Heat Transfer Fluids For Concentrating Solar Power Systems

The Potential of Nanoparticle Enhanced Ionic Liquids (Neils) as Advanced Heat Transfer Fluids
Advances in Clean Energy Technologies
Thermal Energy Storage Analyses and Designs
High-Temperature Static Experiments
ScholarlyBrief
New Concepts and Materials for Thermal Energy Storage and Heat-Transfer Fluids, May 20, 2011
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Heat Transfer and Latent Heat Storage in Inorganic Molten Salts for Concentrating Solar Power Plants
Testing Thermocline Filler Materials and Molten-salt Heat Transfer Fluids for Thermal Energy Storage Systems Used in Parabolic Trough Solar Power Plants
Advances in Thermal Energy Storage Systems

Processes, Systems and Technologies
Summary Report for Concentrating Solar Power Thermal Storage Workshop
SolarPACES
Enhanced dynamic performance testing method for line-concentrating solar thermal collectors
Effects of Particle Concentration and Surfactant Use in Convective Heat Transfer of CuO Nanofluids in Microchannel Flow
Summary Report for Concentrating Solar Power Thermal Storage Workshop
Concentrating Solar Thermal Technologies
From Numerical to Experimental Techniques
Chemical Engineering Practice
Solar Hydrogen Production
Advances in Sustainable Energy
Methods and Applications
Novel Molten Salts Thermal Energy Storage for Concentrating Solar Power Generation
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CFD Techniques and Thermo-Mechanics Applications
Fluid Mechanics, Heat Transfer, and Mass Transfer

Phenylnaphthalene as a Heat Transfer Fluid for Concentrating Solar Power
Study of Solid Particle Materials as High Temperature Thermal Energy Storage and Heat Transfer Fluid for Concentrating Solar Power
Phenylnaphthalene Derivatives as Heat Transfer Fluids for Concentrating Solar Power
Summary Report for Concentrating Solar Power Thermal Storage Workshop
Analysis and Optimisation by CFD Modelling
Annual Report 2013 of the Institute for Nuclear and Energy Technologies
Advances in Concentrating Solar Thermal Research and Technology
Desalination
Introduction to Thermal and Fluid Engineering
Thermophysical Properties of Mixed Alkali and Earth Alkaline Nitrate Salts Used as Heat Transfer Fluids for Concentrated Solar Power
Nanofluids and Their Engineering Applications
Select Proceedings of ICET 2020
Alkenes—Advances in Research and Application: 2013 Edition

HAILIE EWING

The Potential of Nanoparticle Enhanced Ionic Liquids (Neils) as

Advanced Heat Transfer Fluids
Woodhead Publishing
Heat exchange systems used in everything from cars to microelectronics have rapidly advanced in recent years to offer high heat transfer rates in increasingly smaller sizes. However, these systems have become essentially optimized using conventional heat transfer fluids. To test the viability of nanofluids as a new heat transfer fluid, an experimental investigation was designed using a constant pressure drop configuration to drive flow into a heated square microchannel test section. The experimental trials included seven different test fluids tested over varying concentrations and surfactant use. Two identical test sections were used to collect results on heat transfer rates, pressure drop, mass flowrate and pumping power for all fluids. These results show a heat transfer improvement for nanofluids of 8-16% over pure water, with no meaningful increase in pumping power. This result is highly desirable, as it indicates an easily obtainable heat transfer improvement without an associated pumping cost increase. Importantly, the experiment shows the potential viability of nanofluids for heat transfer applications, while acknowledging limitations such as long term nanofluid stability.

Advances in Clean Energy Technologies
BoD – Books on Demand
This book presents select proceedings of the international conference on Innovations in Clean Energy Technologies (ICET 2020) and examines

