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Exploring the Utilization of Newtonian Fluids in Heat Transfer Applications

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Abstract *- This paper presents a comprehensive review of theoretical investigations concerning the influence of Newtonian fluids on heat transfer processes. Newtonian fluids are characterized by a constant viscosity that remains unaffected by variations in shear rate. Their widespread utilization in heat transfer applications is attributed to their consistent and stable flow behaviour, facilitating easier modelling and analysis. A prominent exemplification of the application of Newtonian fluids in heat transfer lies in electronic cooling systems. These fluids, typified by substances like water or oil, efficiently dissipate the heat generated by electronic components through circulation within the cooling system. Moreover, Newtonian fluids play a pivotal role as heat transfer agents in heat exchangers, wherein an array of tubes facilitates the exchange of thermal energy between two fluids separated by a conductive partition. In addition, within the realm of industrial processes, Newtonian fluids find utility in mixing tanks and reactors for tasks ranging from heat transfer between different phases to the maintenance of uniform temperatures within the vessel. The consistent behaviour and low viscosity of Newtonian fluids render them exceptionally effective in mediating heat transfer across diverse applications. This paper presents a comprehensive comparative study between air and Newtonian fluids as heat transfer media in various industrial applications. The objective is to assess the advantages, limitations, and suitability of each medium in different scenarios, considering factors such as thermal efficiency, cost-effectiveness, ease of implementation, and environmental impact. This study embarks on an exploration of the multifaceted utilization of Newtonian fluids in both industrial and consumer contexts, shedding light on their indispensable role in enhancing heat transfer processes.*

Keywords: Newtonian, Heat transfer, Heat exchangers, Fluids, Reactors, Mixing tanks.

1. INTRODUCTION

Newtonian fluids renowned for their heat transfer attributes are extensively employed across a spectrum of engineering and industrial applications. Their burgeoning popularity can be attributed to their exceptional characteristics and user-friendliness. These fluids are distinguished by their capability to facilitate efficient heat transfer while maintaining the quintessential Newtonian fluid trait of consistent viscosity across varying shear rates. Franco et al.[1] considers Newton's law of Viscosity:

$$\tau=\mu\ [du/dy]\ , \qquad (1)$$

where the shear stress τ of a fluid is equal to the product of its dynamic viscosity μ and the rate of shear deformation du/dy. Among the commonly employed fluids that satisfy this criterion are water, air, oil, gasoline, alcohol, glycerol, organic solvents, motor oil, and honey. These fluids exhibit a decrease in viscosity with rising temperatures, a consequence of heightened molecular kinetic energy, which, in turn, leads to more frequent molecular collisions. This phenomenon results in reduced flow resistance and lower viscosity. The temperature dependence of viscosity is best described by the Arrhenius equation:

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$$\mu=\mu_0 \exp[E_A /RT], \quad (2)$$

where viscosity μ is measured in pascals/sec, μ_0 is a constant value measured in pascals/sec, and E_A is the activation energy a molecule must experience before taking part in a reaction, measured in kJ/mol, R is the universal gas constant, 0.00831434 kJ/mol K and T is the absolute temperature in Kelvin. The equation suggests that the viscosity of a fluid decreases exponentially with increasing temperature. Yanniotis et al.[2] utilized the Arrhenius equation satisfactorily to predict the dependency of the viscosity of honey on temperature, proving the Newtonian behavior of honey.

Water reigns as the predominant Newtonian fluid in utilization, primarily attributable to its exceptional thermal conductivity and specific heat capacity, rendering it an exceptionally effective heat transfer medium. Moreover, water enjoys widespread availability and affordability in comparison to alternative heat transfer fluids. In addition to water, other prominent Newtonian fluids endowed with heat transfer capabilities encompass various oils, glycols, and refrigerants. These versatile fluids find application in diverse sectors, including HVAC systems, refrigeration, power generation plants, and chemical processes. Furthermore, they are integral components in heat exchangers, facilitating the transfer of heat between two distinct fluids. Prabhanjan et al.[3] utilized tap water as a heat transfer fluid when comparing the heat transfer coefficient of a helical coil heat exchanger and a straight tube heat exchanger. They found that the water's temperature was affected by the coil geometry of the fluid, thus causing an increase in heat transfer to the helical coil heat exchanger compared to the straight tube heat exchanger. Rudresha et al.[4] investigated a two-phase pulsating heat pipe(PHP) system that used water as the coolant and ethylene glycol as the working fluid at different filling ratios to determine the heat transfer performance under different heat inputs. The results show that the heat transfer increases with the filling ratio and displayed lower thermal resistance up at a 70% filling ratio.

Air, while not as thermally efficient as liquids for heat transfer, remains a prevalent choice in various heat transfer applications owing to its wide availability, cost-effectiveness, and safety considerations.

