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Wojciech UMIŃSKI
Institute for Sustainable Technologies – National Research Institute, Radom
wojciech.uminski@itee.radom.pl

SYSTEM FOR THE DISINFECTION OF CUTTING FLUIDS USING A PULSED ELECTRIC FIELD

Key words

Contamination of cutting fluid, microorganism cell, pulsed electric field (PEF), electroporation.

Abstract

During applying cutting fluids (coolants), which are used in the surface treatment of metals, different microorganisms develop. The effects of microbial growth in the cooling system are the following: the shortened life of coolants, increased operating costs, downtime connected with the replacement of coolant, and the exposure of workers to the harmful impact of infected oil mist on skin, eyes, and upper respiratory tract.

The paper presents the possibility of an innovative application of a pulsed electric field method to disinfect cutting fluids. The contaminated coolant is subjected to a pulsed electric field with the result that there is a rapid destruction of living microorganisms therein, and their spores.

Furthermore, the article demonstrates a laboratory system equipped with a high voltage generator and a control system enabling, inter alia, to change the parameters of the pulsed electric field as well as the laboratory model of the

disinfection cell with variable spacing of the electrodes. A research stand made according to the predefined assumptions is also shown.

The research stand is intended for testing the effectiveness of reducing the degree of biological contamination of the coolant as a function of the parameters of pulsed electric field. The obtained results are related to the results of a research task of a strategic programme entitled: „Support systems of ecological exploitation of industrial oils and technological liquids". Obtaining promising test results will be a stage leading to the development of a system for the disinfection of cutting fluids on a technical scale.

Introduction

Cutting fluids (cutting oils, coolants) are applied in machining processes. Their use increases the efficiency of machines by increasing the cutting speed, improving the quality of machined surfaces, prolonging the life of the cutting tool, reducing friction and energy consumption, as well as by the dissipation of the heat produced during this type of treatment. The most commonly used cooling and lubricating fluids are oil-water emulsions, prepared from concentrates, which are mixed with water in any ratio in order to obtain a stable emulsion [1]. The presence of water and organic matter makes coolants susceptible to contamination by microorganisms [2, 3, 4]. These are mainly bacteria (including pathogens), but also moulds and yeasts, and immunologically reactive compounds of microbial origin. In practice, the microorganisms get into the liquid in a continuous manner during its use. The intensity of their growth depends on the composition of the cutting fluid. The main source of contamination is the water used for the preparation of oil-water emulsions and the pollution getting into the cooling systems from metal workpieces and the environment. In addition to water, a prerequisite for the development of microorganisms is the presence of hydrocarbons or other organic substances such as fats and esters. The presence of bacteria and fungi results in a marked deterioration in the quality of coolants (cooling parameters decrease), and they may accelerate the corrosion processes of both metal workpieces and the elements of machine tools.

During metalworking, oil mist rises around the working stand. On the particles of the mist, there are biological agents – mainly bacteria and endotoxin. The droplets of the mist are of such size that they can easily penetrate the human respiratory tract, and with them, bacteria, fungi, and the fragments resulting from their degradation. The contact of the respiratory epithelium with microorganisms, their cell fragments, and other chemical compounds present in the oil mist (e.g. Sulphur compounds) influences the proper functioning of the respiratory system and may lead to the occurrence of various diseases among workers employed in metal processing [5, 6, 7]. The most common symptoms of diseases associated with the exposure to oil mist are respiratory diseases such as asthma, inflammation of the upper respiratory tract, chronic bronchitis, and allergic alveolitis. As a result of contact with cutting fluids, dermatological disorders such as allergies, acne oil, and bacterial and fungal infections can also occur. In order to reduce the exposure of workers and ensure the high quality of the produced metal objects, it is necessary to prevent microbial contamination of coolants and to take appropriate corrective actions when the number of bacteria or fungi exceeds the norm.

In practice, there are two methods to prevent the microbial contamination. One of them is the replacement of the fluid with a new one, combined with careful washing of the installation for applying the fluid. Research shows that the method gives a short-term effect, because just after several hours, microorganisms start developing again, and after a week, the bacteria levels could rise by 3–4 orders of magnitude. Another method used to reduce the microbial contamination of cutting fluids is adding biocides to the fluid [8]. Formaldehyde, isothiazolins, and boric acid salts are most commonly used as biocides. The formaldehyde was the earliest introduced biocide. However, because of its rapid degradation and evaporation from the liquid, it was used in high concentrations, which resulted in its penetration into the air at the workplace.