a range of durable, energy efficient and next-generation smart green technologies for sustainable future by reflecting on the trends, advances and development taking place all across the globe. The topics covered include smart technologies based product, energy efficient systems, solar and wind energy, carbon sequestration, green transportation, green buildings, energy material, biomass energy, smart cites, hydro power, bio-energy and fuel cell. The book also discusses various performance attributes of these clean energy technologies and their workability and carbon footprint. The book will be a valuable reference for beginners, researchers and professionals interested in clean energy technologies. *Thermal Energy Storage Analyses and Designs* Phenylnaphthalene Derivatives as Heat Transfer Fluids for Concentrating Solar PowerLoop Experiments and Final ReportORNL and subcontractor Cool Energy completed an investigation of higher-temperature, organic thermal fluids for solar thermal applications. Although static thermal tests showed promising results for 1-phenylnaphthalene, loop testing at temperatures to 450 C showed that the material isomerized at a slow rate. In a loop with a temperature high enough to drive the isomerization, the higher melting point byproducts tended to condense onto cooler surfaces. So, as experienced in loop operation, eventually the internal channels of cooler components such as the waste heat rejection exchanger may become coated or clogged and loop performance will decrease. Thus, pure 1-phenylnaphthalene does not appear to be a fluid that would have a sufficiently long lifetime (years to decades) to be used in a loop at the increased temperatures of interest. Hence a decision was made not to test the ORNL fluid in the loop at Cool Energy Inc. Instead, Cool Energy tested and modeled power conversion from a moderate-temperature solar loop using coupled Stirling engines. Cool Energy analyzed data collected on third and fourth generation SolarHeart Stirling engines operating on a rooftop solar field with a lower temperature (Marlotherm) heat transfer fluid. The operating efficiencies of the Stirling engines were determined at multiple, typical solar conditions, based on data from actual cycle operation. Results highlighted the advantages of inherent thermal energy storage in the power conversion system.Concentrating Solar Thermal TechnologiesAnalysis and Optimisation by CFD Modelling

Introduction to Thermal and Fluid Engineering combines coverage of basic thermodynamics, fluid mechanics, and heat transfer for a one- or two-term course for a variety of engineering majors. The book covers fundamental concepts, definitions, and models in the context of engineering examples and case studies. It carefully explains the methods used to evaluate changes in equilibrium, mass, energy, and other measurable properties, most notably temperature. It then also discusses techniques used to assess the effects of those changes on large, multi-component systems in areas ranging from mechanical, civil, and environmental engineering to electrical and computer technologies. Includes a motivational student study guide on CD to promote successful evaluation of energy systems This material helps readers optimize problem solving using practices to determine equilibrium limits and entropy, as well as track energy forms and rates of progress for processes in both closed and open thermodynamic systems. Presenting a variety of system examples, tables, and charts to reinforce understanding, the book includes coverage of: How automobile and aircraft engines work Construction of steam power plants and refrigeration systems Gas and vapor power processes and systems Application of fluid statics, buoyancy, and stability, and the flow of fluids in pipes and machinery Heat transfer and thermal control of electronic components Keeping sight of the difference between system synthesis and analysis, this book contains numerous design problems. It would be useful for an intensive course geared toward readers who know basic physics and mathematics through ordinary differential equations but might not concentrate on thermal/fluids science much further. Written by experts in diverse fields ranging from mechanical, chemical, and electrical engineering to applied mathematics, this book is based on the assertion that engineers from all walks absolutely must understand energy processes and be able to quantify them.

High-Temperature Static Experiments

CRC Press

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ScholarlyBrief KIT Scientific Publishing

This fact sheet describes the purpose, lab specifications, applications scenarios, and information on how to partner with NREL's Thermal Systems Process and Components Laboratory at the Energy Systems Integration Facility. The focus of the Thermal Systems Process and Components Laboratory at NREL's Energy Systems Integration Facility (ESIF) is to research, develop, test, and evaluate new techniques for thermal energy storage systems that are relevant to utility-scale concentrating solar power plants. The laboratory holds test systems that can provide heat transfer fluids for the evaluation of heat exchangers and thermal energy storage devices. The existing system provides molten salt at temperatures up to 800 C. This unit is charged with nitrate salt rated to 600 C, but is capable of handling other heat transfer fluid compositions. Three additional test bays are available for future deployment of alternative heat transfer fluids such as hot air, carbon dioxide, or steam systems. The Thermal Systems Process and Components Laboratory performs pilot-scale thermal energy storage system testing through multiple charge and discharge cycles to evaluate heat exchanger performance and storage efficiency. The laboratory equipment can also be utilized to test instrument and sensor compatibility with hot heat transfer fluids. Future applications in the laboratory may include the evaluation of thermal energy storage systems designed to operate with supercritical heat transfer fluids such as steam or carbon dioxide. These tests will require the installation of test systems capable of providing supercritical fluids at temperatures up to 700 C.