Within HVAC systems, "air" assumes a pivotal role as the primary heat transfer medium, serving to ensure thermal comfort for occupants. The process involves heating or cooling air by passing it through respective heating or cooling coils. Subsequently, the conditioned air is distributed throughout the building via ductwork. The air's capacity to absorb and release heat significantly influences the system's efficiency and its effectiveness in maintaining desired temperatures. In refrigeration systems, air serves as a secondary heat transfer medium, tasked with expelling heat from the refrigerant. Here, the refrigerant undergoes cooling as it passes over a coil that is itself cooled by air. The efficiency of this process relies heavily on the air's ability to extract heat from the coil, ensuring the refrigeration system's effectiveness. Within cooling systems, air stands as the primary heat transfer medium for dissipating heat from equipment or industrial processes. Conventionally, air is blown over surfaces to facilitate heat removal through convection. The air's prowess in heat dissipation is paramount for maintaining the optimal temperature of various industrial equipment and processes. Vlasogiannis et al.[5] tested a two-phase air-water flow as a cold stream in a plate heat exchanger and a single-phase hot water heat stream. When comparing the heat transfer, they found that it is always higher in the two-phase flow due to the presence of air.

Oil finds widespread application as a coolant across various domains, notably in high-performance engines and machinery subjected to substantial heat loads. The use of oil as a coolant boasts several merits, such as its exceptional heat absorption and transfer capabilities, its inherent lubrication attributes, and its resistance to thermal deterioration and breakdown. Shen et al.[6] investigated the use of mineral oil as a dielectric coolant for transformers, along with alternative dielectric oils that are plant-based. They concluded that the plant-based oils are the superior coolant for transformers as they are environment-friendly and satisfy fire-safety requirements.

Newtonian fluids exhibit changes in viscosity primarily in response to temperature variations rather than alterations in shear rate. This behavior results in reduced friction and wear on the equipment employing them. Wurzel[7] describes the uses of glycerol, a Newtonian fluid used in several industries, such as food, pharmaceutical, personal care, printing, and even for creating dynamite (nitro-glycerine).

The process of heat transfer within Newtonian fluids transpires via conduction, convection, and radiation mechanisms. The rate of heat transfer hinges on an interplay of factors encompassing the fluid's thermal conductivity, viscosity, density, specific heat capacity, emissivity, and velocity, alongside the system's geometry and the temperature differential between the fluid and its surrounding environment. Zhang et.al.[8] experimented with forced convection of water, where they studied the freezing behaviour of water subjected to forced convection and emphasized its importance in predicting the frosting of the engine air precooler. They found that while under forced convection, the convective heat transfer between the airflow and liquid phase of water leads to an increase in the temperature of the liquid phase.

The thermal management of technology is increasingly dependent on heat transfer as components are consuming higher amounts of power to increase their productivity. Liquid and air cooling continue to be analysed and innovated to meet the requirements of next-generation devices. Traditionally, air cooling has been used in managing electronics due to its mechanical simplicity, as stated by Etemoglu [9]. Distilled water is conventionally used in liquid cooling systems for electronics as it is electrically non-conductive and has a high thermal capacity and low viscosity. Tie et al.[10] studied the influence of jet arrays [with distilled water] on heat transfer and found the enhancement of heat transfer by increasing Reynold's number with small jets instead of large jets. He et al.[11] used an internal indirect water-cooled heat sink cycle and an external cooling tower cold source cycle to decrease the power consumption of a server tower. They found the ideal water temperature for different ambient temperatures of the server tower and were able to generate a 21.3% reduction in power consumption. This paper also presents a comprehensive comparative study between air and Newtonian fluids as heat transfer media in various industrial applications. The objective is to assess the advantages, limitations, and suitability of each medium in different scenarios, considering factors such as thermal efficiency, cost-effectiveness, ease of implementation, and environmental impact. The study encompasses a range of industrial sectors, including HVAC systems, power generation, chemical processing, and manufacturing, where heat transfer plays a pivotal role. The thermal properties, heat transfer mechanisms, and practical considerations of both air and Newtonian fluids are evaluated to provide a comprehensive perspective on their performance.

Overall, the widespread adoption of Newtonian fluids with heat transfer capabilities is underpinned by their prowess in facilitating efficient heat transfer, user-friendly characteristics, and ready availability. As emerging technologies unfold and the quest for enhanced, sustainable heat transfer solutions gains momentum, the utilization of these fluids is poised to expand further in response to evolving demands.

2. PROPERTIES OF POPULAR NEWTONIAN FLUIDS

All Newtonian fluids have the unique characteristic of "their viscosity changing with temperature and their ability to resist shear rate" in common. Although true, it does not make all Newtonian fluids equally suitable for the same applications.

2.1. Thermophysical Properties of Newtonian Fluids

Considering the thermophysical properties of Newtonian fluids, as described in Table 1, one can select the fluid to be used based on design specifications for different applications and devices.

