

TESTING OF WEAR AND EROSION EFFECTS OF NANOFLUIDS ON METALS: NEW INSTRUMENTS AND ASSESSMENT METHODOLOGIES

Gustavo J. Molina^{1*}, Fnu Aktaruzzaman², Kenshantis Martin², Valentin Soloiu³, Mosfequr Rahman¹
Dept. of Mechanical Engineering, Georgia Southern University, Statesboro, GA 30458, USA

1*corresponding author: gmolina@georgiasouthern.edu, Associate Professor.; 2 Graduate Student; 3 Professor

ABSTRACT

Nanofluids are enhanced alternatives to ordinary cooling fluids, because these nano-size-powder suspensions show superior heat transfer properties. But there is very little understanding of their wear, erosion and corrosion on surfaces. Because there are no standard tests or instruments for nanofluid tribological effects [2] the authors developed two test-rigs and tested multiple surface-change assessment techniques. Research is presented on a nanofluid (2%-alumina-nanopowder in water, and in water/ethylene glycol solutions) tested on specimens of typical heat-exchanger materials (aluminum and copper. The enhanced surface modifications (when same test is conducted with alumina-nanofluids as compared to the base fluids) were assessed by roughness measurements, by weighing of removed-material, and by optical-microscopy. The obtained results show the suitability of the new testing and assessment techniques and they suggest that nanofluids may lead to substantial erosion-corrosion effects.

NEW TEST INSTRUMENTS TO ASSESS TRIBOLOGICAL EFFECTS OF NANOFLUIDS

Previous research by the authors [1-2] showed that long test times and a wide range of fluid speeds were needed to investigate tribological effects of nanofluids on heat-exchanger materials (i.e., aluminum and copper); the authors first developed a new multiple-nozzle test-rig by jet-impingement shown in Figure 1. This instrument comprises eight nozzles of same dimension. On the lower jet-speed (3.5 m/s) side, each nozzle is fed by an independent pump. On the higher jet-speed (5 m/s to 35 m/s) side all nozzles are fed by a high-pressure multiple-stage centrifugal pump (maximum pressure head of 80m) and the fluid flow to each nozzle is independently controlled and measured by inline flow meters (0.2 to 2 gallon/minute for low-speed, and of 2 to 20 gallon/minute for high-speed jet setup). Tested fluid is recirculated and cooled to maintain test maximum temperature of 33C. Specimens of the heat-exchanger materials are square plates of 1inch by 1inch (25.4 mm by 25.4 mm). Further instrument specifications are presented in [3].

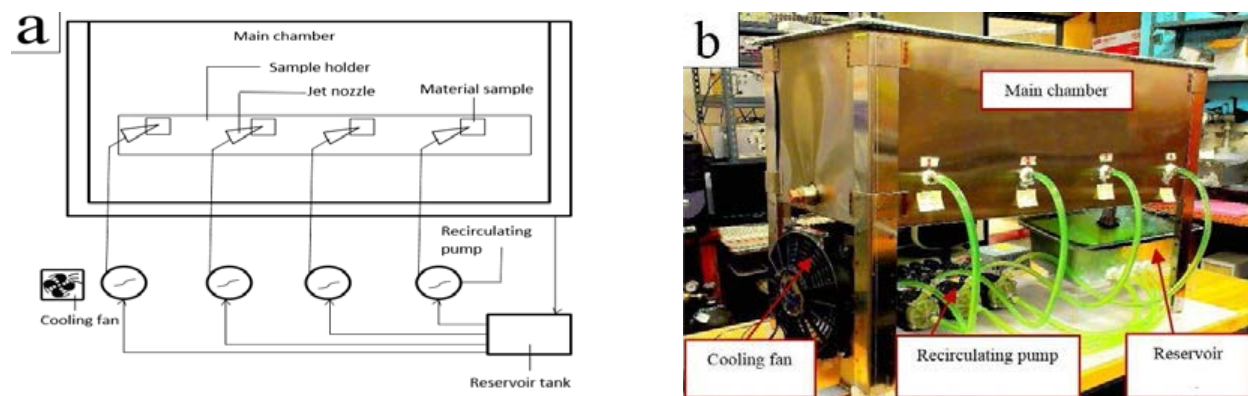


Figure 1. Multiple-nozzle variable-jet-speed impingement test-rig; (a) Schematics and (b) photograph

The author's also developed a new through-flow test-rig, shown in Figure 2, which resembles the typical fluid/material interaction in pipe-type heat-exchangers, because the specimen surfaces are placed parallel to the fluid-flow and inside a conduct. Figure 2 shows schematics and photograph of the through-flow test rig. The instrument is fed by a recirculation pump (of 1m/s-speed flow). Specimens are placed in a magazine, and they

can be inserted and removed independently allowing different test durations. Further instrument specifications are presented in [4].

