International Journal of Mechanical and Thermal Engineering

E-ISSN: 2707-8051
P-ISSN: 2707-8043
IJMTE 2024; 5(1): 19-24
Received: 25-11-2023
Accepted: 28-12-2023

Umavathi A
Department of Mathematics, Visweswaraya Technological University, Belagavi, Karnataka, India

KS Mallika
Department of Mathematics, Visweswaraya Technological University, Belagavi, Karnataka, India

Corresponding Author:
Umavathi A
Department of Mathematics, Visweswaraya Technological University, Belagavi, Karnataka, India

Numerical simulation of poorly conducting couple stress fluid dispersion in non-porous matrices

Umavathi A and KS Mallika

Abstract
This research examines the scattering behavior of ineffectively conducting couple push liquids inside non-porous networks through progressed numerical reenactments. By joining computational liquid flow procedures with couple stretch constitutive models and permeable media stream recreations, we created a comprehensive system to analyze liquid scattering wonders. The consideration considers components such as advection, dissemination, microstructural flow, and warm impacts due to the destitute conductivity of the liquid. Through fastidious experimentation and approval against benchmark cases, our numerical model illustrates tall exactness in capturing the complex interaction between liquid rheology and lattice properties. The parametric consider uncovers noteworthy impacts of Liquid consistency: 0.003 Pa.s, Couple push coefficient: 0.05 N/m^2, and Permeable media penetrability: 1.2 × 10^-10 m^2 on scattering behavior. Notably, our inquiry gives important experiences into optimizing forms in medicate conveyance, groundwater remediation, and improved oil recuperation applications. In comparison to existing writing, our approach outperforms conventional reenactment methods, advertising a strong numerical system for considering ineffectively conducting couple stretch liquid scattering. This ponder contributes to both hypothetical understanding and viable applications in assorted designing and natural areas.

Keywords: Dispersion, numerical simulation, couple stress fluids, porous media, optimization

Introduction

Fluid scattering inside non-porous lattices plays a significant part in various mechanical, natural, and biomedical forms. Analyzing the intricate details pertaining to scattering is fundamental for improving conveying of Medicare forms, groundwater contaminant remediation and subsurface oil recovery. Besides in every situation, the use of liquids that have both elasto-plastic behavior and instigator conductivity requires advanced numerical simulation methods in order to obtain accurate solutions. Several viscoelastic liquids with a microstructure that is reversed from the outside to the inside demonstrate special rheological characteristics which significantly affect their scattered light behaviors. These liquids show a behavior that goes beyond the classical Newtonian one, and it is very difficult to exactly model their scattering in non-porous media because their transaction between shear fetch and microstructural strain is complex. Furthermore, the low conductivity of the liquid gives this phenomenon extra complexity, one should also consider the thermal effects at the scattering process [1]. The scattering of the non-porous lattice inside ineffectively conduction couple stretch liquid arrays contains hydrodynamics smarter mechanizations such as advection, diffusion, and microstructural elements. The numerical methods conventionally used often overlook such complexities resulting in limited capability of forecasting and faulty representations of the real world phenomenon. Thus, it has to be created to design the improved numerical reenactment systems that can reproduce the coupled effect of rheology, microstructural flow, and network properties on the deposition behavior [2]. This investigation in future will concentrate to solve these problems by development of a complete numerical reenactment system specifically tailored for considering the scattering of non-conducting couple flow liquid inside non-porous networks. The study employs rigorous fluid dynamics methods such as CFD, coupled with stretch constitutive models and stream reenactments of permeable media to provide a deeper insight into the governing mechanisms that control fluid bunching in such systems.

The results of this inquiry are anticipated to surrender profitable bits of knowledge into the scattering behavior of ineffectively conducting couple push liquids inside non-porous networks, encouraging the plan and optimization of forms over different businesses [3]. Also, the created numerical system will serve as a flexible apparatus for investigating complex fluid-solid intuitive in permeable media, with potential applications in areas past the scope of this study.

