) 1555–1568

[29] Mohsen Theik¹ oleslami, Application of Control Volume based Finite Element Method (CVFEM) Tor Nanofluid Flow and Heat Transfer, Elsevier, (2019), ISBN: 9780128141526

[30] G. De Vahl Davis, Natural convection of air in a square cavity, a benchmark numerical solution, Int. J. Numer. Methods Fluids 3 (1962) 249–264.

















0.0005 0.00045

0.0002 0.00015

0.0001 5E-05



I 0.022 L 0.02 0.018 L 0.016 I. 0.014 0.012 0.01 0.008 0.006 0.004 0.002

20























Fig. 6. Values of Nuave for various ?a, Ha, Da





Ha = 5

 $\log(Ra) = 3.5$

100.00

75.00

Da



Fig. 7. Values of Be for various n • Ha, Da





Fig. 8. Values of X_d for various Λ^{-} Ha, Da

	Pure water	Fe_3O_4
$\sigma(\varOmega \cdot m)^{^{-l}}$	0.05	25000
$eta imes 10^5 (~K^{-1}~)$	21	1
k(W/m.k)	0.613	6
$C_p(j/kgk)$	4179	,70
$ ho(kg/m^3)$	997.1	د 200

Table1. Features of H_2O and iron oxide

Table2. Various grids and obtained Nu_{ave} at Da = 100, Ha = 1, $Ra = 10^4$ and $\phi = 0.04$.

51×151	71×211	
2.12102	2 :5137	91×271
61×181	2*×241	2.15804
2.14914	2.15365	

Table3. Comr.u. on of current outputs with benchmark [30] at Pr=0.7.

47	$Ra=10^3$	$Ra = 10^4$	$Ra = 10^5$
De Vahl Davis [30]	1.118	2.243	4.519
Prese. t	1.1432	2.2749	4.5199