Nanoparticles as antibacterial fillers in machining process fluids

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Abstract
Process fluids are important as they help create appropriate conditions for machine cutting by improving heat transfer, thereby extending the life of the cutting tool and increasing surface quality of the product. It is essential, however, that one understands the process fluid characteristics (cooling, lubricating and/or cleaning effect, health issues, stability, pureness) and its appropriateness (environmental safety, operating life) prior to use. Increasingly, nanoparticles are being added to process fluids to increase their antibacterial properties, particularly as regards bacterial contamination. In this paper, the antibacterial properties of process fluid nanoparticles are evaluated, along with their availability and characteristics. While antibacterial effects on test bacteria were often difficult to determine due to process fluid and nanoparticle composition, results indicated that nanoparticles reduced bacterial respiratory rates by around 90%. The addition of nanoparticles had no discernable effect on the tribological characteristics of the process fluids.

Keywords: Nanoparticles; antibacterial effects; process fluids; machining

Introduction

- Biocidal ingredients are important - protect the fluids against biological attack by bacteria or fungi, thereby protecting the user against spores and endotoxins.
- Recently, addition of metal oxides, e.g. Titanium dioxide (TiO_2), Silicon dioxide (SiO_2) and diamond (C) has been seen as a promising alternative to conventional antimicrobial techniques, and especially when used in the form of nano-sized particles.
- The photocatalytic oxidation and reduction reactions of such metal oxides have been extensively studied, with TiO_2 now the most commonly used metal oxide due to its chemical stability, high photocatalytic efficiency, lack of toxic side effects and low cost.

Materials and Methods

Process fluid:

a) One sample composed mainly of oxygenated organic compounds comprising glycols and higher alcohols (PFM-2; four substances determined; pH 9.58).
b) Two samples composed of various amines and one oxygen molecule (PFM-1 and PFM-3; around 20 substances determined; pH 9.04 and pH 8.95, respectively).

Nanoparticles:

a) TiO_2 (crushed to 40 – 500 nm), no discernable difference from the declared composition.
b) SiO_2 (crushed to 30 – 500 nm), contained impurities of opal and anatase.
c) Diamond powder (crushed to 30 – 300 nm), no discernable difference from the declared composition.

Over time, larger units of about 50 μm were formed due to aggregation and sedimentation. The maximum total organic carbon concentration in the nanopowders was 20 mg/l.

Microorganisms:

- *Escherichia coli (*evaluate respiratory rate, cell membrane integrity, cultivation test, genotoxicity test).

Experiment design:

- Each batch-test consisted of 18 ml of process fluid (or control sample) + 2 ml saline solution with E. Coli (initial absorbance 0.93 at 600 nm) + 1 g/l of nanoparticle.
- The temperature was maintained within a range of 22 ± 2 °C.

Conclusion

- Both microscopic and respirometry assessments indicate that bacteria are able to adapt to a range of process fluid environments.
- Nanoparticle antibacterial activity was only demonstrated in samples containing TiO_2; impurities in other nanopowders formulations appearing to support bacterial activity rather than suppress it.
- All process fluids showed significant inhibition of cell proliferation, with just one sample (composed of various amines and one oxygen molecule) applied at the highest dilution not exceeding the upper limit of the recommended range for cytostasis in micronucleus tests.

Table 1 Comparison of total O_2 consumption (%)in process fluids after five days (with respect to a control measurement).

Samples	No nanoparticles	PFM + nanoDP	PFM + $nanoSiO_2$	PFM + $nanoTiO_2$
PFM-1	100	1400	1120	1300
PFM-2	100	950	1250	6350
PFM-3	100	1370	2353	6

Table 2 Comparison of the proportion of living cells (%) in process fluids after five days (with respect to a control measurement).

Samples	No nanoparticles		PFM + nanoDP		PFM + $nanoSiO_2$		PFM + $nanoTiO_2$	
	day 1	day 5	day 1	day 5	day 1	day 5	day 1	day 5
PFM-1	100	88	100	272	100	180	100	242
PFM-2	100	150	100	127	100	320	100	900
PFM-3	100	184	100	239	100	639	100	6

Fig. 1 Fluorescent microscope images of *E. Coli* bacteria in solutions containing nanoparticles (left to right: no nanoparticles, nano-DP, nano-SiO_2 and nano-TiO_2; green = live, red = dead cell).

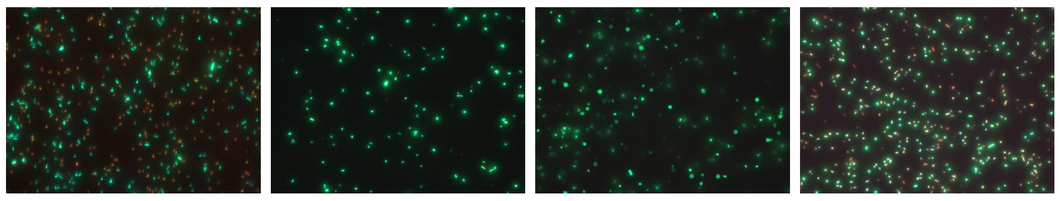


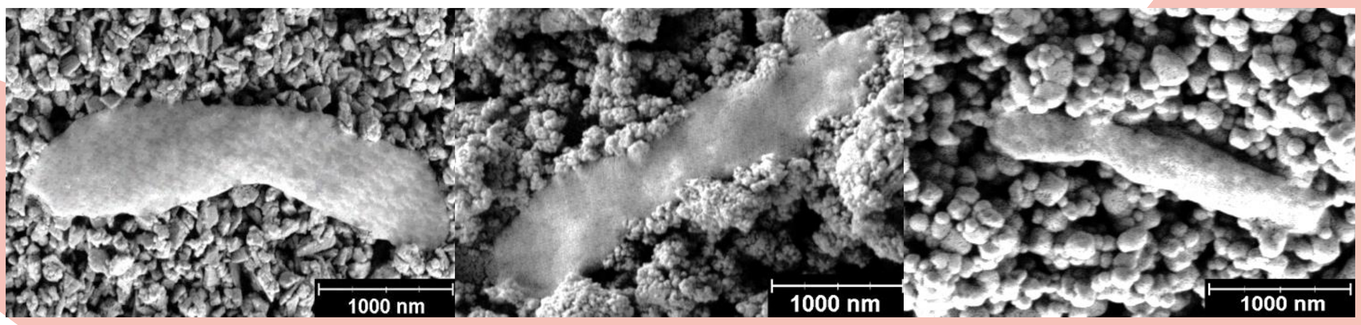
Table 3 Comparison of CFU (%) in process fluids after five days of the experiment (with respect to a control measurement).

Samples	No nanoparticles		PFM + nanoDP		PFM + $nanoSiO_2$		PFM + $nanoTiO_2$	
	day 1	day 5	day 1	day 5	day 1	day 5	day 1	day 5
PFM-1	100	2	100	2	100	1	100	29
PFM-2	100	50	100	1	100	2	100	6
PFM-3	100	1	100	4	100	3	100	2

Table 4 Comparison of cytostasis (%) in process fluids.

Samples	Dilution (C-0.01)	Dilution (C-0.005)	Dilution (C-0.0005)
PFM-1	82.69	101.2	91.03
PFM-2	99.07	96.97	93.93
PFM-3	90.06	53.19	6.142

Fig. 2 Scanning electron microscope images of *E. Coli* bacteria in solutions containing nanoparticles (left to right: nano-DP, nano-SiO_2 and nano-TiO_2).



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