REVIEW ARTICLE

Mini Review on Thermophysical Properties of Heat and Fluid Flow: Assessing Environmental Impacts and Implications

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Abstract

This mini review explores the thermophysical characteristics of heat and fluid flow, emphasizing their importance in understanding environmental consequences and implications. By examining the fundamental interaction between thermal energy and fluid mechanics, this study aims to clarify how these characteristics affect ecological systems, energy efficiency, and climate change. The analysis combines theoretical frameworks with empirical data to assess heat transfer processes, fluid viscosity, and thermal conductivity in various natural and engineered settings. The results highlight the vital role of these properties in influencing environmental phenomena such as weather systems, pollutant distribution, and energy resources management. This work reinforces the need for interdisciplinary strategies to tackle climate-related issues and to enhance industrial practices that reduce negative environmental impacts. Ultimately, the insights derived from this research can guide policy making and foster sustainable approaches in energy generation and environmental stewardship. Furthermore, the study aims to contribute to the development of strategies that enhance resilience to climate variability while promoting efficiency in energy use and minimizing environmental degradation. Moreover, a mathematical model is formulated to investigate the thermophysical properties of heat and fluid flow in the atmosphere.

Keywords: heat transfer, thermal energy, conduction, convection, radiation, climate change, environmental impact, climate variability, sustainability, atmosphere.

1 Introduction

It is important to understand how heat transfer operates in the environment to grasp the complex relationships among thermal energy and Earth's systems. In light of the growing challenges posed by rising global temperatures and climate change, it becomes increasingly necessary to develop better models and simulations of heat transfer mechanisms to address these warming trends. Computational environmental heat transfer systems rely on numerical algorithms and methods to assess heat transfer across various environmental contexts, such as the atmosphere, bodies of water, and terrestrial ecosystems. Research in this area draws upon

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thermodynamics, fluid dynamics, and environmental science to model heat transfer interactions ranging from small-scale exchanges in soil and vegetation to large-scale energy movements in the atmosphere. Utilizing computational fluid dynamics (CFD), finite element analysis (FEA), and other numerical tools, it is possible to recreate scenarios of fluid and thermal energy behaviors, as well as assess the impact of human activities on local and global climate systems. Predicted thermal dynamics in regions with anthropogenic structures offer valuable insights into the phenomenon of urban heat islands, where elevated energy demands and health risks may arise. In developed urban areas, accurately visualizing thermal energy distribution can significantly inform sustainable and resilient urban planning and design strategies. As scientific and technological capabilities advance, the integration of high-performance computing, machine learning, and real-time data collection further enhances the capacity of computational environmental heat transfer studies. This introduction aims to demonstrate how computational techniques can support the resolution of contemporary environmental challenges, ultimately contributing to novel insights and informed decisions in the formulation of future-oriented, data-driven policies.

Cheng [1] examined an unsteady laminar buoyancy-driven flow, fluid in a permeable source, and was heat from below, with previous works [2, 3] observed the dependent of time behavior of a viscous, incompressible fluid undergoing combined convection flow across a triangular prism that is symmetrical and has an uneven surface temperature, utilizing mathematical techniques. Ashraf et al. [4] analyzed the effect of sun rays on the steady shear layer flow featuring both convection in a dense, electrically conducting fluid moving through a vertical permeable source. Sheremet [5] conducted modeling of time dependent introduced convective, presenting numerical results that were compared with earlier research. Mukhopadhyay et al. [6] examined shear layer flow and thermal transport of a fluid through permeable media directed towards a stretched sheet, also considering heat generation or absorption. Archibold et al. [7] explored how fluid and warmth flow behave on an inhabited surface when melting occurs. Reddy [8] provided a mathematical for liquid flow of a two-dimensional cylindrical shape in an environment with high concentrated, as well as accounting for heat radiation. Makinde et al. [9] investigated on thermal and thermophoretic transport in transient magneto hydrodynamic (MHD) shear layer flow over upright permeable plate. Paul [10] examined the findings of a MHD flow an infinite upright flat plate embedded in a permeable material.

Ashraf et al. [11] numerically investigated the natural convection boundary layer flow of nanofluids around a sphere, with particular emphasis on fluid ejection mechanisms from the shear layer into the plume region. Their study demonstrated that nanoparticle inclusion significantly alters thermal boundary layer structure, providing foundational insights for subsequent research on thermophoretic behavior in complex geometries. However, this work did not account for variable viscosity effects, which was later addressed by Abbas et al. [12] through their examination of coupled variable viscosity and thermophoretic transport in mixed convection flow around spherical surfaces. Their findings revealed that temperature-dependent viscosity enhances thermophoretic particle accumulation near boundaries - a critical mechanism for understanding atmospheric particulate distribution patterns.

While Yang et al. [13] primarily focused on heat transfer enhancement in phase-change materials, their comprehensive review of nanoparticle-enhanced thermal conductivity mechanisms offers valuable methodological parallels for studying thermophoretic particle behavior in climatic systems. Building on these foundations, Nadeem et al. [14–16] established direct linkages between fossil fuel-derived thermophoretic particles and climate change through sophisticated multiphysics modeling. Their series of studies demonstrated that: (i) increasing thermophoresis parameter (N_t) reduces near-surface particle concentration while enhancing upper atmospheric accumulation [14]; (ii) plume temperature gradients in porous atmospheric structures intensify thermophoretic convection [15]; and (iii) catalytic chemical reactions can significantly modify thermophoretic transport dynamics in stratified atmospheres [16].

Nabwey et al. [17] advanced the field through transient analysis of oscillatory mixed convection, proposing a novel "velocity-temperature-concentration triple fluctuation" model that provides new perspectives on intermittent extreme thermal events in climate systems. Complementing this work, Iqbal et al. [18] developed a groundbreaking cross-sphere numerical framework coupling hydrospheric density

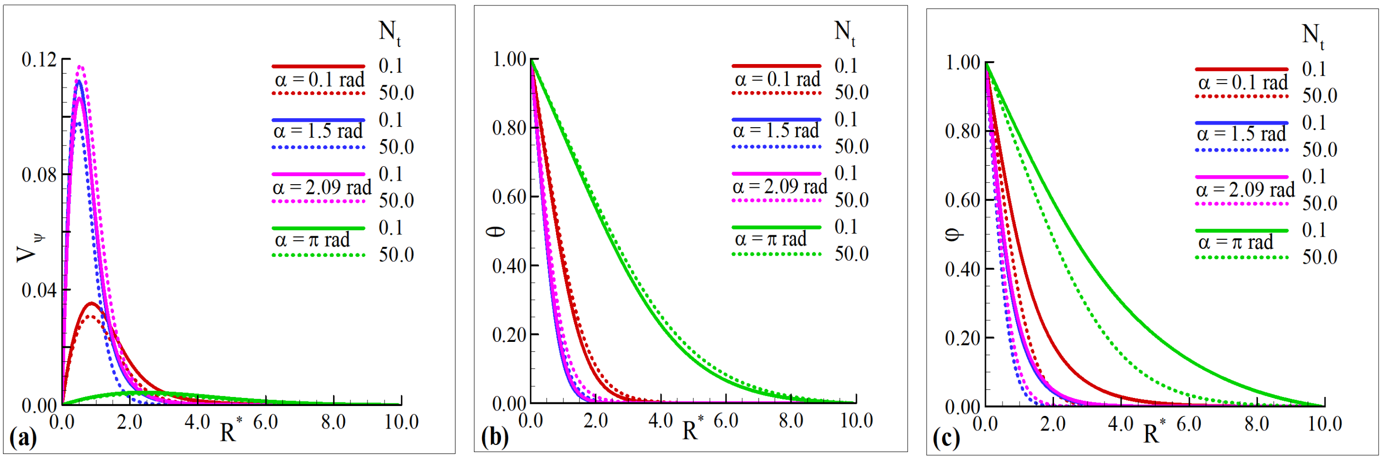

Figure 1. The geometrical interpretation of (a) V_ψ, (b) θ, and (c) φ for various values of N_t where other are $\mathrm{Pr} = 0.71$, $\mathrm{Sc} = 0.5$, $\gamma_A = 0.5$, $k = 0.1$, and $\varepsilon_A = 0.5$ [14].

variations with atmospheric thermal jumps, revealing that oceanic temperature gradients modulate thermophoretic efficiency through boundary layer stability alterations. Most recently, Imtiaz et al. [19] challenged conventional geometric assumptions by demonstrating that hybrid nanofluid convection along inclined hemispherical surfaces generates asymmetric thermophoretic particle distributions - a finding with potential implications for understanding regional disparities in polar amplification effects.

2 Mathematical Model and Governing Equations

A mathematical model in terms of rectangular coordinate system is formulated and length L is fixed at T_w, C_w. T_A and C_A are the atmosphere temperature and mass concentration respectively with $T_w > T_A$ and $C_w > C_A$. $(\bar{u}, \bar{v})$ are the velocities. In this case, it is assumed that the fluid's base is incompressible, whereas the viscosity and thermal conductivity vary with temperature. The viscosity and thermal conductivity in the source region are expressed as:

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

$$\rho\left(\bar{u}\frac{\partial \bar{u}}{\partial \bar{x}} + \bar{v}\frac{\partial \bar{u}}{\partial \bar{y}}\right) = \frac{\partial}{\partial \bar{y}}\left(\mu_s \frac{\partial \bar{u}}{\partial \bar{y}}\right) - g\rho\beta_T(T - T_p) - g\rho\beta_C(C - C_P) \tag{2}$$

$$\rho C_p\left(\bar{u}\frac{\partial T}{\partial \bar{x}} + \bar{v}\frac{\partial T}{\partial \bar{y}}\right) = \frac{\partial}{\partial \bar{y}}\left(k_s \frac{\partial T}{\partial \bar{y}}\right) \tag{3}$$

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$$\bar{u}\frac{\partial C}{\partial \bar{x}} + \bar{v}\frac{\partial C}{\partial \bar{y}} = D_B \frac{\partial}{\partial \bar{y}}\left(\frac{\partial C}{\partial \bar{y}}\right) - \frac{\partial}{\partial \bar{y}}\left(\bar{V_T} C\right) \tag{4}$$

Subject to the Conditions of Boundaries:

$$\bar{u} = \bar{v} = 0, \quad T = T_W, \quad C = C_W \quad \text{at} \quad \bar{y} = 0, \bar{x} \geq 0. \tag{5}$$

$$\bar{u} \to U_P, \quad T \to T_P, \quad C \to C_P \quad \text{as} \quad \bar{y} \to \infty, \bar{x} \geq 0. \tag{6}$$

where $\bar{V_T} = -\frac{kU_P L}{T}\frac{\partial T}{\partial \bar{y}}$.

The above model is transformed in to primitive form for computational solution and is solved numerically by using finite difference technique.

3 Results and Discussion

Warmth transmission via thermophoretic convection have been investigated in atmosphere. The physical impacts of various dimensionless parameters on velocity profile, temperature profile and thermophoretic concentration will be shown graphically. Using PVF, the dimension-free model is transformed into a coding format, then the discretization technique is used to discretize the resulting equations.

Figure 1(a) and Figure 1(b) illustrate that an increase in the thermophoresis parameter leads to a rise in both fluid velocity and temperature profiles, while other parameters are held constant. In contrast, the thermophoretic concentration exhibits an opposite trend, as shown in Figure 1(c). When the thermophoretic effect is significant, particles tend to accumulate more densely in specific regions, resulting in localized temperature variations. These areas, characterized by particle congregation, can experience elevated temperatures due to the enhanced absorption of solar radiation. Such accumulation also influences the spatial distribution of particle concentration in the atmosphere. As a result, the motion of particles governed by the thermophoresis parameter contributes to variations in temperature and thermophoretic concentration, thereby affecting atmospheric dynamics and climate patterns, particularly those linked to fossil fuel emissions. Although the temperature and concentration profiles attain their maximum values at specific points in Figure 1, it can be concluded that both temperature and thermophoretic concentration are higher near the surface compared to regions farther away from it.

4 Conclusion

The present mini review examines the combined effects of variable viscosity, variable thermal conductivity, and thermophoretic transport within atmospheric environments. This analysis is grounded in the observation that the combustion of fossil fuels in source regions significantly influences flow behavior and thermal characteristics. Specifically, an increase in the thermophoresis parameter leads to a reduction in fluid velocity and an enhancement in temperature distribution across all regions. Meanwhile, the mass concentration distribution initially increases in the regions closer to the source, followed by a decline in the broader atmospheric domain. This trend is attributed to the diminishing temperature gradient at greater distances from the source region.

Data Availability Statement

Data will be made available on request.

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Conflicts of Interest

The author declare no conflicts of interest.

Ethical Approval and Consent to Participate

Not applicable.

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