In connection with the planned entry into force of the “EU biocide directive” (from 2014) imposing significant restrictions on the use of biocides, new liquid coolants and lubricants, which do not contain such measures, will appear on the market. The main advantage of these liquids is that they possess the capacity to prevent the growth of bacteria and lack toxic additives with bactericidal action. An alternative to the above methods of coolant disinfection are new technologies in which no chemicals are used for decontamination. An environmentally friendly method for decontamination of cutting fluids mixed with water, containing mineral oils, is provided by Kaysser, which is a HP manufactured device, which uses ultraviolet light (UV-C) for disinfection [9]. The germicidal UV-C impact is performed by passing a thin film of coolant (approx. 1.5 mm) on a rotating cylinder surrounded on one side by shielded fluorescent tubes. This arrangement provides an additional circuit of coolant that flows back into the machine after disinfection. The method is effective even in the case of microorganisms that have developed a resistance to bactericidal and fungicidal chemical measures. Works on the use of UV for the disinfection of coolants are performed in ITeE – PIB in Radom within the research task of strategic programme entitled: “Support systems of ecological exploitation of industrial oils and technological liquids”. The method of pulsed electric field (PEF) used for disinfection of cutting fluids seems to be innovative and at the same time ecological [10, 11]. This method has been tested for several years in a pilot or semi-technical devices for food preservation. It uses the impact of high voltage pulses on the food placed between two electrodes [12, 13]. The main preserving factor is the electric field acting destructively on microflora existing in food. The essence of the influence is the use of high voltage for a very short period of time, expressed in microseconds, for a single pulse.

1. The mechanism and the influence of the electric field on the cell

The microbial cells are surrounded by a cell membrane, which acts as a barrier and allows the cell to maintain different substances within itself such as a cytoplasm and organelles [14, 15]. Each cell membrane is polarized. It means that there is a difference of charges (the positive charges carried by the cations and the negative charges carried by the anions) between its outer and inner surface. This implies that, across the membrane, there is a potential difference, or voltage, called a resting potential (membrane potential), which usually ranges from -20 to -200 mV depending on the type of organism and the type of cell. This potential is expressed as a negative value because there are slightly more negative charges inside the cell than the positive ones.

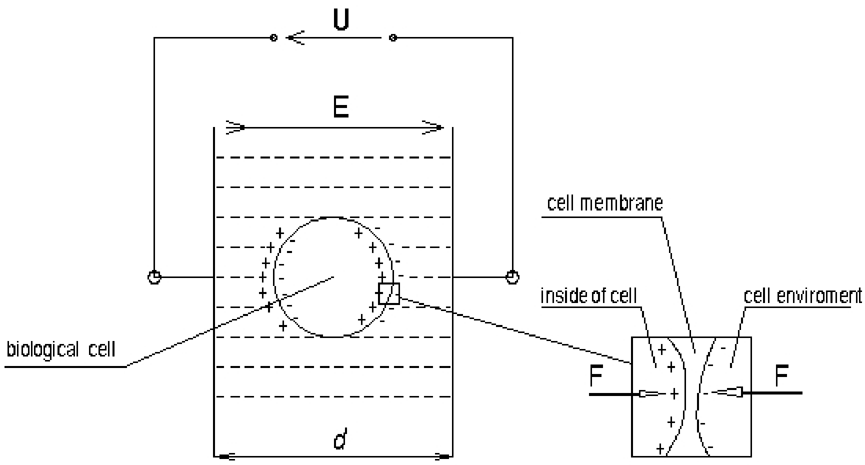

Fig. 1. Schematic representation of the impact of the electric field on the cell

The mechanism of the inactivation of the cells under the influence of electric field is not fully understood. There are various theories that attempt to explain this phenomenon. Currently, the most popular and most widely accepted explanation for this phenomenon is the electroporation of the cell membrane (Figure 1). A biological cell behaves in a manner similar to a capacitor with a low dielectric constant. Therefore, when it is placed in the electric field,

$$\mathbf{E} = \mathbf{U}/d,$$

where **U** – the voltage applied to the area of influence of the electric field,
d – distance between the electrodes defining the area of influence of the electric field,

the ions inside and outside the cell will move in the direction of the applied electric field. This in turn leads to the accumulation of free, opposite electric charges on both sides of the cell membrane. These charges are influenced by force **F** proportionally to the intensity of the electric field **E** and the size of the charge q,

$$\mathbf{F} = \mathbf{E}\, q,$$

causing localised pressure increases on the cell membrane, which leads to changes in its thickness and to the formation or growth of existing membrane pores. A defective cell membrane is more permeable to small molecules, which facilitates the equalization of the osmotic pressure between the external environment and the contents of the cell. This may cause the cell to further swell. If the natural cell membrane potential rises above the natural, which is the critical value of about 1V due to the applied electric field, the disruption of the cell membrane occurs causing the cell death – irreversible electroporation occurs. The critical voltage depends on the size of the cell. The smaller it is, the higher the critical voltage must be applied.