TABLE 1: Thermophysical Properties of Popular Newtonian Fluids

Newtonian Fluid	**Chemical Composition**	**Thermal Conductivity [w/mk]**	**Specific Heat Capacity [kJ/kg-K]**	**Specific Gravity**	**Viscosity [Pas]**	**Cost [$/gal]**
Water	H_2O	0.609	4.186	1.00	10^-3	9.60
Air	-	0.033	1.005	0.0013	10^-5	-
Silicone Oil	$[-Si(CH_3)_2O-]n$	0.157	1.51	0.97	-	294.95
Molten Salt	$NaNO_3$-KNO_3	0.5501	1.53	-	1.7*10^-3	6.46
Ethylene Glycol	$C_2H_6O_2$	0.258	3.647	1.11	1.61*10^-2	38
Mineral Oil	$C_{16}H_1ON_2Na_2O_7S_2$	0.126	1.86	0.845-0.905	2.144*10^-3	22.99
Distilled Water	H_2O	0.599	4.186	1.00	10^-3	1.22
Propylene Glycol	$C_3H_8O_2$	0.147	3.747	1.026	1.65*10^-3	70
Carbon Dioxide	CO_2	0.0168	0.846	1.53	1.57*10^-5	0.02
Helium	He	0.1567	5.1926	0.137	1.96*10^-5	0.02
Liquid Mercury	Hg	8.69	0.139	13.59	6*10^-3	3,400
Motor Oil (unused)	C_nH_{2n}	0.144	1.91	0.82	-	12.72

2.2. Advantages, Disadvantages, and Applications of Popular Newtonian Fluids

The choice of the appropriate Newtonian fluid for a heat transfer application must be accompanied by highlighting its advantages and disadvantages. Depending on a Newtonian fluid's environment, its characteristics might be detrimental to its surroundings, making them only acceptable in certain applications. Table 2 highlights the advantages, disadvantages, and applications of fluid groups of popular Newtonian fluids.

TABLE 2: Advantages, Disadvantages, and Applications of Popular Newtonian Fluids

Fluid Group	**Advantages**	**Disadvantages**	**Applications**
Water	i. High heat capacity and thermal conductivity ii. Low viscosity iii. Non-toxic iv. Low expansion v. High availability	i. Thickens at high levels of conductivity, which can lead to corrosion ii. Material destruction due to cavitation at high pressures	i. Heat Exchangers ii. Nuclear Reactors iii. Geothermal Energy
Silicone Oil	i. High shear stability ii. High oxidation applications iii. Non-corrosive iv. Non-toxic	i. Expensive ii. Low surface tension iii. Large thermal expansion coefficient	i. Heat baths
Mineral Oil	i. Low viscosity	i. High rates of oxidation and decomposition	i. Thermal Heaters
Glycols	i. High thermal conductivity ii. Low viscosity iii. Low cost	i. Thermal oxidation leads to corrosion	i. Antifreeze in automobiles
Air	i. Low cost ii. Low toxicity iii. High availability	i. Not as efficient as water	i. Heat Exchangers ii. HVAC Units
Liquid Metals	i. Low melting-points ii. Low viscosity iii. High thermal conductivity	i. Flammable ii. Highly susceptible to corrosion	i. CSP systems
Molten Salt	i. Do not require pressurization ii. High boiling points iii. High cost	i. Low viscosity ii. High chance of corroding alloys iii. High freezing point	i. Thermal Energy Storage

2.2.1. Advantages

a. *Predictable Flow Behavior:* Newtonian fluids exhibit a reliable and uniform flow behavior, simplifying their modeling and analysis in heat transfer applications. This predictability enables engineers to make precise predictions regarding flow rates, pressure fluctuations, and heat transfer rates, streamlining the design process.

i. Good et al.[12] utilized air to replace thermal oil as a heat transfer fluid in a novel Concentrating Solar-thermal Power (CSP) solar receiver. This was done to overcome the limited operating temperature of 450°C with thermal oil, which they could do and increased to 650°C with air. In this situation, air was more desirable than thermal oil due to its availability, cost, and low toxicity.

ii. Coupled with CSP systems is Thermal Energy Storage (TES), where molten can be used as a heat transfer medium to replace thermal oil. Bonk et al.[13] investigated five molten salt variations: Solar Salt, HitecXL, LiNaK-Nitrate, Hitec, and CaLiNaK, and determined the thermophysical properties of each. Due to their low melting temperature, they found that salt mixtures such as Hitec, HitecXL, LiNaK-Nitrate, and CaLiNaK are candidates for HTF in CSP TES systems.

iii. Jithin et al.[14] investigated using deionized water, mineral oil, and engineered fluid in a single-phase immersion cooling for a lithium-ion battery. They found that when using the deionized water, the heat is removed from the battery almost at the same rate as heat generated. When comparing the viscosity of the fluids, it was noticeable that the pressure drop and power consumption were greater for the mineral oil and engineered fluid. Therefore, deionized water, as expected is best suited for decreasing power consumption.

b. *High Thermal Stability:* Certain Newtonian fluids, including mineral oils, demonstrate remarkable thermal stability, allowing them to withstand high temperatures without experiencing degradation or breakdown. Consequently, these fluids prove highly suitable for demanding high-temperature applications such as power generation and industrial processes.

iv. Li et al.[15] proposed using liquid metals to replace water as the working fluid to enhance heat transport in heat exchangers, as liquid metals have higher thermal conductivity than water.

v. Trimbake et al.[16] utilized mineral oil as a coolant in jet impingement immersion cooling of lithium-ion batteries due to its thermal stability. They found that the mineral oil maintained a uniform temperature along and within the cells of the batteries compared to natural air convection cooling.

c. *Compatibility with Equipment:* Newtonian fluids frequently exhibit compatibility with an extensive array of heat transfer equipment, encompassing heat exchangers, boilers, and piping systems. This inherent versatility renders them a flexible and adaptable option for a multitude of heat transfer applications.