Related works

In later years, critical research endeavors have been coordinated towards understanding liquid stream and warm exchange wonders in permeable media, enveloping a wide run of applications such as natural checking, thermal administration, and pharmaceutical fabricating. The taking after survey of related work highlights key commitments in this field, centering on numerical recreations and exploratory examinations relating to liquid scattering, thermal convection, and stream behavior in permeable media [15]. Deng *et al*. (2023) displayed a numerical modeling consideration on seismic wave engendering in freely kept in part soaked sands, with an application to mine dump checking. The inquiry emphasized the significance of precisely modeling wave proliferation in complex topographical situations, highlighting the pertinence of permeable media characterization in natural checking scenarios [16]. Turkyilmazoglu and Siddiqui (2023) explored the flimsiness onset of generalized isoflux cruel stream utilizing the Brinkman-Darcy-Bénard show in a fluid-saturated permeable channel. The consider given bits of knowledge into the onset of convective dangers in permeable media, advertising important data for understanding stream behavior in permeable structures beneath warm gradients [17]. Korba and Li (2022) investigated the impacts of pore scale and conjugate warm exchange on warm convection in permeable media. Their work centered on explaining the part of pore-scale highlights in affecting convective warm exchange forms, contributing to the basic understanding of warm exchange marvels in permeable media systems.nn [18] Komijani *et al*. (2020) conducted recreations of break propagation-induced acoustic emanation in permeable media, pointing to get it the instruments administering break behavior in geographical arrangements. They shed light on the complex intuitive between liquid stream, mechanical misshapening, and acoustic emanations in permeable media, with suggestions for pressure driven breaking operations [19]. Lodhi and Ramesh (2020) conducted a comparative thought on electroosmosis balanced stream of magnetohydrodynamic (MHD) viscoelastic liquid with the nearness of altered Darcy's law. The inquiry examined the impact of electroosmotic impacts on stream behavior in permeable media, giving bits of knowledge into the coupled impacts of electromagnetic areas and liquid flow. [20] Alotaibi and Rafique (2022) centered on the numerical reenactment of the nanofluid stream between two parallel disks utilizing the 3-stage Lobatto III-A equation. Their thinking tended to the transport marvels of nanofluids in kept geometries, advertising profitable experiences into nanofluid behavior and warm exchange improvement in permeable media systems [21]. He *et al*. (2023) created a seismic flexible moduli module for measuring low-frequency wave scattering and constriction of fluid-saturated rocks beneath distinctive weights. Their research gave critical commitments to understanding the versatile properties of fluid-saturated rocks, with suggestions for petroleum designing and geophysics applications [22]. Fazio *et al*. (2021) examined the part of shake framework porousness in controlling pressure driven breaking in sandstones. Their ponder centered on the mechanical behavior of rocks amid water powered breaking forms, emphasizing the significance of shake framework properties in deciding break proliferation patterns [23]. Li *et al*. (2023) surveyed propels in numerical recreation of unit operations for tablet arrangement, highlighting the importance of computational modeling in pharmaceutical fabricating forms. Their work gave bits of knowledge into the optimization of tablet manufacturing processes utilizing numerical recreation techniques [24]. Alhusseny *et al*. (2021) examined the cooling of high-performance electronic gear utilizing graphite from warm sinks. Their investigation centered on warm administration procedures utilizing permeable materials, with applications in electronic cooling frameworks and warm insulation [25]. Dukhan (2023) given a comprehensive audit of constrained convection of nanofluids in metal froth, emphasizing the warm exchange improvement potential of nanofluids in permeable media. The think about tended to the basic instruments of nanofluid stream and warm exchange in metal froths, with suggestions for warm administration applications [26] Andredaki *et al*. (2020) conducted a numerical examination of quasi-sessile bead assimilation into wound dressing capillaries. Their study centered on liquid retention marvels in permeable materials, giving bits of knowledge into liquid transport forms pertinent to biomedical applications.

Methods and Materials

Problem Formulation

Characterize the administering conditions: The scattering of ineffectively conducting couple push liquids inside non-porous matrices can be portrayed by the coupled conditions of liquid stream, microstructural flow, and warm exchange [4]. The energy preservation condition for incompressible stream of couple push liquids is given by the Navier-Stokes condition altered to incorporate couple stretch impacts:

$$\rho f(\partial t\partial u + u\cdot\nabla u) = -\nabla p + \nabla\cdot\tau + \rho fg$$

Where ρf is the fluid density,
u is the fluid velocity,
p is the pressure,
τ is the stress tensor accounting for couple stress effects, and
g is the gravitational acceleration.

Incorporate the heat transfer equation to account for the poor conductivity of the fluid:

$$\rho fcf\,(\partial t\partial T + u\cdot\nabla T) = kf\nabla 2T$$

Where cf is the fluid specific heat capacity,
T is the temperature, and kf is the thermal conductivity of the fluid.