2. Disinfection system of cutting fluids

Figure 2 shows a diagram of the system using the pulsed electric field method in food processing [16]. It consists of three basic components: a high-voltage pulse generator, disinfection cell, and a control system with process control.

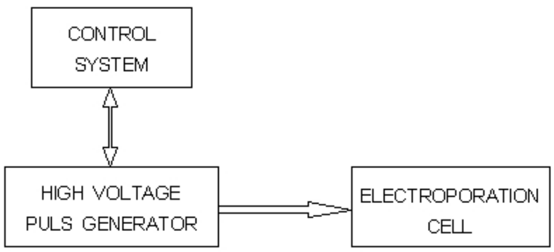

Fig. 2. Diagram of the system of pulsed electric field in food processing

The Institute for Sustainable Technologies – National Research Institute in Radom developed and built a research stand for disinfecting cutting fluids in laboratory conditions, which is shown in Fig. 3.

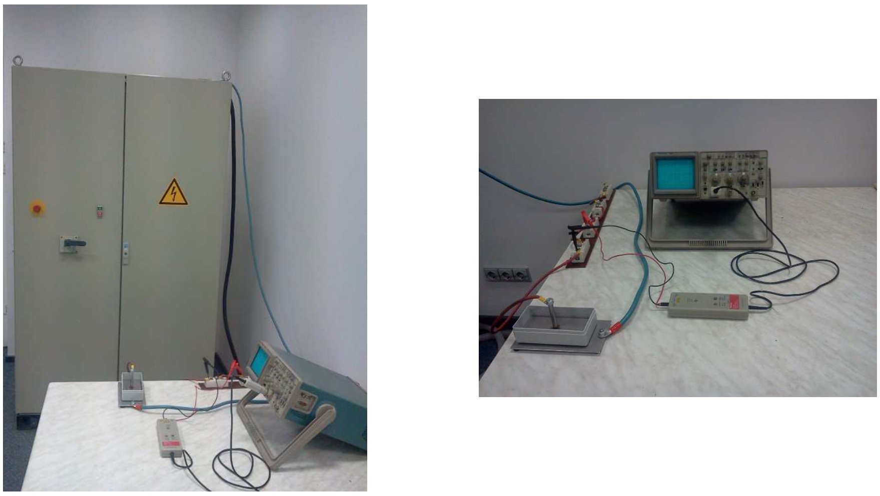

Fig. 3. Laboratory research stand for the disinfection of cutting fluids

The stand consists of a high voltage pulse generator with an integrated microprocessor control system and a stationary disinfection cell, which comprise a PEF system as well as a digital oscilloscope. The oscilloscope allows the registration of the voltage pulse waveforms for analysis with a view to select optimal parameters of the pulsed electric field for the disinfection of the coolant.

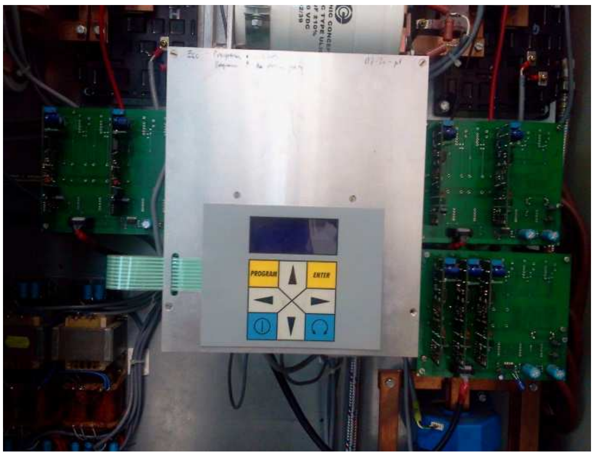

Fig. 4. The control system integrated with the high voltage pulse generator

The high voltage pulse generator produces rectangular pulses with a pulse power up to 3 MW, with energy expended up to 90 kWs per second in continuous operation. The control system integrated with the generator (Fig. 4) is equipped with a keyboard that allows for setting the following output voltage pulse parameters:

- The voltage up to 20 kV,
- Pulse repetition frequency in the range of 1 Hz to 3 kHz, every 1 Hz,
- Pulse width in the range of 1 μs to 200 μs, every 1 μs, and
- The generation of pulse „packages" with the set number of pulses in the range of 1–99 and the set frequency and pulse width in the "package".