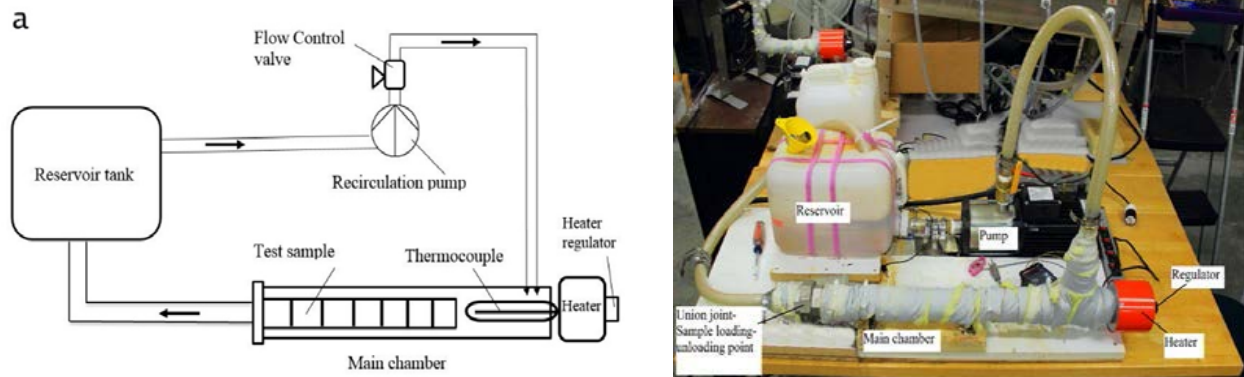


Figure 2. Through-flow test-rig for testing of nanofluid effects; (a) Schematics and (b) photograph

METHODOLOGY AND SELECTED EXPERIMENTAL RESULTS

Extensive results obtained with the jet-impingement and through-flow rigs were presented in [3,4]; selected results are presented here on the effects of distilled water, a mixture of 50% of ethylene glycol in water (as reference fluids), and their nanofluids of 2% vol. of added nano-alumina. Materials were 3003-T3 aluminum and copper 110 alloys (of Ra roughness not greater than 5 μ inch). Jet-impingement tests were carried out for 3, 7, 14, 28, 56, 112, 240, 312 and 408 hours for each of the fluids, and for sequence of 3 to 112 hours for through-flow tests. Wear was assessed by pre- and post-test roughness, optical microscopy, and weight-change measurements of the copper and aluminum specimens. Figure 3 and 4 present typical results from jet-impingement tests. For the used low jet-speed of 3.5m/s, significantly different roughness changes occurred for distilled water as compared to those from its nanofluid, and they are shown in 500X-magnification microscopy of Figure 3; while roughness changes were not significant for the solution of 50% ethylene glycol in water or for its nanofluid, 5,000X-magnification microscopy shown in Figure 4 (for nanofluid only) revealed that nascent surface changes had occurred: small pitting (existing before treatment and smaller than 8 micrometers) became larger after test (to 10-15 micrometers), which suggests start of erosion. No significant weight changes were observed. Figure 5 presents results with through-flow test-rig for aluminum and for distilled water and its nanofluid: roughness significantly changed, for both distilled water and for its nanofluid. Optical microscopy (500X magnification) in Figure 5 shows the surface modifications: treatments with nanofluids led to higher wear and erosion as compared to reference fluid, these surface modifications are in agreement with those of Figure 3 for jet-impingement. Similar results but of lower magnitude (i.e., lower wear and erosion for same test times) occurred for copper specimens when tested by same fluids and nanofluids; they are presented in [3,4].

CONCLUSIONS

The designed test-rigs were proved successful and employed surface assessment techniques showed appropriate to obtain results in reasonable test times: roughness measurements and optical microscopy before- and after-test yield significant results, in particular optical microscopy was able to assess the surface changes in all tested cases while weight-change measurement did not reflected the existent surface changes for the used test times (of up to 408 hours). The tribological effects of nanofluids where studied with both test-rigs for two materials (Al and Cu), and for water and water plus ethylene glycol as reference fluids, and their nanofluids of 2% added alumina nanopowder. Results suggest significant erosion and wear effects from nanofluid action, and larger as compared to those from the reference fluids: wear for ethylene glycol and its nanofluid were substantially lower than those for distiller water and its nanofluid: these differences suggest that corrosion effects are also important in the observed surface changes by nanofluids (because of the well-known anti-corrosion properties of ethylene glycol). This research also shows that the simpler test rig with jet-impingement action can yield similar surface changes and results than those from the more complex flow-through test-rig.