vi. Garrett et al.[17] compared water, carbon dioxide, and helium as coolants in a nuclear reactor model, finding that water could maintain the fusion reactor temperature better than carbon dioxide and helium.

vii. Qin et al.[18] used silicone oil in a model to measure the heat dissipation of light-emitting diodes (LEDs) by submerging a LED in the oil. They chose silicone oil because of its good electrical heat dissipation and high heat capacity, causing it to avoid catching fire easily.

viii. Velasco et al. [19] experimented with the performance of a CO2 water-to-water heat pump and a water storage tank for domestic hot water (DHW) production to increase water temperature distribution. At high water flow rates at the gas cooler it reduced the systems coefficient of performance (COP) due to a reduction of water temperature at the top of the storage tank, reduction of the COP of the CO2 heat pump, increasing the use of the compressor to get the water at the top of the tank to the desired temperature.

2.2.2. Disadvantages

a. *Susceptibility to Fouling:* Newtonian fluids may exhibit susceptibility to fouling, characterized by the accumulation of deposits on the heat transfer equipment's surface. Such fouling can result in a diminished efficiency of heat transfer and an escalation in maintenance expenditures.

i. Liu et al.[20] investigated the use of glycol as an antifreeze in cooling tower's solar generation systems, as they are sensitive to freezing in winter and affect the solar system's performance. The glycol was added to the water of the cooling tower, which decreased the heat transfer efficiency of the tower, thus rendering it unsuitable for this application.

b. *Limited Temperature Range:* Certain Newtonian fluids, including water and various oils, possess a restricted operational temperature range. For instance, water's boiling point at 100°C can impose limitations on its suitability for high-temperature applications.

ii. Fernández et al.[21] evaluated the replacement of mineral oil as the liquid insulation in power transformers with vegetable-based and silicone-based dielectric oils. They described the harmful effects of mineral oil, such as being non-biodegradable and a fire hazard. They found that using vegetable-based dielectric oils was a better alternative due to their high flash points.

c. *Limited Stability:* Certain Newtonian fluids may deteriorate or degrade with the passage of time, especially when subjected to elevated temperatures or harsh environmental conditions. Such degradation can curtail their serviceable lifespan, resulting in the need for more frequent replacements or maintenance procedures.

iii. Vignarooban et al.[22] discusses the effect of different HTF, such as air, water/steam, thermal oils, organic fluids, molten salts, and liquid metals in CSP systems. They found molten salts most advantageous due to their extremely high boiling points. Consequently, molten salt proposed dangers due to its high-corrosive nature with the pipes and containers of CSP systems made of metal alloys.

iv. Soni et al.[23] discuss the disadvantages of using mineral oil as transformer oil. It is considered an environmental hazard in spillage, limited stock, and flammability, which has caused explosions in mineral-based transformers.

d. *Scarcity:* Availability of certain Newtonian fluids varies globally, creating the need to explore and research substitute fluids for applications where these Newtonian fluids are traditionally used.

v. Du Plessis[24] describes water scarcity in water-stressed areas, deducing that industrial applications are responsible for the degradation of water around the globe. Finding alternatives for water in industries, such as heat transfer applications, can be more helpful to the environment.

3. COMPARISON OF LIQUID COOLING VS AIR COOLING IN ELECTRONICS

Inadequate heat dissipation can occur when the thermal design of any electronic device is insufficient or when the cooling system is not properly sized for the heat load generated by the components. Liquid and air cooling provide a thermal control that allows the component to maintain a temperature at its functional and allowable limits. Table 3 showcases the comparison between liquid and air cooling of the electronics.

TABLE 3: Liquid Cooling and Air-Cooling Issues

ISSUE	Liquid Cooling	Air Cooling
Heat Dissipation	More effective due to high thermal conductivity leading to lower temperatures and improved performance of electronics. i. Zhang et al. [25] discusses use of ethylene glycol in liquid flow cooling system to improve the uniform temperature distribution of battery packs. They chose aluminum for their design, which improved the cooling performance and allowed maintaining a stable temperature with the battery pack. This shows how compatible materials can optimize liquid cooling. ii. Wang et al. [26] proposed a thermal management system for a lithium-ion battery pack to prevent overheating, using a phase change material (PCM) that was cooled by a water liquid cooler attachment. They found that the PCM could absorb a significant amount of heat from the battery, and the water cooler could remove the excess heat from the PCM to maintain its effectiveness. This resulted in a system that could effectively regulate the battery pack's temperature.	Less effective in electronics i. Zhang. et al. [27] conducted an experimental investigation on the limits of air cooling in high-power dissipation packages and suggested liquid cooling as an alternative. They tested air and deionized water and found that the liquid cooling method can go beyond air cooling in heat dissipation due to the high thermal performance of liquid cooling.
Noise	Less noise due to the use of pump to circulate the coolant, hence quicker than a fan. i. Khalaj et al. [28] compared the use of air-cooling and liquid-cooling methods in data centers, listing the advantages and disadvantages of each. The paper states that liquid cooling has noise reduction, higher cooling capacity, and lower power consumption than air cooling. However, potential leaks and corrosion risks require more planning than in an air-cooling system.	Generates more noise due to fans needing to move air across the heat sin or radiator. i. Aglawe. et al. [29] details the functionality of air cooling as it is a system that requires high circulation speeds to properly cool electronics, resulting in undesirable high noise and vibrations.
Maintenance	Requires more maintenance as the coolant needs periodic replacement and system needs checks for leaks and other issues. i. Kheirabadi et al. [30] reviewed the application of liquid and air cooling in server electronics and	Require little maintenance beyond cleaning the dust from the fans and heat sink. i. Lu. et al. [31] present an investigation of thermal management improvement for EV batteries using forced air cooling. They