The stationary cell for coolant disinfection is shown in Fig. 5.

Fig. 5. Stationary cell for disinfection of cutting fluids

It was made based on the cuboid, polycarbonate container, wherein two rectangular stainless steel electrodes of dimensions 70 × 145 mm were placed. One of the electrodes connected to the negative grounded pole of the generator is permanently attached to the cell and forms its bottom. Second, the movable electrode is connected to the positive pole of the generator. The distance between the electrodes is determined by means of insulating spacers with a height of d = 3, 6, and 9 mm. This creates the possibility of abrupt changes in electric field intensity at a fixed output voltage. For maximum output voltage U = 20 kV and the electrodes distance d = 3 mm, the electric field E in the disinfection cell achieves the value of approximately 66 kV/cm.

Conclusions

The developed research stand allows for testing the effectiveness of reducing the degree of biological contamination of the coolant with the use of the pulsed electric field method. Additionally, the results obtained in such a way can be compared with the outcomes of the research task developed in the strategic programme entitled: „Support systems of ecological exploitation of industrial oils and technological liquids".

The design of the high voltage pulse generator and laboratory cell for disinfecting enable one to conduct research within a wide range of parameter changes in pulsed electric field. Consequently, it is possible to predict the optimum values of these parameters in terms of technological and economic processes of coolants decontamination. Obtaining promising results will form the basis for designing a system for disinfecting cutting fluids on a technical scale.

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References

1. Total: Ciecze do obróbki metali. http://www.total.com.pl/pro/B2B-produkty-dla-przemyslu/li-materialy-informacyjne/li-poradnik.html, grudzień 2014.
2. Ruggeri D.: Pielęgnacja chłodziw obróbczych w małych zakładach. http://www.houghton.com.pl/pl_aktualnosci-artykuly.php, styczeń 2015.
3. Ceprowski M. Zanieczyszczenia mikrobiologiczne cieczy obróbkowych. Bezpieczeństwo Pracy 09/2012, s. 16–19.
4. Trafny E.A.: Skażenie mikrobiologiczne cieczy chłodzaco-smarujących i sposoby jego ograniczenia. Obróbka metali 04/2012, s. 40–41.
5. Lewandowski R.: Ciecze chłodząco-smarujące jako źródło czynników biologicznych zagrażających zdrowiu pracowników. Bezpieczeństwo Pracy 04/2013, s. 5–7.
6. Ceprowski M., Kozajda A., Zielińska-Jankiewicz K., Szadkowska-Stańczyk I.: Szkodliwe działanie czynników biologicznych uwalnianych podczas procesów obróbki metali z użyciem chłodziw. Medycyna Pracy 57(2) 2006, s. 139–147.
7. Nitzsche F.: Mikrobiologisches Wachstum in Kühlschmierstoffen. Rozwój mikroorganizmów w chłodziwach. Ind.Diam.Rdsch., 2008, t. 42, nr 1, s. 70–73.
8. Kein Platz für Schadbakterien. Nie ma miejsca dla szkodliwych bakterii. Masch.u.Werkz., 10/2009, s. 40–41.
9. Anders S.: Natürlich und keinfrei. Eliminowanie zarodków bakterii, grzybów i wirusów bez użycia preparatów chemicznych. Werkst.u.Betr., 2009, t. 142, nr 3, s. 66–67.

10. Zhang Q., Barbosa-Canovas G.V., Swanson B.G.: Engineering Aspects of Pulsed Electric Field Pasteurization. Joumal of Ford Engineering 25 /1995, pp. 261–281.
11. De Vito F.: Application of Pulsed Electric Field (PEF) Techniques in Food Processing. Rozprawa Doktorska, UNIVERSITÀ DEGLI STUDI DI SALERNO, 2006.
12. Wiktor A., Witrowska-Rajchert D.: Zastosowanie pulsacyjnego pola elektrycznego do wspomagania procesów usuwania wody z tkanek roślinnych. ŻYWNOŚĆ. Nauka. Technologia. Jakość, 2012, 2 (81), s. 22–32.
13. Kinetics of Microbial Inactivation for Alternative Food Processing Technologies – Pulsed Electric Fields. http://www.fda.gov/Food/Food ScienceResearch, grudzień 2014.
14. Toepfl S., Heinz V., Knorr D.: Application of Pulsed Electric Fields in Liquid Processing. http://scholar.google.pl/ listopad 2014.
15. