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A Study of the Application of Newtonian Fluids in Heat Transfer

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Abstract **-** This paper reviews the experimental and numerical findings on the impact of Newtonian fluids in heat transfer. Newtonian fluids are characterized by a constant viscosity that does not depend on the shear rate. They are commonly used in heat transfer applications because they exhibit predictable and stable flow behaviour, making them easier to model and analyze. A popular application of Newtonian fluids in heat transfer is electronic cooling. The heat generated by electronic components can be dissipated by circulating the Newtonian fluids, such as water or oil, through a cooling system. Newtonian fluids are also used as heat transfer fluid in heat exchangers, which use a series of tubes to transfer heat between two fluids separated by a conductive barrier. Newtonian fluids are also used for industrial processes like mixing and agitation in mixing tanks and reactors to transfer heat between different phases or to maintain a consistent temperature within the vessel. The predictable behaviour and low viscosity make Newtonian fluids efficient in heat transfer across the barrier. This study explores the use of Newtonian fluids in heat transfer applications in both industrial and consumer settings.

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

1. Introduction

Newtonian fluids with heat transfer properties are widely used in various engineering and industrial applications, and their popularity is increasing due to their unique properties and ease of use. These fluids are characterized by their ability to transfer heat efficiently and exhibit the properties of a Newtonian fluid, such as a constant viscosity under different shear rates. Franco et al.[1] considers Newton's law of Viscosity:

$$\tau \quad \mu \frac{du}{dy} \tag{1}$$

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. The popular fluids meeting this criterion are water, air, oil, gasoline, alcohol, glycerol, organic solvents, motor oil, and honey. These fluids have their viscosity decreasing with increasing temperatures, as the molecules have greater kinetic energy, leading to more frequent collisions between them, resulting in lower flow resistance and viscosity. The temperature dependence of viscosity is best described by the Arrhenius equation:

$$\mu \quad \mu_0 exp \frac{E_A}{RT}, \tag{2}$$

where viscosity μ is measured in pascals/sec, μ_o 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 is the most widely used Newtonian fluid due to its high thermal conductivity and specific heat capacity, making it an efficient heat transfer medium. It is also readily available and relatively inexpensive compared to other heat transfer fluids. Other popular Newtonian fluids with heat transfer properties include oils, glycols, and refrigerants. These fluids are used in various applications, such as HVAC, refrigeration, power plants, and chemical processes. They are also used in heat exchangers, transferring heat from one fluid to another. 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 is not as efficient as a heat transfer fluid as liquids, due to its lower thermal conductivity and specific heat capacity. However, it is still commonly used in various heat transfer applications due to its easy availability, low cost, and ease of use in terms of safety considerations. In HVAC systems, air is used as the primary heat transfer medium to provide thermal comfort to occupants. The air is heated or cooled by passing through heating or cooling coils and then distributed throughout the building using ductwork. The air's ability to absorb and release heat is important to the system's efficiency and effectiveness. In refrigeration systems, air is used as a secondary heat transfer medium to remove heat from the refrigerant. The refrigerant is cooled by passing over a coil that is cooled by air, and the cooled refrigerant is then used to provide cooling. In this case, the air's ability to remove heat from the coil is important for the system's efficiency. In cooling systems, air is the primary heat transfer medium to remove heat from equipment or processes. Air is typically blown over a surface to remove heat through convection. The air's ability to remove heat is essential in maintaining the proper temperature of a variety of industrial equipment or process. 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 is commonly used as a coolant in various applications, particularly in high-performance engines and machinery with a high heat load. Oil has several advantages as a coolant, including its ability to absorb and transfer heat efficiently, its lubrication properties, and its ability to resist thermal degradation 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 change their viscosity with temperature and not with shear rate, decreasing the friction and wear of the device they are using. 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).