New Concepts and Materials for Thermal Energy Storage and Heat-Transfer Fluids,

May 20, 2011 Springer
This document summarizes a workshop on thermal energy storage for concentrating solar power (CSP) that was held in Golden, Colorado, on May 20, 2011. The event was hosted by the U.S. Department of Energy (DOE), the National Renewable Energy Laboratory, and Sandia National Laboratories. The objective was to engage the university and laboratory research communities to identify and define research directions for developing new high-temperature materials and systems that advance thermal energy storage for CSP technologies. This workshop was motivated, in part, by the DOE SunShot Initiative, which sets a very aggressive cost goal for CSP technologies -- a levelized cost of energy of 6 cents per kilowatt-hour by 2020 with no incentives or credits.
New Concepts and Materials for Thermal Energy Storage and Heat-Transfer Fluids - Scholar's Choice Edition John Wiley & Sons
Parabolic trough power systems that utilize concentrated solar energy to generate electricity are a proven technology. Industry and laboratory research efforts are now focusing on integration of thermal energy storage as a viable means to enhance dispatchability of concentrated solar energy. One option to significantly reduce costs is to use thermocline storage systems, low-cost filler materials as the primary thermal storage medium, and molten nitrate salts as the direct heat transfer fluid. Prior thermocline

evaluations and thermal cycling tests at the Sandia National Laboratories' National Solar Thermal Test Facility identified quartzite rock and silica sand as potential filler materials. An expanded series of isothermal and thermal cycling experiments were planned and implemented to extend those studies in order to demonstrate the durability of these filler materials in molten nitrate salts over a range of operating temperatures for extended timeframes. Upon test completion, careful analyses of filler material samples, as well as the molten salt, were conducted to assess long-term durability and degradation mechanisms in these test conditions. Analysis results demonstrate that the quartzite rock and silica sand appear able to withstand the molten salt environment quite well. No significant deterioration that would impact the performance or operability of a thermocline thermal energy storage system was evident. Therefore, additional studies of the thermocline concept can continue armed with confidence that appropriate filler materials have been identified for the intended application.

Heat Transfer and Latent Heat Storage in Inorganic Molten Salts for Concentrating Solar Power Plants Academic Press

Binary and ternary mixtures of molten salt nitrates (LiNO3 -NaNO3 and KNO3) are ideal candidates as large scale phase change thermal energy storage materials and as heat transfer fluids for concentrating solar power systems. They have higher specific heat capacities and wider operating temperature ranges (150-600 C) compared to the silicon based oils which are currently used in parabolic trough type plants. For design considerations related to power plant and equipment, it is critically important to know the thermo-physical properties of molten salt nitrates; as thermal conductivity being one of the most important. In this regard, the measurements of thermal conductivity of molten salt nitrates are of interest in the present study."

Testing Thermocline Filler Materials and Molten-salt Heat Transfer Fluids for Thermal Energy Storage Systems Used in Parabolic Trough Solar Power Plants CRC Press

ORNL and subcontractor Cool Energy completed an investigation of higher-temperature, organic thermal fluids for solar thermal applications. Although static thermal tests showed promising results for 1-phenylnaphthalene, loop testing at temperatures to 450 C showed that the material isomerized at a slow rate. In a loop with a temperature high enough to drive the isomerization, the higher melting point byproducts tended to condense onto cooler surfaces. So, as experienced in loop operation, eventually the internal channels of cooler components such as the waste heat rejection exchanger may become coated or clogged and loop performance will decrease. Thus, pure 1-phenylnaphthalene does not appear to be a fluid that would have a sufficiently long lifetime (years to decades) to be used in a loop at the increased temperatures of interest. Hence a decision was made not to test the ORNL fluid in the loop at Cool Energy Inc. Instead, Cool Energy tested and modeled power conversion from a moderate-temperature solar loop using coupled Stirling engines. Cool Energy analyzed data collected on third and fourth generation SolarHeart Stirling engines operating on a rooftop solar field with a lower temperature (Marlotherm) heat transfer fluid. The operating efficiencies of the Stirling engines were determined at multiple, typical solar conditions, based on data from actual cycle operation. Results highlighted the advantages of inherent thermal energy storage in the power conversion system.

