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Study of thermodynamic, transport and volumetric properties of nanofluids containing ZrO_2 nanoparticles in polypropylene glycol, polyvinyl pyrrolidone and water†

Nasrin Jebreili, Elaheh Janbezar, Mohammed Taghi Zafarani-Moattar, Hemayat Shekari* and Behrang Golmohammadi

Zirconium dioxide (ZrO_2) nanofluids are used in cooling systems, solar energy, and heat exchangers, offering improved heat transfer and efficiency across a wide temperature range. The aim of this work was to study the influence of polypropylene glycol (PPG) and polyvinyl pyrrolidone (PVP) and aqueous solutions of them as a base fluid on stability, volumetric properties, and viscosity of nanofluids containing Zirconium oxide (ZrO_2) nanoparticles. The stability of these nanofluids has been confirmed using UV-Vis spectroscopy, and the particle size distribution of the systems using dynamic light scattering (DLS). Among these systems ZrO_2 -PPG and ZrO_2 - H_2O -PVP30% have appropriate stability. The density, speed of sound and viscosity of these nanofluids have been measured at $T = (293.15 \text{ to } 318.15) \text{ K}$. From these data, the excess molar volume (V_m^E) and isentropic compressibility (κ_s) have been determined. The effects of ZrO_2 nanoparticles and temperature have also been investigated on volumetric and transport properties of aqueous solutions of PPG and PVP. The (V_m^E) values were fitted to the Redlich-Kister, Ott et al., and polynomial equations. Also, the isentropic compressibility (κ_s) values were correlated with the polynomial equation. The Eyring-NRTL and Eyring-mNRF models have been used for correlating of the viscosity of the nanofluids with temperature dependency. The performance of the Einstein, Brinkman, Lundgren and Batchelor models in the prediction of viscosity of the nanofluids has also been analyzed.

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1. Introduction

Technological advancements in the field of power generation cause an increment in the creation of heat during work processes. As a result, the need to reduce the generated heat becomes more essential.¹ Nanofluids are one of the most promising cooling agent that transferring heat efficiently. These materials are suspensions of nanoparticles with the size of 1–100 nm, that possess specific characteristics such as high thermal conductivity that can make them potentially a suitable alternative to other coolers.² The creation of nanofluids necessitates the utilization of nanoparticles and a base fluid; these materials can be characterized by their unique properties and can offer potential applications in various fields such as heat transfer, lubrication, and advanced materials science.³ One of the primary obstacles encountered in the utilization of nanofluids pertains to their inherent stability. The tendency of nanoparticles to agglomerate, driven by strong intermolecular

forces, results in clotting and sedimentation within the channels through which nanofluids are passed. Consequently, their ability to effectively enhance thermal conductivity is hindered. As a result, increasing the stability of nanofluids can be considered a significant objective. Many researchers have applied various strategies to improve nanofluid stability; including the incorporation of surfactants, polymers, ultrasound, and mechanical agitation.^{4–6} One of the cost effective methods to improve the stability of nanoparticles in a base fluid is utilization of polymers.⁷

Polymers on the other hand unlike the other applicants can be categorized as cost-effective, more accessible, that makes them a favorable and robust ingredient in the industry. One of the most important features of a polymer is that they can improve the stability of nanofluids. There are several methods to enhance the stability of nanofluids, the initial method involves the creation of an adsorbed layer, where polymers possess the ability to be adsorbed onto the surface of nanoparticles, consequently forming a protective layer. This protective layer, serves the crucial function of inhibiting direct contact between nanoparticles, thereby preventing their aggregation and accumulation within the fluid medium.⁸ Furthermore, another strategy involves the generation of steric repulsion,

Department of Physical Chemistry, Faculty of Chemistry, University of Tabriz, Tabriz, 52662-64471, Iran. E-mail: hemayat@tabrizu.ac.ir; Fax: +98 4233246119; Tel: +98 4233292094

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Table of Contents Research On Thermodynamic Transport Pr

1. Understanding the eBook Research On Thermodynamic Transport Pr
 - The Rise of Digital Reading Research On Thermodynamic Transport Pr
 - Advantages of eBooks Over Traditional Books
2. Identifying Research On Thermodynamic Transport Pr
 - Exploring Different Genres
 - Considering Fiction vs. Non-Fiction
 - Determining Your Reading Goals
3. Choosing the Right eBook Platform
 - Popular eBook Platforms
 - Features to Look for in an Research On Thermodynamic Transport Pr
 - User-Friendly Interface
4. Exploring eBook Recommendations from Research On Thermodynamic Transport Pr
 - Personalized Recommendations
 - Research On Thermodynamic Transport Pr User Reviews and Ratings
 - Research On Thermodynamic Transport Pr and Bestseller Lists
5. Accessing Research On Thermodynamic Transport Pr Free and Paid eBooks

- Research On Thermodynamic Transport Pr Public Domain eBooks
- Research On Thermodynamic Transport Pr eBook Subscription Services
- Research On Thermodynamic Transport Pr Budget-Friendly Options
- 6. Navigating Research On Thermodynamic Transport Pr eBook Formats
 - ePub, PDF, MOBI, and More
 - Research On Thermodynamic Transport Pr Compatibility with Devices
 - Research On Thermodynamic Transport Pr Enhanced eBook Features
- 7. Enhancing Your Reading Experience
 - Adjustable Fonts and Text Sizes of Research On Thermodynamic Transport Pr
 - Highlighting and Note-Taking Research On Thermodynamic Transport Pr
 - Interactive Elements Research On Thermodynamic Transport Pr
- 8. Staying Engaged with Research On Thermodynamic Transport Pr
 - Joining Online Reading Communities
 - Participating in Virtual Book Clubs
 - Following Authors and Publishers Research On Thermodynamic Transport Pr
- 9. Balancing eBooks and Physical Books Research On Thermodynamic Transport Pr
 - Benefits of a Digital Library
 - Creating a Diverse Reading Collection Research On Thermodynamic Transport Pr
- 10. Overcoming Reading Challenges
 - Dealing with Digital Eye Strain
 - Minimizing Distractions
 - Managing Screen Time
- 11. Cultivating a Reading Routine Research On Thermodynamic Transport Pr
 - Setting Reading Goals Research On Thermodynamic Transport Pr
 - Carving Out Dedicated Reading Time
- 12. Sourcing Reliable Information of Research On Thermodynamic Transport Pr
 - Fact-Checking eBook Content of Research On Thermodynamic Transport Pr
 - Distinguishing Credible Sources
- 13. Promoting Lifelong Learning
 - Utilizing eBooks for Skill Development

- Exploring Educational eBooks

14. Embracing eBook Trends

- Integration of Multimedia Elements
- Interactive and Gamified eBooks

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