	determined that air cooling was the least effective cooling strategy due to heat transfer and cost. This is due to the thermophysical properties of air, as it yields low heat transfer compared to liquid but is more desirable than liquid cooling when considering maintenance and installation.	chose air cooling because of its simple layout. They compared forced air convection to natural convention, showing that forced air convection is the most effective in reducing temperature rise in the battery. A dependency relationship was found between the velocity and direction of the airflow and temperature reduction.
Cost	More expensive due to due to the additional hardware pump, radiator, tubing, and coolant requirements. i. Zimmermann et al. [32] reported on the cooling of the supercomputer Aquasar, using both liquid and air cooling. In this application, they used deionized hot water [up to 60°C] as the coolant and repurposed it for space heating, creating direct energy reuse. Their observations showed that the hot water-cooling system has a higher heat transfer coefficient than conventional air-cooling systems and greater energy savings due to the reuse of hot water.	Less expensive due to typical requirement of a heat sink and fan i. Blinov et al. [33] described single-phase liquid cooling as a closed loop that transfers heat from a heat source to a heat exchanger. They compared it to a two-phase liquid cooling system, which uses the evaporated vapor of the coolant fluid to absorb heat from the electronic devices. It then condenses into a liquid and returns to the heat source in a closed loop. They determined that while two-phase liquid cooling can have better thermal management in high-power electronic applications, they are unpredictable and more costly than the single-phase method.
Space	Requires more space due to the additional hardware and components. This can be an issue in small form factor or compact systems where space is limited. i. In electric vehicles (EV), the cooling of the battery pack has been experimented on using air cooling, non-direct liquid cooling, direct liquid cooling, and indirect-contact liquid cooling. Saw. et al. [34] determined that using air as a heat transfer medium is not as effective as using water or ethylene glycol in non-direct liquid cooling for EV battery packs because of the limitations due to the dangers of inhomogeneous temperature distribution within the batteries For indirect liquid cooling, the battery pack has an attachment of cooled plates surrounding it to extract heat from the battery and have uniform temperature distribution. The disadvantage to this type of liquid cooling is that it increases the weight of the battery and cost due to the addition of components.	Requires relatively less space. i. Zu et al. [35] conducted research on heat dissipation of battery packs to reduce the temperature rise by using forced air cooling. To test its performance, they developed and compared a longitudinal battery pack, a horizontal battery pack, and a double U-type duct model for a battery pack with a bottom mode. Their results showed that increasing air velocity could reduce the temperature rise in the battery pack, increasing heat dissipation. By choosing air cooling for the battery pack, they could test different placements and sizes for the battery model.
Compressibility	a. Thermal Effect: Liquids are typically considered to be incompressible. In liquid cooling systems, maintaining a consistent temperature is crucial for effective heat dissipation. b. Pressure Variation: Rapid changes in pressure, particularly in systems with high compressibility, can lead to pressure spikes or fluctuations. These variations may require pressure relief mechanisms or the use of expansion tanks to maintain system stability. c. Energy Consumption: Understanding how the changes in pressure and volume affect the cooling liquid is essential for designing efficient and reliable liquid cooling systems, whether they are used in	a. Thermal Effect: As air is compressed, its density increases, leading to higher thermal capacity which is advantageous for applications requiring rapid cooling. b. Pressure Variation: Changes in air pressure due to compression can lead to pressure drops, which impact airflow and cooling efficiency. c. Energy Consumption: Higher compressibility can lead to improved cooling performance but may require more energy to achieve and maintain the desired conditions. d. Temperature Changes: Compressing air leads to changes in temperature due to the

	industrial processes, electronics cooling, or other applications. d. Temperature Changes: Changes in pressure can lead to temperature variations in the liquid due to adiabatic heating or cooling. e. Safety: High-pressure conditions resulting from liquid compression require safety precautions. Once should ensure that the system components can withstand the pressure, and relief valves or safety mechanisms may be necessary to prevent over-pressurization.	adiabatic heating or cooling effect. Understanding these temperature variations is critical for designing effective air-cooling systems, especially in applications where precise temperature control is necessary. e. Safety: High Pressure conditions resulting from air compression require careful considerations of safety measures, including appropriate selection of materials and components to withstand the increased pressure.

3.1. Applications of Heat Transfer

a. **Heat exchanger:** This apparatus facilitates the transfer of heat between two fluids while ensuring they remain isolated in separate chambers, preventing any mixing. Heat exchangers come in diverse forms, including shell and tube, spiral, loop, fin and flat, among others. One notable industrial application for heat exchangers is within HVAC (Heating, Ventilation, and Air Conditioning) systems.

i. Jouhara et al.[36] investigated water as a working fluid in a wraparound loop heat pipe (WLHP) heat exchanger in HVAC systems. The results showed that the thermal performance of water as the working fluid was higher than with conventional HVAC systems that use refrigerants.

ii. Missaoui et al.[37] investigated the helical coil heat exchanger with water as the working fluid, for domestic refrigeration and water heating, and determined the variable pitch coils on the heat exchanger improved the overall heat transfer coefficient by 36.48% when compared to a normal coil. They found that the design of the helical coil directly impacts the water temperature distribution.

b. **Mixing tanks:** These are mechanically stirred containers designed to uphold a consistent temperature. When dissimilarly heated fluids are combined within the mixing tank, the agitation process facilitates heat transfer, ensuring an even distribution of heat throughout the mixture. Newtonian fluids excel in this context due to their ability to maintain viscosity despite variations in mixing speed within the tank. This technology finds valuable application in the food and beverage industry.

iii. Śmieja et al.[38] describes the pasteurization applications of milk, a Newtonian fluid that has to be held at a constant temperature for a set period to ensure the product's shelf life is not reduced due to bacteria buildup. Agitated systems use water heated by an external source as a heat transfer medium to distribute the heat evenly throughout the milk.

c. **Fluidized bed reactors (FBR):** These systems harness the thermal properties of Newtonian fluids like air and steam to optimize heat transfer between a fluid and a solid medium. The process involves the passage of the fluid through a high-velocity flow bed of solid particles, effectively heating or cooling the solid material.

iv. The industrial application in chemical processing has been explored by Li et al.[39], who utilized the steam generated using distilled water to fluidize the catalyst of a fluidized bed reactor in a catalytic cracking of cottonseed oil. The produced fluid was liquid rich in gasoline and diesel. The role of distilled water in this experiment was to facilitate the heat transfer of steam and temperature control to the fluidized bed reactor.

d. **Consumer Consumption Applications:** They make use of heat transfer with Newtonian fluids, such as the following:

v. Water heaters: Taira [40] proposed using CO2 to replace refrigerants in water heaters in residential homes. They found that using CO2 could reduce the power output from their home while still being capable of heating water to 90° C. The heat transfer of the CO2 and other refrigerants were comparable, with CO2 having greater benefits in reducing greenhouse gases. Ihiourne et al.[41] conducted an experimental study using a water-to-air heat exchanger to replace the use of a boiler in a greenhouse, resulting in lower CO2 emissions of 142g/day compared to 41,000 g/day, along with an improvement in the greenhouse's internal air temperature at night of 4°C to 5°C.

vi. Electronics cooling: In our electronic devices, such as mobile phones, laptop computers, and tablets, heat transfer is used to cool the devices as it is essential to maintain a certain operating temperature. Alnaimat [42] experimented on the use of air-water mist evaporating cooling in a heat sink compared to air cooling, finding an increase of 158% in heat transfer when using the mist at 1-6% in the heat sink. Heat sinks such as these can be used in microelectronic cooling systems.

e. **Competition for Newtonian Fluids:** Non-Newtonian Power-Law fluids, also known as shear-thinning fluids, exhibit viscosity that varies with shear rate and they follow the Power-Law model, where viscosity (η) is related to shear rate (γ) by the equation: η = K * γ^n , where K is the consistency coefficient, and n is the flow behavior index. The value of n determines the degree of shear-thinning: n < 1 indicates significant shear-thinning behavior. They are widely used in a variety of industries [where heat transfer capabilities of power-law fluids play a vital role], like food processing [ketchup, mayonnaise, etc.], oil and gas industry [Crude oil, drilling mud, hydraulic fracturing fluid, etc.], polymer processing, pharmaceuticals, wastewater treatment [sludge] and nanofluids used for electronic cooling.

4. CONCLUSION

In summary, the examination of Newtonian fluids' role in heat transfer applications has revealed a spectrum of advantages and drawbacks. Newtonian fluids play a pivotal role in the realm of heat transfer, offering a multitude of advantages that significantly enhance their suitability for various applications. These fluids exhibit desirable attributes such as predictable flow behaviour, low viscosity, ease of handling, exceptional thermal stability, and compatibility with equipment, rendering them an appealing choice for numerous heat transfer scenarios. Predictable flow behaviour of Newtonian fluids simplifies their modelling and analysis, allowing for precise predictions of flow rates, pressure drops, and heat transfer rates. These fluids efficiently transfer heat due to their stable viscosity, which makes them well-suited for applications where precise control of temperature and heat dissipation is critical. The high thermal stability of Newtonian fluids allows them to operate at elevated temperatures without breaking down or degrading, which leads to their compatibility with a wide range of heat transfer equipment, including heat exchangers, boilers, and piping systems. Newtonian fluids are generally safe to handle, and their properties are well-understood, minimizing risks associated with heat transfer processes. The reliable nature of Newtonian fluids simplifies the design and modelling of heat transfer systems. These advantages collectively underscore the significance of Newtonian fluids in optimizing heat transfer efficiency and effectiveness across a myriad of industrial and consumer applications. As technology advances and the demand for more efficient and sustainable heat transfer solutions continues to grow, Newtonian fluids are expected to maintain their prominent role as reliable and versatile heat transfer media.

Nonetheless, it is essential to acknowledge certain limitations, including their susceptibility to high shear stress and the potential for fouling and corrosion. The selection of a fluid for a specific heat transfer application necessitates a nuanced consideration of various factors, encompassing the unique requisites of the application, the fluid's inherent properties, and any potential constraints imposed by the fluid's characteristics. Future research endeavours hold the promise of deeper insights into the properties and behaviours of Newtonian fluids in the realm of heat transfer, thereby paving the way for the development of more efficient and effective heat transfer systems.

References

[1] Franco, J.M. and Partal, P., 2010. The newtonian fluid. Rheology, 1, pp.74-95.

[2] Yanniotis, S., Skaltsi, S. and Karaburnioti, S., 2006. Effect of moisture content on the viscosity of honey at different temperatures. Journal of Food Engineering, 72(4), pp.372-377.

[3] Prabhanjan, D.G., Raghavan, G.S.V. and Rennie, T.J., 2002. Comparison of heat transfer rates between a straight tube heat exchanger and a helically coiled heat exchanger. International communications in heat and mass transfer, 29(2), pp.185-191.

[4] Rudresha, S., Babu, E.R. and Thejaraju, R., 2023. Experimental Investigation and Influence of Filling Ratio on

Heat Transfer Performance of a Pulsating Heat Pipe. Thermal Science and Engineering Progress, p.101649.

[5] Vlasogiannis, P., Karagiannis, G., Argyropoulos, P. and Bontozoglou, V., 2002. Air–water two-phase flow and heat transfer in a plate heat exchanger. International Journal of Multiphase Flow, 28(5), pp.757-772.

[6] Shen, Z., Wang, F., Wang, Z. and Li, J., 2021. A critical review of plant-based insulating fluids for transformer: 30-year development. Renewable and Sustainable Energy Reviews, 141, p.110783.

[7] Wurzel, K.A., Wexler, P. (2005) "Glycerol," in Encyclopedia of toxicology. 2nd edn. Oxford, UK: Elsevier, pp. 449–451.

[8] Zhang, D., Wang, Y., Yuan, X., Yue, X., Liu, J. and Liu, W., 2023. Freezing modes of water droplet on cold plate surface under forced convection. Applied Thermal Engineering, p.120025. [8] Bilgen, E. and Oztop, H., 2005. Natural convection heat transfer in partially open inclined square cavities. International Journal of Heat and Mass Transfer, 48(8), pp.1470-1479.

[9] Etemoglu, A.B., 2007. A brief survey and economical analysis of air cooling for electronic equipments. International communications in heat and mass transfer, 34(1), pp.103-113.

[10] Tie, P., Li, Q. and Xuan, Y., 2011. Investigation on the submerged liquid jet arrays impingement cooling. Applied thermal engineering, 31(14-15), pp.2757-2763.

[11] He, W., Zhang, J., Li, H., Liu, S., Wang, Y., Lv, B. and Wei, J., 2022. Optimal thermal management of server cooling system based cooling tower under different ambient temperatures. Applied Thermal Engineering, 207, p.118176.

[12] Good, P., Zanganeh, G., Ambrosetti, G., Barbato, M.C., Pedretti, A. and Steinfeld, A., 2014. Towards a commercial parabolic trough CSP system using air as heat transfer fluid. Energy Procedia, 49, pp.381-385.

[13] Bonk, A., Sau, S., Uranga, N., Hernaiz, M. and Bauer, T., 2018. Advanced heat transfer fluids for direct molten salt line-focusing CSP plants. Progress in Energy and Combustion Science, 67, pp.69-87.

[14] Jithin, K.V. and Rajesh, P.K., 2022. Numerical analysis of single-phase liquid immersion cooling for lithium-ion battery thermal management using different dielectric fluids. International Journal of Heat and Mass Transfer, 188, p.122608.

[15] Li, H. and Liu, J., 2011. Revolutionizing heat transport enhancement with liquid metals: Proposal of a new industry of water-free heat exchangers. Frontiers in Energy, 5, pp.20-42.

[16] Trimbake, A., Singh, C.P. and Krishnan, S., 2022. Mineral oil immersion cooling of lithium-ion batteries: an experimental investigation. Journal of Electrochemical Energy Conversion and Storage, 19(2).

[17] Garrett, G. and Watson, J., 2019. Comparison of water, helium, and carbon dioxide as coolants for next generation power plants using TRACE. Annals of Nuclear Energy, 126, pp.292-302.

[18] Qin, Y., Lin, D. and Hui, S.Y., 2009. A simple method for comparative study on the thermal performance of LEDs and fluorescent lamps. IEEE Transactions on Power Electronics, 24(7), pp.1811-1818.

[19] Velasco, F.J.S., Haddouche, M.R., Illán-Gómez, F. and Garcia-Cascales, J.R., 2022. Experimental characterization of the coupling and heating performance of a CO2 water-to-water heat pump and a water storage tank for domestic hot water production system. Energy and Buildings, 265, p.112085.

[20] Liu, J., Zhang, L., Chen, Y., Yin, Z., Shen, Y. and Sun, Y., 2022. Study of the Technologies for Freeze Protection of Cooling Towers in the Solar System. Energies, 15(24), p.9640.

