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NANOFLUIDS, HEAT-TRANSFER EQUIPMENT AND PLAIN-VANILLA

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Recent advances in nanofluids research have demonstrated the potential for using nanofluids in heat-transfer equipment to enhance its efficiency and/or performance. Nanoparticle materials can be very inexpensive and the technology for producing nanofluids is mature. However, the commercial viability of nanofluids in heat-transfer equipment hinges on the application of high-quality nanofluid dispersions; i.e., ones in which the nanoparticles remain suspended indefinitely or quickly re-suspend upon agitation. In general, the nanofluid and the system design need to be robust enough to re-suspend nanoparticles upon equipment restart and cause no damage to the equipment if settling does occur during shutdown. To solve these problems, much more needs to be known about the physical chemistry of various nanoparticle materials and more applied research is required to predict how nanofluids interact with system components on a long-term basis. Consequently, if nanofluids are to be used on a large scale in heat-transfer equipment, significantly more research will be required to ensure system reliability.

KEY WORDS: *nanofluids, nanolubricants, equipment*

1. INTRODUCTION

For nearly 30 years, I have investigated and attempted to contribute to the advancement of the technology used to achieve system efficiency improvements via enhanced heat transfer. Therefore, you can imagine my disbelief when I found myself cursing my high-efficiency heat pump because of its repair cost, which was several times what I would have spent had it been a plain-vanilla heat pump; my payback vaporized in a single repair. This episode has not really shaken my belief in technology; rather, it has strengthened my advocacy for cost-effective technology. Choices between energy-efficient and low-efficient products should be no-brainers. High-efficiency products should be cost effective and reliable, in equal balance.

Nanoparticle materials can be very inexpensive and the technology for producing nanofluids is mature. The production of inks, paints, coatings, and suntan lotions is old enough to be a very competitive industry. Thus, nanofluids probably set the benchmark for cost-effective technologies. But can the same be said about nanofluids and reliability? The importance and the answer to this depend on the application. When inks, paints, coatings, and suntan lotions are no longer stable, the consequence may be very limited. However, the consequence of an unstable nanofluid for heat-transfer equipment may be quite severe. Consequently, if nanofluids are to be used on a large scale in heat-transfer equipment, significant research will be required to ensure system reliability.

2. RESEARCH NEEDS

For various applications, there may be good reason to use a nanofluid in heat-transfer equipment to improve its efficiency and/or performance. Some of these reasons, such as increased thermal conductivity, have been illustrated for general modes of heat transfer in Wen et al. (2009). Wang et al. (2008) discussed the potential benefit of nanofluids for applications such as transportation, electronics cooling, space exploration, national defense, and nuclear systems. Fox et al. (2011) showed the benefit of nanofluids as nanoparticle-enhanced ionic liquids (NEILs) for increasing the energy stored per volume in concentrated solar power units. Jwo et al. (2009) showed that the efficiency of a refrigerant system was improved by 4.4% by putting nanoparticles in the refrigerant lubricant; i.e., nanolubricant. My own work with nanolubricants shows that the boiling heat transfer of refrigerant/lubricants can be improved by as much as 113%, on average, by using a nanolubricant rather than the traditional chiller lubricant (Kedzierski, 2012). However, the point of this article is that the significant potential for refrigerators, chillers, and space exploration will remain in the laboratory if the nanofluid is not a good nanofluid.

Regardless of the application, a good, competitive nanofluid is one in which the nanoparticles remain suspended indefinitely or quickly re-suspend upon agitation. The ability of the nanofluid to maintain its stability in heat-transfer equipment will determine system reliability. Surfactants and/or functionalized nanoparticles may be the key to achieving stability of the nanoparticle suspension, but they add an additional level of complexity to its application, which is poorly understood.

If we knew everything about how nanoparticles in nanofluids physically and chemically behave in real systems, some of us might be driving around with nanoparticles in our car fluids or sitting in our backyards above nanofluids in our ground source heat pumps. That hasn't happened yet for potentially beneficial research applications, mainly because we have neither the basic nor the applied research to predict how nanofluids interact with system components on a long-term basis. For example, can filters that are rated to let nanoparticles pass do so long term or do the filters encourage agglomeration and eventually clog? How do we ensure that our surfactant does not react with any of the system components? If we are using a nanolubricant where the surfactant works perfectly fine, how do we ensure that it does its job in the presence of another fluid, such as a refrigerant? What happens to nanoparticles traveling past the blades of a centrifugal pump over time? Can NEILs be made thermally stable at elevated temperatures for an extended time and cause minimal erosion and corrosion of system components? In general, how long can we expect the nanofluid to remain stable and inert in heat-transfer equipment?

These are all engineering problems that can be solved once we have the basic and applied research to bring to bear. Test tube compatibility tests, centrifuge tests, system aging tests, and erosion/corrosion tests will contribute to this endeavor. In general, the nanofluid and the system design need to be robust enough to re-suspend nanoparticles upon equipment restart and cause no damage to the equipment if settling does occur during shutdown. To solve these problems, much more needs to be known about the physical chemistry of various nanoparticle materials in order to discourage agglomeration. For example, diamond nanoparticles are very tempting to use because of their very large thermal conductivity, but much research will be needed to devise surface engineering techniques to mitigate their propensity for coalescing. Also, surfactants must be developed that are inert with respect to heat exchanger materials and, in addition, remain associated with the nanoparticle rather than being coaxed away by other system materials. Special coatings covalently bonded to nanoparticles eliminate the need for surfactants and the problems associated with them. More of these coatings must be developed for more nanoparticles and more applications.

3. CONCLUSIONS

As engineers and scientists advance nanofluid technology, an important part of nanofluid research should be that we follow the spirit of the Hippocratic Oath and ensure that the nanoparticle first does no harm to the system. Concerted research will eventually lead to compatible and stable nanofluids that create the opportunity for more cost-effective, reliable, and high-efficiency products. If this is not presently the case for a particular application, design engineers should have patience and stick with the traditional, "plain-vanilla" fluid until the research scientists and engineers develop the compatible nanofluid for the application.

REFERENCES

Fox, E. B., Visser, A. E., Bridges, N., Gray, J. R., Garcia-Diaz, B., Maginn, E. J., and Khan, J. A., Report to DOE: Thermally-stable ionic liquid carriers for nanoparticle-based advanced heat transfer in concentrating solar energy applications, 3rd quarter FY11 progress report, *SRNL-STI-2011-00543*, Savannah River National Laboratory, Aiken, SC, 2011.

Jwo, C., Jenga, L., Teng, T., and Chang, H., Effects of nanolubricant on performance of hydrocarbon refrigerant system, *J. Vac. Sci. Technol. B*, vol. **27**, no. 3, pp. 1473–1477, 2009.

Kedzierski, M. A., R134a/Al_2O_3 Nanolubricant mixture boiling on a rectangular finned surface, *ASME J. Heat Transf.*, vol. **134**, no. 12, pp. 121501-1–121501-8, 2012.

Wang, X. Q. and Mujumdar, A. S., A review on nanofluids–Part II: Experiments and applications, *Braz. J. Chem. Eng.*, vol. **25**, no. 4, pp. 631–648, 2008.

Wen, D., Lin, G., Vafaei, S., and Zhang, K., Review of nanofluids for heat transfer applications, *Particuology*, vol. **7**, no. 2, pp. 141–150, 2009.