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Functional and environmental evaluation of alternative disinfection methods for cutting fluids

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Abstract

Cutting fluids are widely used to ensure high production quality and process stability in machining processes. However, especially in case of water based cutting fluids microbial contamination leads to a reduced performance and thus, shortened service life. To control the growth of microorganisms biocides are used in practice. Biocides, however, can be toxic to humans and the use is officially regulated, whereby alternative disinfection methods e.g. ultraviolet radiation or ozone are getting more in the focus. This paper describes and performs a functional and an environmental evaluation of alternative disinfection methods.

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Keywords: Cutting Fluid; Microbial Contamination; Disinfection Methods; UV Radiation; Ozone

1. Introduction

The application of cutting fluids in machining processes is of great importance to maintain a high productivity. The use of cutting fluid has a crucial influence on the workpiece quality, tool wear and power demand of the cutting process and the machining system [1]. Thus, keeping up the cutting fluid quality and ensuring a long service life are critical issues from technological but also economic and environmental perspective. Particularly water based cutting fluids are susceptible to microorganisms and this leads to a reduction in service life [2]. In order to control and to reduce the microbial contamination of cutting fluids biocides are widely used as preservatives in practice. However, due to their toxicological properties biocides can be toxic to humans and can create health-related problems. As a consequence, the use of biocides is limited by regulations and might be further restricted in the future. Besides the use of biocides also other physical and chemical methods exist that can possibly be applied to reduce microbial contamination [3], [4]. These methods differ greatly in terms of applicability and related environmental impacts. Therefore, this paper investigates the functionality of alternative disinfection methods on microorganisms in cutting fluids. Based on the results of an experimental study and additional studies described in the literature the environmental impact of different disinfection methods is analyzed and discusses.

2. Research Background

2.1. Cutting fluids and the development of microorganisms

Cutting fluids are used in different machining processes to cool, to lubricate and to transport metal ships. By the fulfillment of these tasks it is possible to increase the efficiency of the process [1]. However, due to different requirements regarding workpiece materials, tools and type of processes a wide range of different cutting fluids exists. Generally, cutting fluids consist of a base fluid and an additive package. This package includes on the one hand additives such as extreme-pressure-additives, anti-wear-additives, anti-foam-additives or anti-corrosion-additives [5].

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The base fluid on the other hand can be distinguished, according to DIN 51385 between water miscible and non-water miscible fluids [6]. The non-water based fluids consist of 80-95 % mineral oil as a base fluid, while water based fluids contain a significant lower share of base oil. They can further be distinguished between emulsions and dilutions and normally consist of 85-98 % water. The other share comprises the base oil and the additive package, which includes emulsifiers or solublizers [5].

As non-water based cutting fluids are usually not affected by microorganisms they are not within the scope of this study. In contrast water based fluids provide conditions that support the growth of microorganisms and they are mainly contaminated by bacteria and fungi. Bacteria are simple organisms and can be distinguished by different aspects. In this case it is reasonable to differentiate anaerobic and aerobic bacteria. While aerobic bacteria need oxygen for reproduction, anaerobic bacteria can exist without oxygen [7]. Fungi, however, are more complex organisms and can be classified in a group related to animals and plants [7]. Different research studies analyzed the types of bacteria and fungi that could be detected in cutting fluids. Most of the bacteria belong to the genus Pseudomonas, but also other bacteria were detected such as Comamonas, Staphylococcus and Achromobacter [2], [8], [9] and [10]. In case of fungi species such as Aspergillus and Fusarium could be detected [2], [9]. However, Rabenstein et al. described that the types of detected microorganisms vary over time as there are pioneer and secondary species [2].

2.2. Impact of contaminated cutting fluid

Microorganisms have an impact on the condition and performance of cutting fluids [11]. The components of the cutting fluid (additives and base fluid) serve as nutrients and enable a growth of microorganisms. However, these components are metabolized gradually and not simultaneously. Microorganisms prefer readily biodegradable substances, while substances with complex molecules have a low bioavailability and are later metabolized. Thus, the microbial degradation of cutting fluids depends on the composition of the fluid as well as the existence of different species of microorganisms [12].

This demonstrates the interdependencies between cutting fluid and a microbial contamination. Koch and Rabenstein have demonstrated in their research that emulsifiers and solubilizers influence the microbial degradation rate of the base oil. Adding emulsifiers leads to a higher bioavailability of the base oil and thus an accelerated microbial degradation [13]. Further, Koch and Rabenstein demonstrated the microbial degradation of corrosion inhibitors as well. Most corrosion inhibitors contain nitrogen which is an important nutrient for microorganisms. Thus, their bioavailability and microbial degradation is even higher compared to emulsifiers [13]. A reduction of corrosion inhibitors leads to corrosion issues on machine parts or workpieces. Additionally, microbial degradation processes lead to an enrichment of acidic metabolites into the cutting fluid resulting in a decreasing pH value that enhances the corrosive effect [14]. By the microbial degradation of important components such as base oil, emulsifier and corrosion inhibitors there is a decreasing stability of the water based emulsion and a decreasing technical performance of the cutting fluid. This leads to quality issues such as higher surface roughness and tool wear and as a result a shortened service life of the cutting fluid. Brinksmeier et al. has demonstrated the influence of contaminated cutting fluids on the technical performance within a research project. For a drilling process it could be verified that microorganisms have an impact on the process quality expressed as the surface quality and tool wear [11].

However, a shortened service life due to microbial contamination also has an economical and environmental impact. Since cutting fluids have to be renewed frequently it results in costs for the disposal of used fluid and acquisition of new fluid. Additionally, every change of cutting fluid also means a machine downtime and thus, unproductive time. Besides the costs for disposal and acquisition a shortened service life results in a higher demand of resources as well.

Another important aspect concerning contaminated cutting fluid focuses on occupational health and safety. The hygienic and toxicological risks for machine operators that have to work with cutting fluids are not to be neglected. Especially by inhalation, by skin injuries or through the mucous membranes in the facial area microorganisms can enter the body [9], [14]. This may cause skin irritation or dermatitis and in some case it may also lead to allergic reactions [9].

2.3. Possible disinfection methods

The described impacts of contaminated cutting fluid require the use disinfection methods in order to control the growth of microorganisms. The aim of these methods is to maintain the characteristics and technical performance of cutting fluids as long as possible and thus to increase service life. Therefore, possible chemical and physical disinfection methods are discussed in the following.

Biocides

Biocides are defined as chemical agents, which are used individually or in combination to eliminate microorganisms and are used among other applications for the disinfection of cutting fluids [15]. Biocides may either be used preventively within the additive package of the cutting fluid or they can be added continuously or only added in case of microbial contamination [16]. There are different biocides available that can be used and due to different microorganisms these biocides are sometimes also combined. Selvaraju et al. analyzed the effect of formaldehyde and non-formaldehyde biocides at various concentrations (100 – 100,000 ppm (parts per million)) against two different species of microorganisms in cutting fluids. It was revealed that the type of biocide and its concentration have a significant influence [17]. However, the maximal concentration of biocides is often officially regulated, since the toxicological properties of the biocides may have negative impact on the health of the machine operator [9]. Therefore, a compromise has to be reached between type and concentration of biocides that are still effective against microorganisms but at the same time