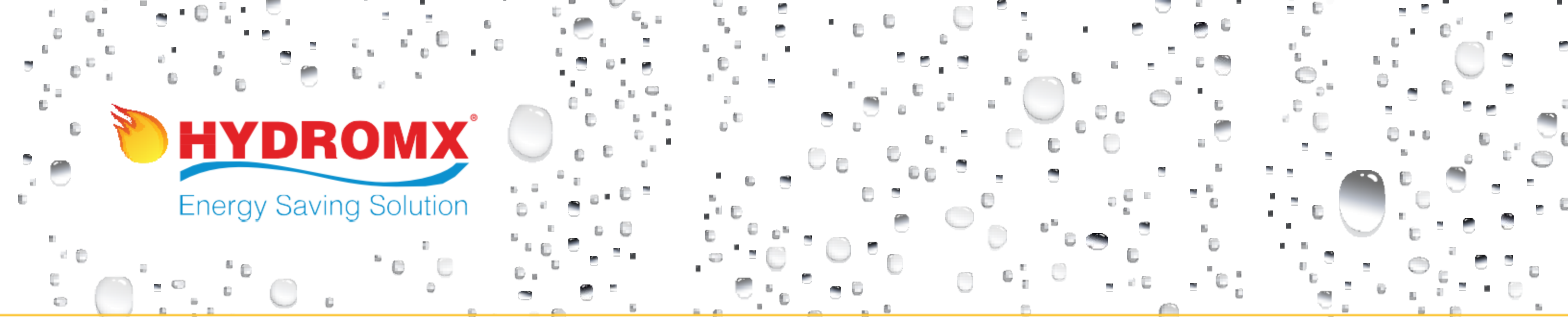

HYDROMX WHITE PAPER:

THE HYDRODYNAMICS OF NANOFLUIDS

INTRODUCTION

The goal of nanofluids is to achieve the highest possible thermal properties at the smallest possible ratio of nanoparticles to the base fluid through uniform dispersion and stable suspension of the nanoparticles. It is vital to understand how nanoparticles enhance energy transport in liquids to achieve this goal.

Thousands of research papers have been published showing nanofluids' thermal effectiveness to explain the mathematical mechanics of a working nanofluid. These papers illustrate the improved thermal performance of nanofluids over their base fluids.

WHY TRADITIONAL ENGINEERING EQUATIONS CAN'T PREDICT THE PERFORMANCE OF NANOFLUIDS

The essence of this document is to explain why it is not possible to use traditional, Newtonian-fluid formulas for nanofluids.

Inherently, nanofluids are non-Newtonian, presenting a paradigm shift that requires a new way of looking at nanofluids. Hence, standard thermal properties of materials, such as specific heat, cannot precisely quantify the impact of a nanofluid on their HVAC designs. This white paper is authored to answer more scientific questions about this non-traditional, energy-saving technology.

Furthermore, the engineering community at all levels needs a white paper that provides the standard thermal properties of materials, such as specific heat, to quantify the impact of a nanofluid on their HVAC designs precisely.

This document is written to explain why it's not possible to use existing formulas (which were designed based on 150-year-old knowledge for Newtonian fluids under laminar fluid flow conditions) and present the reason for a paradigm shift required to be able to comprehend working nanofluids.

THE TYPES OF FLUIDS

There are two types of fluids: Newtonian and non-Newtonian.

Today's traditional heat transfer fluids (water and glycol) are considered Newtonian fluids as they behave in a repeatable manner where their viscosity is constant and not dependent on stress. The relationship between shear stress and shear rate is linear. The coefficient of viscosity is constant.

In contrast, non-Newtonian fluids' behaviors cannot be explained under Newton's Law of Viscosity. Non-Newtonian fluids' viscosity changes under force (shear stress and shear rate). To better understand how non-Newtonian fluids behave, we need to study rheology and viscous behavior.

Rheology is the branch of physics that describes materials' deformation and flow behavior. Viscosity is the internal friction of a fluid.

All liquids are composed of molecules; dispersions also contain significantly larger particles. When put into motion, molecules and particles are forced to slide along each other. They develop a flow resistance caused by internal friction. Larger components present in a fluid are the reason for higher viscosity values.

If viscosity remains constant while the shear rate increases, a fluid is described as Newtonian. Non-Newtonian fluids, which do not exhibit this behavior, fall into two categories: shear thinning or shear thickening.

With shear-thinning materials, as the name suggests, viscosity decreases with increasing shear rate. As shear is applied, the material's structure breaks down, it flows more readily, and friction is reduced. Most fluids and semisolids, including nanofluids (like Hydromx), fall into this group.

Conversely, shear-thickening materials exhibit increased viscosities at increasing shear rates. The apparent viscosity of non-Newtonian fluids is not a material property (as is the case for Newtonian fluids).

In heat transfer applications, heat transfer coefficients and the Prandtl and Reynolds numbers depend upon the flow properties of the fluid, such as viscosity. With non-Newtonian nanofluids, the correct viscosity measurement method is "Apparent Viscosity," where the shear rate directly affects the viscosity.

The specific heat capacity partially determines the convective flow nature of the nanofluid. The value of the specific heat capacity is estimated using theoretical models assuming the nanoparticles and the base fluid at thermal equilibrium within the realm of Newtonian behavior of fluids.