[21] Fernández, I., Ortiz, A., Delgado, F., Renedo, C. and Perez, S., 2013. Comparative evaluation of alternative fluids for power transformers. Electric Power Systems Research, 98, pp.58-69.

[22] Vignarooban, K., Xu, X., Arvay, A., Hsu, K. and Kannan, A.M., 2015. Heat transfer fluids for concentrating solar power systems–a review. Applied Energy, 146, pp.383-396.

[23] Soni, R. and Mehta, B., 2023. A review on transformer condition monitoring with critical investigation of mineral oil and alternate dielectric fluids. Electric Power Systems Research, 214, p.108954.

[24] Du Plessis, A. and du Plessis, A., 2019. Current and future water scarcity and stress. Water as an inescapable risk: current global water availability, quality and risks with a specific focus on South Africa, pp.13-25.

[25] Zhang, T., Gao, Q., Wang, G., Gu, Y., Wang, Y., Bao, W. and Zhang, D., 2017. Investigation on the promotion of temperature uniformity for the designed battery pack with liquid flow in cooling process. Applied Thermal Engineering, 116, pp.655-662.

[26] Wang, R., Liang, Z., Souri, M., Esfahani, M.N. and Jabbari, M., 2022. Numerical analysis of lithium-ion battery thermal management system using phase change material assisted by liquid cooling method. International Journal of Heat and Mass Transfer, 183, p.122095.

[27] Zhang, H.Y., Pinjala, D. and Teo, P.S., 2003, December. Thermal management of high power dissipation electronic packages: From air cooling to liquid cooling. In Proceedings of the 5th Electronics Packaging Technology Conference (EPTC 2003) (pp. 620-625). IEEE.

[28] Khalaj, A.H. and Halgamuge, S.K., 2017. A Review on efficient thermal management of air-and liquid-cooled data centers: From chip to the cooling system. Applied energy, 205, pp.1165-1188.

[29] Aglawe, K.R., Yadav, R.K. and Thool, S.B., 2022. Current Technologies on Electronics Cooling and Scope for Further Improvement: A Typical Review. In Proceedings of the International Conference on Industrial and Manufacturing Systems (CIMS-2020) Optimization in Industrial and Manufacturing Systems and Applications (pp. 389-408). Springer International Publishing.

[30] Kheirabadi, A.C. and Groulx, D., 2016. Cooling of server electronics: A design review of existing technology. Applied Thermal Engineering, 105, pp.622-638.

[31] Lu, Z., Meng, X.Z., Wei, L.C., Hu, W.Y., Zhang, L.Y. and Jin, L.W., 2016. Thermal management of densely-packed EV battery with forced air cooling strategies. Energy Procedia, 88, pp.682-688.

[32] Zimmermann, S., Meijer, I., Tiwari, M.K., Paredes, S., Michel, B. and Poulikakos, D., 2012. Aquasar: A hot water cooled data center with direct energy reuse. Energy, 43(1), pp.237-245.

[33] Blinov, A., Vinnikov, D. and Lehtla, T., 2011. Cooling Methods for High-Power Electronic Systems. Power & Electrical Engineering, (29).

[34] Saw, L.H., Tay, A.A.O. and Zhang, L.W., 2015, March. Thermal management of lithium-ion battery pack with liquid cooling. In 2015 31st thermal measurement, modeling & management symposium (SEMI-THERM) (pp. 298-302). IEEE.

[35] Xu, X.M. and He, R., 2013. Research on the heat dissipation performance of battery pack based on forced air cooling. Journal of Power Sources, 240, pp.33-41.

[36] Jouhara, H. and Meskimmon, R., 2018. An investigation into the use of water as a working fluid in wraparound loop heat pipe heat exchanger for applications in energy efficient HVAC systems. Energy, 156, pp.597-605.

[37] Missaoui, S., Driss, Z., Slama, R.B. and Chaouachi, B., 2022. Experimental and numerical analysis of a helical coil heat exchanger for domestic refrigerator and water heating. International Journal of Refrigeration, 133, pp.276-288.

[38] Śmieja, M., Bogdański, P. and Czerwiński, K., 2018, October. Modelling of pasteurization process line in dairy industry in context of process control. In AIP Conference Proceedings (Vol. 2029, No. 1, p. 020074). AIP Publishing LLC.

[39] Li, H., Shen, B., Kabalu, J.C. and Nchare, M., 2009. Enhancing the production of biofuels from cottonseed oil by fixed- fluidized bed catalytic cracking. Renewable Energy, 34(4), pp.1033-1039.

[40] Taira, S., Nakayama, H. and Kumakura, E., 2010, February. The development of heat pump water heaters using CO2 refrigerant. In Proceedings of the 2010 International Symposium on Next-generation Air Conditioning and Refrigeration Technology.

[41] Ihoume, I., Tadili, R., Arbaoui, N., Bazgaou, A., Idrissi, A., Benchrifa, M. and Fatnassi, H., 2022. Performance study of a sustainable solar heating system based on a copper coil water to air heat exchanger for greenhouse heating. Solar Energy, 232, pp.128-138.

[42] Alnaimat, F., 2022. Heat transfer analysis of air-mist evaporative cooling in heat sink. International Journal of Thermofluids, 14, p.100145.