Advances in Thermal Energy Storage Systems LAP Lambert Academic Publishing

This book addresses the evaluation and optimization of key elements in concentrating solar thermal (CST) technologies, such as solar receivers and working fluids, using computational fluid dynamics (CFD) modeling. It discusses both general and specific aspects, explaining the methodology used to analyze and evaluate the influence of different parameters on the facility performance. This information provides the basis for optimizing design and operating conditions in CST systems.

Processes, Systems and Technologies Woodhead Publishing

Interest in capturing the energy of the sun is rising as demands for renewable energy sources increase. One area of developing research is the use of concentrating solar power (CSP), where the solar energy is concentrated by using mirrors to direct the sunlight towards a collector filled with a heat transfer fluid (HTF). The HTF transfers the collected energy into pressurized steam, which is used to generate energy. The greater the energy collected by the HTF, the more efficent the electrical energy production is, thus the overall efficiency is controlled by the thermal fluid. Commercial HTFs such as Therminol{reg_sign} (VP-1), which is a blend of biphenyl and diphenyl oxide, have a significant vapor pressure, especially at elevated temperatures. In order for these volatile compounds to be used in CSP systems, the system either has to be engineered to prevent the phase change (i.e., volatilization and condensation) through pressurization of the system, or operate across the phase change. Over thirty years ago, a class of low-melting organic compounds were developed with negligible vapor pressure. These compounds are referred to as ionic liquids (ILs), which are organic-based compounds with discrete charges that cause a significant decrease in their vapor pressure. As a class, ILs are molten salts with a melting point below 100 C and can have a liquidus range approaching 400 C, and in several cases freezing points being below 0 C. Due to the lack of an appreciable vapor pressure, volatilization of an IL is not possible at atmospheric pressure, which would lead to a simplification of the design if used as a thermal fluid and for energy storage materials. Though the lack of a vapor pressure does not make the use of ILs a better HTF, the lack of a vapor pressure is a compliment to their higher heat capacity, higher volummetric density, and thus higher volumetric heat capacity. These favorable physical properties give ILs a pontential advantage over the current commerically used thermal fluids. Also within the past decade nanofluids have gained attention for thermal conductivity enhancment of fluids, but little analysis has been completed on the heat capacity effects of the nanoparticle addition. The idea of ILs or nanofluids as a HTF is not new, as there are several references that have proposed the idea. However, the use of ionic liquid nanofluids containing nanomaterials other than carbon nanotubes has never before been studied. Here, for the first time, nano-particle enhanced ILs (NEILs) have been shown to increase the heat capacity of the IL with no adverse side effects to the ILs thermal stability and, only at high nanoparticle loading, are the IL physical properties affected. An increase of volumetric heat capacity translates into a better heat transfer fluid as more energy is stored per volumetric unit in the solar concentrating section, thus more efficency in increased steam pressure. Results show that the properties of the NEIL are highly dependant on the suspended nanomaterial and careful materials selection is required to fully optimize the nanofluid properties.

Summary Report for Concentrating Solar

Power Thermal Storage Workshop CRC Press
This broad-based book covers the three major areas of Chemical Engineering. Most of the books in the market involve one of the individual areas, namely, Fluid Mechanics, Heat Transfer or Mass Transfer, rather than all the three. This book presents this material in a single source. This avoids the user having to refer to a number of books to obtain information. Most published books covering all the three areas in a single source emphasize theory rather than practical issues. This book is written with emphasis on practice with brief theoretical concepts in the form of questions and answers, not adopting stereo-typed question-answer approach practiced in certain books in the market, bridging the two areas of theory and practice with respect to the core areas of chemical engineering. Most parts of the book are easily understandable by those who are not experts in the field. Fluid Mechanics chapters include basics on non-Newtonian systems which, for instance find importance in polymer and food processing, flow through piping, flow measurement, pumps, mixing technology and fluidization and two phase flow. For example it covers types of pumps and valves, membranes and areas of their use, different equipment commonly used in chemical industry and their merits and drawbacks. Heat Transfer chapters cover the basics involved in conduction, convection and radiation, with emphasis on insulation, heat exchangers, evaporators,

condensers, reboilers and fired heaters. Design methods, performance, operational issues and maintenance problems are highlighted. Topics such as heat pipes, heat pumps, heat tracing, steam traps, refrigeration, cooling of electronic devices, NOx control find place in the book. Mass transfer chapters cover basics such as diffusion, theories, analogies, mass transfer coefficients and mass transfer with chemical reaction, equipment such as tray and packed columns, column internals including structural packings, design, operational and installation issues, drums and separators are discussed in good detail. Absorption, distillation, extraction and leaching with applications and design methods, including emerging practices involving Divided Wall and Petluk column arrangements, multicomponent separations, supercritical solvent extraction find place in the book.
SolarPACES Academic Press
Hybrid Nanofluids for Convection Heat Transfer discusses how to maximize heat transfer rates with the addition of nanoparticles into conventional heat transfer fluids. The book addresses definitions, preparation techniques, thermophysical properties and heat transfer characteristics with mathematical models, performance-affecting factors, and core applications with implementation challenges of hybrid nanofluids. The work adopts mathematical models and schematic diagrams in review of available experimental methods. It enables readers to create new techniques,

resolve existing research problems, and ultimately to implement hybrid nanofluids in convection heat transfer applications. Provides key heat transfer performance and thermophysical characteristics of hybrid nanofluids Reviews parameter selection and property measurement techniques for thermal performance calibration Explores the use of predictive mathematical techniques for experimental properties
Enhanced dynamic performance testing method for line-concentrating solar thermal collectors CRC Press
A key technological issue facing the success of future Concentrating Solar Thermal Power (CSP) plants is creating an economical Thermal Energy Storage (TES) system. Current TES systems use either sensible heat in fluids such as oil, or molten salts, or use thermal stratification in a dual-media consisting of a solid and a heat-transfer fluid. However, utilizing the heat of fusion in inorganic molten salt mixtures in addition to sensible heat, as in a Phase change material (PCM)-based TES, can significantly increase the energy density of storage requiring less salt and smaller containers. A major issue that is preventing the commercial use of PCM-based TES is that it is difficult to discharge the latent heat stored in the PCM melt. This is because when heat is extracted, the melt solidifies onto the heat exchanger surface decreasing the heat transfer. Even a few millimeters of thickness of solid material on heat transfer surface results in a large drop in

heat transfer due to the low thermal conductivity of solid PCM. Thus, to maintain the desired heat rate, the heat exchange area must be large which increases cost. This project demonstrated that the heat transfer coefficient can be increase ten-fold by using forced convection by pumping a hyper-eutectic salt mixture over specially coated heat exchanger tubes. However, only 15% of the latent heat is used against a goal of 40% resulting in a projected cost savings of only 17% against a goal of 30%. Based on the failure mode effect analysis and experience with pumping salt at near freezing point significant care must be used during operation which can increase the operating costs. Therefore, we conclude the savings are marginal to justify using this concept for PCM-TES over a two-tank TES. The report documents the specialty coatings, the composition and morphology of hypereutectic salt mixtures and the results from the experiment conducted with the active heat exchanger along with the lessons learnt during experimentation.

Effects of Particle Concentration and Surfactant Use in Convective Heat Transfer of CuO Nanofluids in Microchannel Flow Academic Press

Binary and Ternary mixtures of Molten Salt Nitrates are ideal candidates for future concentrating solar power (CSP) plant heat transfer fluids (HTFs) because of their high operating temperature limits resulting in greater Rankine efficiency. The inclusion of these HTFs into CSP plants is expected to revolutionize the industry by allowing for energy and cost savings that are attractive to potential plant developers and investors. It is vital for plant designers to have access to fully characterized thermo-physical properties of the intended HTFs, with thermal conductivity, viscosity, and specific heat capacity being the most crucial. Existing literature has not fully elucidated the thermo-physical properties of binary and ternary molten salt nitrates through their operating temperature range. This work presents the viscosity of eutectic ternary and binary compositions of molten alkali salt nitrates (Li-NO3, K-NO3, and Na-NO3) up to 550°C. A device to measure the thermal conductivity of these salts with accuracy at elevated temperatures was designed and built as no commercial offerings are able to withstand the corrosive nature of molten salt at high temperatures. The device is shown to accurately measure the thermal conductivity of water at room temperature. The present work is a step towards fully characterizing the thermo-physical properties of the aforementioned molten salts.