To better visualize this, imagine the different sizes (and types) of piping a heat transfer fluid goes through in a building. Using all known theoretical models to precisely calculate the thermal enhancement of a nanofluid in the working system, unfortunately, collapses for non-Newtonian fluids..

TURBULENT FLOW

In real-world applications, heating or cooling processes operate under Forced Turbulent Flow conditions. This empirically creates a significant problem for the engineering community as the Forced Turbulent Flow's thermal and physical mechanisms have yet to be formulated, not even for Newtonian Fluids, due to the complexities of the fluid's behavior in any given system.

During Turbulent Flow, first micron-level, then nano-level, then atomic-level vortexes (eddies) are created. Eddies mainly occur vertical or opposite to the flow and hamper the thermal transfer in Newtonian fluids. With nanofluids, in contrast, such vortexes infinitely enhance the interaction between nanoparticles, which improves the fluid's mass thermal properties.

Compared to conventional solid-liquid suspensions for heat transfer intensifications, nanofluids having properly dispersed nanoparticles possess the following advantages:

- High specific surface area and therefore more heat transfer surface between particles and fluids.
- High dispersion stability with predominant Brownian motion of particles.
- Reduced pumping power compared to pure liquid to achieve equivalent heat transfer intensification.
- Reduced particle clogging as compared to conventional slurries, thus promoting system miniaturization.
- Adjustable properties, including thermal conductivity and surface wettability, by varying particle concentrations, suit different applications.

WHY ACADEMIC PAPERS ON NANOFLUIDS CONTRADICT EACH OTHER

Each academic researcher would have to write their thesis on their area of doctoral interest. A chemical engineer will look at nanofluids in terms of stability, pH, zeta potential, size, shape, material type etc. A physicist would focus on dimensionless numbers and their suitable formulations to explain the effects of nanofluids under certain strict assumptions.

But as stated above, in real-world applications, only turbulent flow conditions occur. All known formulae for thermal equations are developed for Newtonian fluids. In real-world nanofluid applications, none of these conditions exist!

The only methodology that remains to measure and verify the efficacy of a nanofluid in a real-world application is to compare two identical (or similar) before and after periods. Furthermore, this fact was also approved and recognized by the USGBC's official verdict upon the "Efficient Heat Transfer Fluids Product Category Rule," which stated that only "Exceptional Calculation Methodology" under ASHRAE 90.1 would have to be used for such fluids.

OTHER SCIENTIFIC SUPPORT FOR NANOFLUID THERMAL ENHANCEMENT

In the absence of precise formulas that explain the effectiveness of nanofluids as a heat transfer mechanism, the following explanations have been proposed:

Brownian Motion
Many researchers believe that there is an apparent enhancement of heat transfer due to the Brownian motion of nanoparticles. Their speculations rely on nanoparticles providing a larger surface area for molecular collisions. The higher momentum and higher surface exchange area of nanoparticles (higher mass concentrations compared to the host fluid molecules) are believed to carry and transfer thermal energy more efficiently at greater distances inside the base fluid before they release it in a colder region of the fluid (tiny packets of energy).

Interfacial Layer Theory (Kapitza resistance)

The Kapitza resistance is a thermal boundary resistance arising from thermal energy carrier scattering at an interface (scattering of phonons and electrons). The type of carrier scattered will depend on the materials governing the interfaces. In liquid-solid interfaces (e.g., nanoparticle-based fluid interfaces), the boundary resistance is believed to decrease; hence the overall thermal resistance of the system (e.g., a nanofluid in this case) is believed to reduce.

Aggregation and Diffusion

This suggests a formation of a linear assembly of nanoparticle chains upon their suspension in the base fluid. The occurrence of this chain assembly is speculated to provide a faster path for heat transfer through the nanofluid (more rapid heat diffusion).

Electrical Double Layer (EDL) Theory

This theory proposes an alteration of the strength of intermolecular interaction forces, which changes the mean free path of the nanoparticles and augments the heat transfer of molecules.

Flattening of Velocity Profile Due to Viscosity

This idea proposes that the viscosity change of nanofluids leads to a more uniform velocity profile for flows in pipes and ducts than the expected parabolic velocity profile (Poiseuille flow). The increased near-wall velocity is believed to increase the convective heat transfer coefficient observed in these applications.

Near Field Radiation

Some researchers suggest infrared radiation emission and absorption augmentation at the nanoscales (near field radiation). This enhances heat transfer between the heating surface and the nanoparticles, the base fluid molecules, and between the nanoparticles themselves by 2-3 times compared to the far-field radiation estimates.

Thermophoretic Forces

Thermophoretic forces on nanoparticles arise from temperature gradients in the fluid, causing the concentration of nanoparticles to change around heating and cooling sides relative to the mean value. The consequence of this nanoparticle redistribution is altering the heat transfer coefficient accordingly.

Shear-thinning behavior of flows

Some researchers proved that nanofluids exhibit non-Newtonian characteristics with shear thinning behavior. The viscosity is believed to reduce at the solid boundaries of a flowing nanofluid because the shear rate of the nanofluids increases along the walls. This promotes increased heat transfer between the wall and the liquid because the thermal boundary layer width is reduced. It also provides a beneficial lubrication effect.

Phonon Transfer

A few researchers suggested that nanofluids have an increased heat transfer rate due to specialized phonon and electron interaction and scattering at the nanoscales (ballistic heat transport).