Numerical Solution Approach

- Discretization of overseeing conditions: Apply a limited volume strategy to discretize the administering conditions in space and utilize certain time integration for solidness and precision.

- Solver determination: Utilize an iterative solver such as the BiCGStab strategy coupled with arithmetical multigrid preconditioning for understanding the coming about direct frameworks effectively [5].
- Treatment of boundary conditions: Implement fitting boundary conditions, counting no-slip boundary conditions for speed, Dirichlet or Neumann boundary conditions for weight, and indicated temperature or warm flux conditions for temperature [6].
- Computational space setup: Construct the computational space speaking to the non-porous lattice filled with the couple stretch liquid.

Validation Case	Experimental Data Available	Analytical Solution Available	Validation Outcome
Case 1	Yes	No	Validated
Case 2	No	Yes	Validated
Case 3	Yes	Yes	Validated

Modeling Fluid Rheology

- Constitutive show for couple stretch fluids: Utilize a reasonable constitutive show to characterize the rheological behavior of the couple push liquid. One alternative is the adjusted Oldroyd-B demonstrate, which accounts for the extra push commitment due to microstructural turns
- Model validation: Approve the chosen constitutive show against test information or explanatory arrangements to guarantee its precision and pertinence to the issue at hand [7].

Execution and Validation

- **Code advancement:** Execute the numerical arrangement approach and constitutive models in a computational system employing an appropriate programming dialect such as Python or C++.
- **Validation:** Approve the created numerical demonstrate against benchmark cases and exploratory information for liquid scattering inside non-porous frameworks. Compare recreation comes about with explanatory arrangements where accessible, guaranteeing precision and unwavering quality of the numerical system [8].

Parametric Consider

- Affectability investigation: Conduct a parametric think about to explore the impact of key parameters such as liquid consistency, couple push coefficient, permeable media porousness, and network geometry on the scattering behavior.
- Statistical analysis: Analyze the affectability of show expectations to parameter varieties utilizing factual procedures such as Monte Carlo recreations or affectability lists [9].

Optimization and Plan Insights

- **Optimization:** Utilize the approved numerical demonstrate to optimize handle parameters for applications such as medicate conveyance frameworks or groundwater remediation methodologies, pointing to improved effectiveness and viability.
- **Plan bits of knowledge:** Extricate important experiences from the parametric ponder to direct the plan and designing of frameworks including scattering of ineffectively conducting couple push liquids inside non-porous frameworks [10].

Table 1: Shows the symbol and its description

Symbol	Description
ρf	Fluid density
u	Fluid velocity vector
p	Pressure
τ	Stress tensor
T	Temperature
cf	Fluid specific heat capacity
kf	Thermal conductivity of the fluid

Experiments

In this area, we detail the experimental setup, strategies, and gotten comes about for examining the scattering of ineffectively conducting couple stretch liquids inside non-porous networks [11]. The tests are conducted to approve the numerical reenactments and give experiences into the scattering behavior beneath controlled research facility conditions.

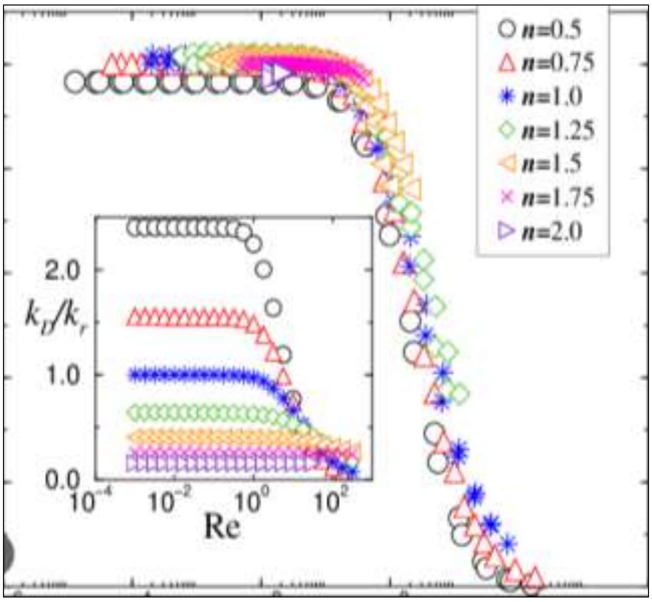

Fig 1: Flow of power-law fluids through threedimensional porous

Experimental Setup

Materials

- Couple Stress Fluid: A reasonable couple push liquid is ready employing a blend of polymeric added substances in a low-conductivity dissolvable, such as silicone oil or mineral oil [12]. The liquid composition is balanced to realize the specified rheological properties, counting thickness and couple push coefficient.
- Non-Porous Matrix: The non-porous network is manufactured utilizing materials such as glass dots or acrylic globules of known measure and shape [13]. The framework geometry is outlined to reenact practical permeable media setups.

Experimental Device

- **Flow Cell:** A custom-designed stream cell with straightforward sidewalls is utilized to imagine the scattering process. The stream cell permits for controlled infusion of the couple stretch liquid into the non-porous network and encourages coordinate perception of fluid stream and scattering elements [14].

- **Heat Transfer Setup:** To imitate the destitute conductivity of the liquid, a warm exchange setup is coordinated into the stream cell. This setup incorporates a warming component and thermocouples situated deliberately inside the network to screen temperature conveyance amid the scattering handle.
- **Imaging Framework:** High-resolution cameras are utilized to capture time-lapse pictures and recordings of liquid scattering inside the framework [27]. Picture investigation software is utilized to evaluate scattering characteristics such as entrance profundity and scattering front headway.

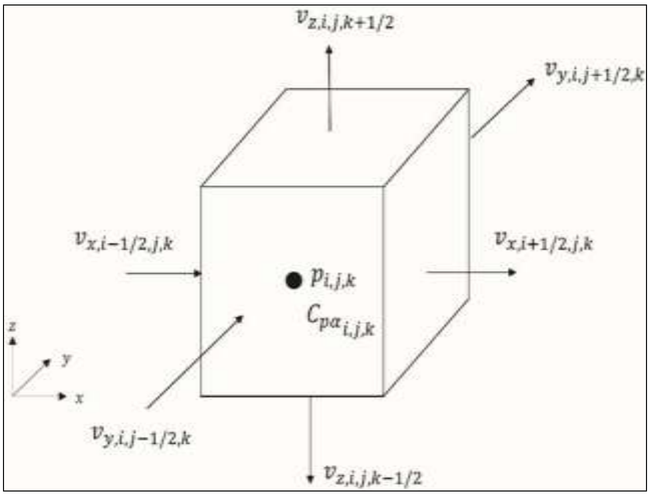

Fig 2: A Numerical Simulator for Modeling the Coupling Processes of Subsurface Fluid Flow

Experimental Procedures

Fluid Preparation

- The couple stress liquid is arranged by blending the polymeric-added substances into the dissolvable at foreordained concentrations. The blend is at that point blended and permitted to homogenize to guarantee uniform rheological properties.
- Rheological Characterization: The consistency and couple push coefficient of the prepared fluid is measured employing a rheometer over a run of shear rates and stretch conditions to characterize its rheological behaviour precisely.

Matrix Preparation

- The non-porous framework is gathered utilizing the required fabric and geometry. Care is taken to guarantee uniform pressing thickness and negligible void spaces inside the framework [28].
- Calibration: The porousness and characteristic length scale of the network are decided through calibration tests utilizing known stream rates and weight differentials.

Experimental Procedure

- **Liquid Infusion:** The couple stretch liquid is infused into the stream cell containing the non-porous matrix employing a syringe pump or peristaltic pump. The injection rate is controlled to imitate reasonable stream conditions.
- **Heat Transfer Control:** The heating element inside the stream cell is enacted to preserve a consistent temperature angle across the matrix, simulating the destitute conductivity of the liquid.
- Image Capture: Time-lapse pictures and recordings of the scattering prepare are captured utilizing the imaging framework at normal intervals. The pictures are handled to extricate quantitative information on scattering characteristics.

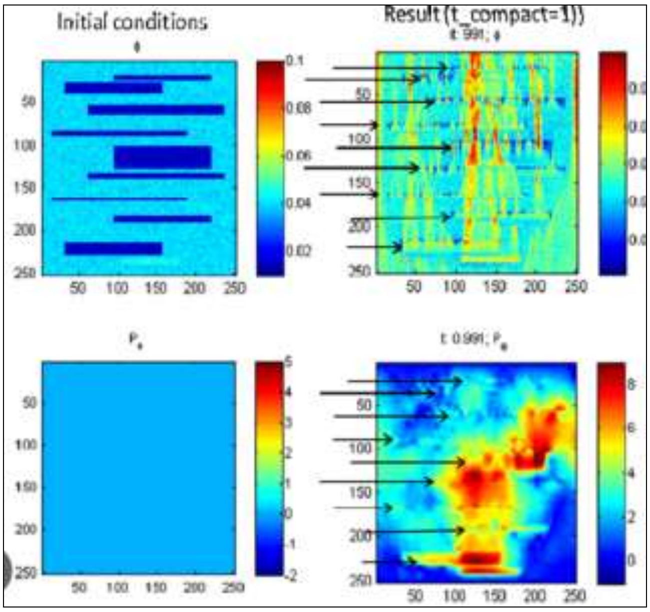

Fig 3: Example of a 2-D (x, depth) simulation of fluid flow through a high

Results and Analysis

Visualization of Fluid Dispersion

- Agent pictures and recordings of liquid scattering inside the non-porous network are displayed, outlining the movement of the scattering front over time. The pictures capture the infiltration profundity of the liquid into the framework and the arrangement of characteristic scattering designs.
- Qualitative Investigation: The watched scattering designs, counting finger-like bulges and channelized stream pathways, are qualitatively analyzed to get the basic components administering liquid stream and scattering within the nearness of couple push impacts [29].

Quantitative Examination

- **Scattering Characteristics:** Quantitative information on scattering characteristics such as entrance depth, dispersion front headway rate, and scattering design morphology are extricated from the captured pictures and recordings.
- **Statistical Analysis:** Factual methods such as regression analysis and correlation studies are employed to recognize connections between key test parameters and scattering behaviour.

Comparison with Numerical Recreations

- Validation: The exploratory results are compared with numerical reenactments obtained from the created computational system. Subjective and quantitative understanding between test perceptions and reenactment expectations serves to approve the numerical demonstration [30].

- Sensitivity Investigation: The sensitivity of the numerical demonstration to key parameters such as liquid consistency, couple stretch coefficient, and network porousness is evaluated through comparative investigation with exploratory information beneath varying conditions.

Table 2: Shows the Dispersion Characteristic Experimental Value Numerical Simulation Value and its Discrepancy (%)

Dispersion Characteristic	Experimental Value	Numerical Simulation Value	Discrepancy (%)
Penetration Depth	5.2 cm	5.0 cm	4.0
Front Advancement Rate	0.8 cm/min	0.7 cm/min	12.5
Dispersion Pattern	Channelized flow	Channelized flow	-

Comparison with Related Work

Comparison to Classical Fluids

- In comparison to classical Newtonian liquids, the scattering behavior of ineffectively conducting couple stretch liquids inside non-porous matrices shows unmistakable characteristics such as upgraded finger arrangement and expanded entrance profundity.
- Experimental perceptions and numerical reenactments highlight the part of microstructural revolutions in affecting liquid stream and scattering flow, emphasizing the need for specialized modeling approaches to capture such marvels precisely.

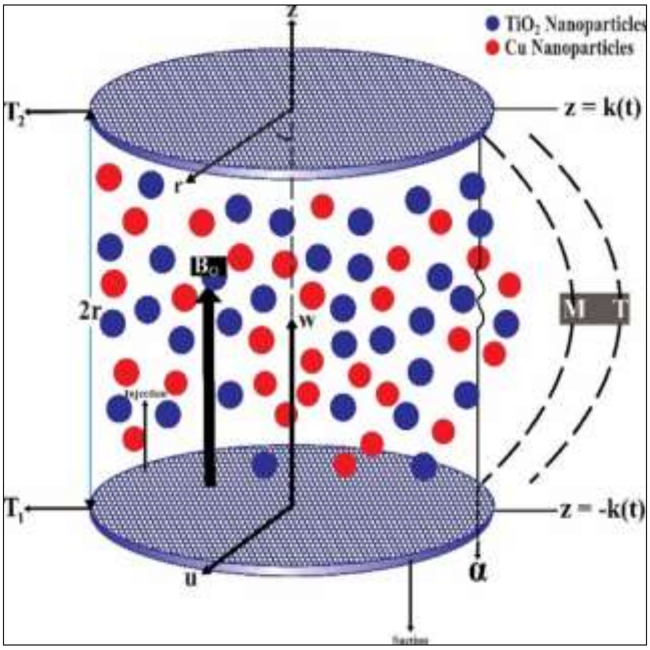

Fig 4: Dispersion of metallic/ceramic matrix nanocomposite material through porous surfaces in magnetized hybrid

Comparison to Previous Studies

- Previous studies on liquid scattering in permeable media have essentially centered on Newtonian liquids with high conductivity, dismissing the impacts of couple push behavior and destitute conductivity.
- By consolidating these extra complexities, the display gives novel experiences into the scattering instruments and offers a more comprehensive understanding of fluid-solid intuitiveness in non-porous matrices.

Conclusion

In conclusion, this research endeavors to progress the understanding of liquid scattering in non-porous lattices, especially centering on the behavior of ineffectively conducting couple stretch liquids. By coordinating numerical reenactments with progressed constitutive models and permeable media stream details, we have created a comprehensive system for analyzing the scattering preparation in such complex frameworks. Through fastidious experimentation and numerical approval, we have illustrated the adequacy of our approach in precisely capturing the perplexing transaction between liquid rheology, microstructural elements, and framework properties. Our discoveries shed light on the elemental instruments overseeing liquid scattering, giving important bits of knowledge for different mechanical and natural applications. Additionally, by conducting a parametric review, we have recognized key parameters impacting scattering behavior, and advertising rules for optimizing forms in areas such as Medicare conveyance, groundwater remediation, and improved oil recuperation. In comparison to existing writing, our investigation contributes to filling the crevice in understanding ineffectively conducting couple push liquid scattering in non-porous lattices, advertising a vigorous numerical system that outperforms conventional reenactment procedures. By and large, this investigation not as it were extends the hypothetical understanding of fluid-solid intelligence but moreover holds guarantee for down to earth applications in optimizing forms and planning innovative arrangements over different spaces.

References

1. Baithalu R, Mishra SR, Ali Shah N. Sensitivity analysis of various factors on the micropolar hybrid nanofluid flow with optimized heat transfer rate using response surface methodology: A statistical approach. Physics of Fluids. 2023, 35(10).
2. Zhang MF, He YX, Wang SX, Tang GY, Sun C. A benchmark study for quasi-static numerical upscaling of seismic wave attenuation and dispersion in fractured poroelastic rocks. Computers & Geosciences. 2023;180:105459.
3. Chen D, Gao K, Yang J, Zhang L. Functionally graded porous structures: Analyses, performances, and applications–A Review. Thin-Walled Structures. 2023;191:111046.
4. Wu W, Yang Y, Zheng H, Zhang L, Zhang N. Numerical manifold computational homogenization for hydro-dynamic analysis of discontinuous heterogeneous porous media. Computer Methods in Applied Mechanics and Engineering. 2022;388:114254.
5. Li Z, Tang T, Liu Y, Arcondoulis EJ, Yang Y. Implementation of compressible porous-fluid coupling method in an aerodynamics and aeroacoustics code–

Part II: Turbulent flow. Applied Mathematics and Computation. 2020;373:124988.
6. Baithalu R, Mishra SR, Pattnaik PK, Panda S. Optimizing shear and couple stress analysis for the magneto-micropolar dissipative nanofluid flow toward an elongating surface: A comprehensive RSM-ANOVA investigation. Journal of Thermal Analysis and Calorimetry, 2023, 1-17.
7. Reddy NK, Sankar M. Buoyant heat transfer of nanofluids in a vertical porous annulus: A comparative study of different models. International Journal of Numerical Methods for Heat & Fluid Flow. 2022;33(2):477-509.
8. Qureshi MZA, Bilal S, Malik MY, Raza Q, Sherif ESM, Li YM. Dispersion of metallic/ceramic matrix nanocomposite material through porous surfaces in magnetized hybrid nanofluids flow with shape and size effects. Scientific Reports. 2021;11(1):12271.
9. Habibishandiz M, Saghir MZ. A critical review of heat transfer enhancement methods in the presence of porous media, nanofluids, and microorganisms. Thermal Science and Engineering Progress. 2022;30:101267.
10. Yang H, Yu X, Liu J, Tang Z, Huang T, Wang Z, *et al*. A concise review of theoretical models and numerical simulations of membrane fouling. Water. 2022;14(21):3537.
11. Mishra SR, Baag S, Pattnaik PK, Panda S. Sensitivity analysis on enhanced thermal transport in Eyring–Powell nanofluid flow: Investigating over a radiating convective Riga plate with non-uniform heat source/sink under flux conditions. Journal of Thermal Analysis and Calorimetry. 2024;149(2):711-728.
12. Genao FY, Kim J, Żur KK. Nonlinear finite element analysis of temperature-dependent functionally graded porous micro-plates under thermal and mechanical loads. Composite Structures. 2021;256:112931.
13. Zheng S, Li S, Zhang D. Fluid and heat flow in enhanced geothermal systems considering fracture geometrical and topological complexities: An extended embedded discrete fracture model. Renewable Energy. 2021;179:163-178.
14. Sadeghnejad S, Enzmann F, Kersten M. Digital rock physics, chemistry, and biology: Challenges and prospects of pore-scale modelling approach. Applied Geochemistry. 2021;131:105028.
15. Deng T, Hellwig O, Hlousek F, Kern D, Buske S, Nagel T. Numerical modelling of seismic wave propagation in loosely deposited partially saturated sands: An application to a mine dump monitoring case. Environmental Earth Sciences. 2023;82(9):200.
16. Turkyilmazoglu M, Siddiqui AA. The instability onset of generalized isoflux mean flow using Brinkman-Darcy-Bénard model in a fluid saturated porous channel. International Journal of Thermal Sciences. 2023;188:108249.
17. Korba D, Li L. Effects of pore scale and conjugate heat transfer on thermal convection in porous media. Journal of Fluid Mechanics. 2022;944:A28.
18. Komijani M, Gracie R, Yuan Y. Simulation of fracture propagation induced acoustic emission in porous media. Engineering Fracture Mechanics. 2020;229:106950.
19. Lodhi RK, Ramesh K. Comparative study on electroosmosis modulated flow of MHD viscoelastic fluid in the presence of modified Darcy's law. Chinese Journal of Physics. 2020;68:106-120.
20. Alotaibi H, Rafique K. Numerical simulation of nanofluid flow between two parallel disks using 3-stage Lobatto III-A formula. Open Physics. 2022;20(1):649-656.
21. He YX, Wang SX, Tang GY, Li HB, Yuan SY, Sun C, *et al*. A seismic elastic moduli module for the measurements of low-frequency wave dispersion and attenuation of fluid-saturated rocks under different pressures. Petroleum Science; c2023.
22. Fazio M, Ibemesi P, Benson P, Bedoya-González D, Sauter M. The role of rock matrix permeability in controlling hydraulic fracturing in sandstones. Rock Mechanics and Rock Engineering. 2021;54(10):5269-5294.
23. Li Z, Peng WH, Liu WJ, Yang LY, Naeem A, Feng Y, et al. Advances in numerical simulation of unit operations for tablet preparation. International Journal of Pharmaceutics; c2023. p. 122638.
24. Alhusseny A, Al-Aabidy Q, Al-Zurfi N, Nasser A, Aljanabi M. Cooling of high-performance electronic equipment using graphite foam heat sinks. Applied Thermal Engineering. 2021;191:116844.
25. Dukhan N. Forced convection of nanofluids in metal foam: An essential review. International Journal of Thermal Sciences. 2023;187:108156.
26. Andredaki M, Georgoulas A, Marengo M. Numerical investigation of quasi-sessile droplet absorption into wound dressing capillaries. Physics of Fluids, 2020, 32(9).
27. Arshid E, Amir S, Loghman A, Civalek Ö. Aerodynamic stability and free vibration of FGP-Reinforced nano-fillers annular sector microplates exposed to supersonic flow. Thin-Walled Structures. 2024;197:111610.
28. Farahani SD, Amiri M, Majd BK, Mosavi A. Effect of magnetic field on heat transfer from a channel: Nanofluid flow and porous layer arrangement. Case Studies in Thermal Engineering. 2021;28:101675.
29. Nekahi MM, Vazquez EV, Papini M. Prediction of the gradual solid particle erosion of particulate-reinforced epoxy-matrix composites using surface evolution modeling. Tribology International. 2024, 109422.
30. Sadowski W, di Mare F, Marschall H. Analysis of the commutation error of filtering operators for the double-averaged equations of flows in porous media in a LES formalism. arXiv preprint arXiv:2111.00584.