Colloidal Nanoparticle-Enabled Tribological Modifiers

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Frictional losses account for between 2 and 4 percent of the gross domestic product (GDP) of an industrialized nation, according to the European Network for Industrial Wear Prevention. In 2015, this equated to an annual cost of over $700B in the United States and the European Union. Advanced nanoparticle lubricant modifiers are a novel and untapped technology that can significantly reduce frictional losses and mechanical wear, above and beyond the impact of existing technologies.

A great deal of research has been conducted on particle systems, lubricant types, operating conditions, and manufacturing methods, and this research shows that nanoparticles can have a tremendous impact (on the order of 30%) in reducing wear and friction. However, the development of commercially viable nanoparticle-based additives has languished due to three factors:

1-It has been difficult to identify cost effective input materials that are suitable as additives.

2-Current production processes are inherently expensive and/or unscalable.

2-Stable colloidal particles have been very difficult to generate with common methods.

Nanofoundry addresses these seemingly disparate issues in a one step process. Our microfluidic reactor can produce a stable hydrophobic inorganic nanoparticle dispersion that substantially reduces friction in a single reaction step:

Low cost input materials: Nanofoundry's proprietary process provides impeccable control over particle size, morphology, consistency, and chemical formulation allowing us to convert a wide range of low cost input materials into consistent, high performance nanoparticle additives.

Low cost and scalable process: As a continuous wet chemical process, Nanofoundry's technology is efficient in terms of energy, labor, and capital investment.

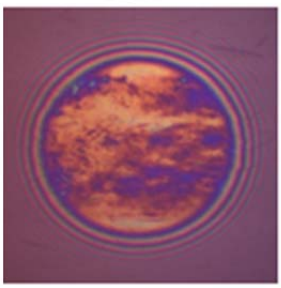
Colloidal stability: Nanofoundry has demonstrated the ability to generate stable colloids of environmentally benign and inexpensive nanoparticles using its proprietary microfluidic process. These particles demonstrate no material segregation within lubricant base stocks for time periods exceeding 6 months. ASTM D1703 stability tests are currently ongoing and there is no indication of phase separations.

Preliminary test data indicates that consistently small and spherically-shaped particles are essential to decreasing the coefficient of friction observed under working conditions. All measurements were performed with a high frequency reciprocating test rig (HFRR) which provides excellent quantification of boundary friction conditions within a lubrication package. All samples were suspended in at 2% w/w loading in Exxon PAO4 as the base oil stock and tests were conducted at 3 different temperatures. Table 1 presents the varying morphologies and compositions tested during this work.

Sample	Average Wear Scar	Friction Coefficients		
	um2	**70oC**	**100oC**	**130oC**
PAO base Oil	**1800**	**0.178**	**0.274**	**0.341**
PAO with 0.01 wt% friction modifier		**0.167**	**0.211**	**0.129**
PAO with 0.01 wt% ZDDP wear modifier	**435**			
0.01 wt% Our Colloid	**435**	**0.140**	**0.116**	**0.099**
0.5 wt% Our Colloid	**380**	**0.137**	**0.116**	**0.088**

Table 1: Index of materials properties

This data demonstrates that Nanofoundry's stable oleophilic colloid is distinctively superior at enhancing wear resistance with significant reduction in friction coefficients over oil base alone, especially as temperatures approach operational conditions within a device. Using a mini-traction machine with space layer imaging you can see the high uniformity of the tribofilm, with Nanofoundry's Zn colloid (on the left) compared to the more traditional wear resistance additive ZDDP (right).



Given the excellent results shown in our preliminary data, we have initiated lab-scale production of various materials with Zn as the primary metal. Zn based colloid is surface-capped with Oleic acid making it black and it has excellent stability in hexanes and PAO4 base oil stocks for extended (>6 months currently) time periods with no special mixing or agitation required. The material manufactured in continuous flow demonstrates much smaller particle size and a high degree of monodispersity within the matrix. This observable functionalization is at the root of the long-term stability of these materials.

We conclude from a review of the published literature and our own analysis that our technology represents a highly feasible, low cost path to the commercialization of colloidal nanoparticle-enabled tribological modifiers. The 2016 global market for lubricant additives is $14B. Our product is supplemental and complementary to existing technology. We estimate the revenue potential to be well in excess of $2 billion.

Nanofoundry has significant expertise in chemistry, surface science, and applied physics. This, coupled with our proprietary microfluidic production capability, gives us the ability to develop a distinctive, protectable product of substantial market value, with a high level of confidence within a rapid development time frame.