Heat transfer in Newtonian fluids occurs through conduction, convection, and radiation. The heat transfer rate depends on the fluid's thermal conductivity, viscosity, density, specific heat capacity, emissivity, and velocity, as well as the geometry of the system and the temperature difference between the fluid and its surroundings. 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.

Overall, the popularity of Newtonian fluids with heat transfer properties is driven by their ability to efficiently transfer heat, ease of use, and widespread availability. As new technologies emerge and the demand for more efficient and sustainable heat transfer solutions increases, the use of these fluids is expected to continue to grow.

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	i. Low viscosity ii. High chance of corroding alloys iii. High freezing point iv. High cost	i. Thermal Energy Storage

2.2.1 Advantages

a. *Predictable Flow Behavior:* Newtonian fluids have a predictable and consistent flow behavior, which makes them easy to model and analyze in heat transfer applications. This allows engineers to accurately predict flow rates, pressure drops, and heat transfer rates, hence, simplifying 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*: Some Newtonian fluids, such as mineral oils, have high thermal stability and can operate at high temperatures without breaking down or degrading. This makes them suitable for high-temperature applications like power generation or 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 are often compatible with a wide range of heat transfer equipment, such as heat exchangers, boilers, and piping systems. This can make them a versatile choice for various 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 can be prone to fouling or the buildup of deposits on the surface of heat transfer equipment. This can reduce heat transfer efficiency and increase maintenance costs.

   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*: Some Newtonian fluids, such as water and oils, have a limited temperature range over which they can be used. For example, water has a boiling point of 100°C, which can limit its use in 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*: Some Newtonian fluids can degrade or break down over time, particularly when exposed to high temperatures or other harsh conditions. This can limit their useful life and require more frequent replacement or maintenance.

   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*: Some Newtonian fluids are not easily available throughout the globe for all applications. This leads to developing and researching replacement fluids for devices where Newtonian fluids are common.

   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.	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.

	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.	
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 sink 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 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.	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 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 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	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.

	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.	

3. Applications of Heat Transfer

a. **Heat exchanger**: It is a device that transfers heat from two fluids without allowing for the fluids to mix together, as they are in separate chambers. There are various types of heat exchangers, such as shell and tube, spiral, loop, fin and flat, and many others. The industrial application is HVAC 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 that the variable pitch coils on the heat exchanger improved the overall heat transfer coefficient by 36.48% compared to a normal coil. They found that the design of the helical coil directly impacts the water temperature distribution.

b. **Mixing tanks**: They are mechanically agitated vessels that maintain a constant temperature. When the fluids being mixed within the mixing tank are of different temperatures, heat transfer occurs as the agitation of the fluids causes a distribution of heat evenly throughout the mixture. Newtonian fluids are advantageous in this situation as they can maintain their viscosity when the mixing speed changes within the tank. It finds an 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)**: They use Newtonian fluids such as air and steam to enhance heat transfer between a fluid and a solid. The fluid is passed through a bed of solid particles at a high velocity, heating or cooling the solid.

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 CO_2 to replace refrigerants in water heaters in residential homes. They found that using CO_2 could reduce the power output from their home while still being capable of heating water to 90° C. The heat transfer of the CO_2 and other refrigerants were comparable, with CO_2 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 CO_2 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.

4. Conclusion

In conclusion, the study of the application of Newtonian fluids in heat transfer has shown that these fluids have several advantages and disadvantages when used in various heat transfer applications. The predictable flow behaviour, low viscosity, ease of handling, high thermal stability, and compatibility with equipment make Newtonian fluids an attractive choice for many heat transfer applications. However, some of the disadvantages of Newtonian fluids, such as their limited ability to handle high shear stress and their potential for fouling and corrosion, must also be considered. Overall, the choice of fluid for a particular heat transfer application will depend on several factors, including the specific requirements of the application, the fluid properties, and any potential limitations of the fluid. Further research can help to understand better the properties and behaviour of Newtonian fluids in heat transfer, leading to more efficient and effective heat transfer systems.

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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.