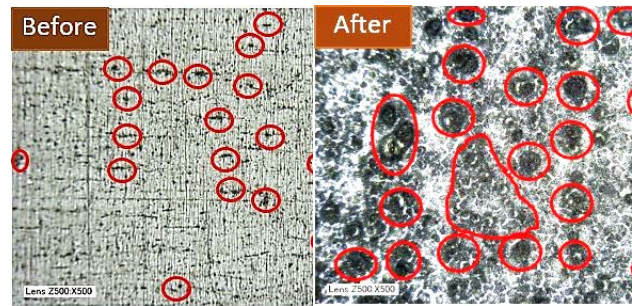
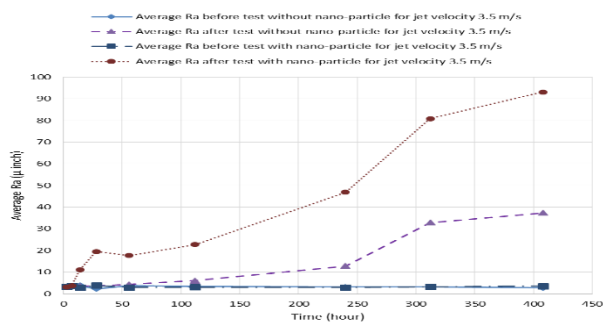


Figure 3. Jet-impingement tests: Ra roughness for 3003-T3 aluminum before and after 3, 7, 14, 28, 56, 112, 240, 312 and 408 hour-treatments with distilled water as reference fluid, and with its nanofluid of 2% nano-alumina and optical microscopy images (Magnif:500X) for 408 hour-test with nanofluid. Jet-speed speed 3.5m/s. Nozzle to target distance of 1 inch (25.4mm)

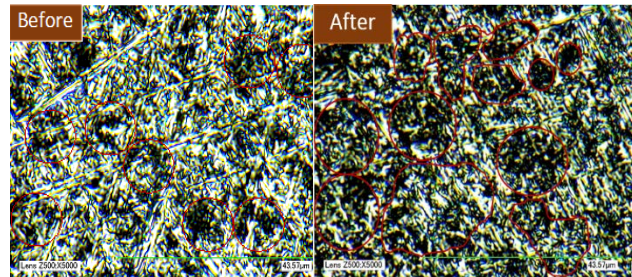
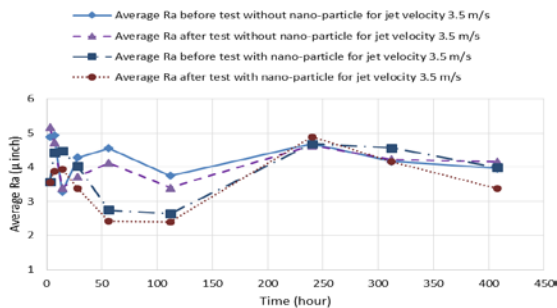


Figure 4. Jet-impingement tests: Ra roughness for 3003-T3 aluminum before and after 3,7,14,28,56,112,240,312 and 408 hour treatments with 50/50% ethylene glycol in water (reference fluid), and with its nanofluid of 2% nano-alumina and optical microscopy (Magnif:5000X) for 408 hour-test with nanofluid. Jet-speed speed 3.5m/s. Nozzle to target distance of 1 inch

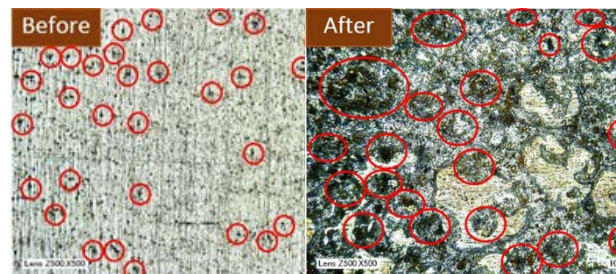
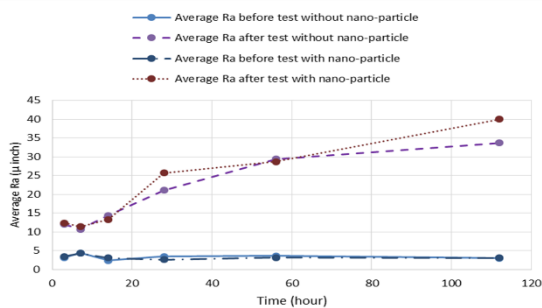


Figure 5. Through-flow tests: Average Ra for 3003-T3 aluminum after 3, 7, 14, 28, 56 and 112 hour-treatments with distilled water as reference fluid, and its nanofluid of 2% nano-alumina and optical microscopy images (Magnif.:500X) before and after test of 112 hour-test with nanofluid. Flow speed 1m/s.

References

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