Summary Report for Concentrating Solar Power Thermal Storage Workshop Springer Nature

Heat transfer enhancement has seen rapid development and widespread use in both conventional and emerging technologies. Improvement of heat transfer fluids requires a balance between experimental and numerical work in nanofluids and new refrigerants.

Recognizing the uncertainties in development of new heat transfer fluids, Advances in New Heat Transfer Fluids: From Numerical to Experimental Techniques contains both theoretical and practical coverage.
Concentrating Solar Thermal Technologies CRC Press
Nanofluids are solid-liquid composite material consisting of solid nanoparticles suspended in liquid with enhanced thermal properties. This book introduces basic fluid mechanics, conduction and convection in fluids, along with nanomaterials for nanofluids, property characterization, and outline applications of nanofluids in solar technology, machining and other special applications. Recent experiments on nanofluids have indicated significant increase in thermal conductivity compared with liquids without nanoparticles or larger particles, strong temperature dependence of thermal conductivity, and significant increase in critical heat flux in boiling heat transfer, all of which are covered in the book. Key Features Exclusive title focusing on niche engineering applications of nanofluids Contains high technical content especially in the areas of magnetic nanofluids and dilute oxide based nanofluids Feature examples from research applications such as solar technology and heat pipes Addresses heat transfer and thermodynamic features such as efficiency and work with mathematical rigor Focused in content with precise technical definitions and treatment

From Numerical to Experimental Techniques Cuvillier Verlag
This document summarizes a workshop on thermal energy storage for concentrating solar power (CSP) that was held in Golden, Colorado, on May 20, 2011. The event was hosted by the U.S. Department of Energy (DOE), the National Renewable Energy Laboratory, and Sandia National Laboratories. The objective was to engage the university and laboratory research communities to identify and define research directions for developing new high-temperature materials and systems that advance thermal energy storage for CSP technologies. This workshop was motivated, in part, by the DOE SunShot Initiative, which sets a very aggressive cost goal for CSP technologies -- a levelized cost of energy of 6 cents per kilowatt-hour by 2020 with no incentives or credits.

Chemical Engineering Practice
Springer
After decades of research and development, concentrating solar thermal (CST) power plants (also known as concentrating solar power (CSP) and as Solar Thermal Electricity or STE systems) are now starting to be widely commercialized. Indeed, the IEA predicts that by 2050, with sufficient support over ten percent of global electricity could be produced by concentrating solar thermal power plants. However, CSP plants are just but one of the many possible applications of CST systems.
Advances in Concentrating Solar Thermal Research and Technology

provides detailed information on the latest advances in CST systems research and technology. It promotes a deep understanding of the challenges the different CST technologies are confronted with, of the research that is taking place worldwide to address those challenges, and of the impact that the innovation that this research is fostering could have on the emergence of new CST components and concepts. It is anticipated that these developments will substantially increase the cost-competiveness of commercial CST solutions and reshape the technological landscape of both CST technologies and the CST industry. After an introductory chapter, the next three parts of the book focus on key CST plant components, from mirrors and receivers to thermal storage. The final two parts of the book address operation and control and innovative CST system concepts. Contains authoritative reviews of CST research taking place around the world Discusses the impact this research is fostering on the emergence of new CST components and concepts that will substantially increase the cost-competitiveness of CST power Covers both major CST plant components and system-wide issues

Solar Hydrogen Production Scholar's Choice

Thermal Energy Storage Analyses and Designs considers the significance of thermal energy storage systems over other systems designed to handle large quantities of energy, comparing storage technologies and emphasizing the importance, advantages, practicalities, and operation of thermal energy storage for large quantities of energy production. Including chapters on thermal storage system configuration, operation, and delivery processes, in particular the flow distribution, flow arrangement, and control for the thermal charge and discharge processes for single or multiple thermal storage containers, the book is a useful reference for engineers who design, install, or maintain storage systems. Includes computer code for thermal storage analysis, including code flow charts Contains a database of material properties relevant to storage Provides example cases of input and output data for the code

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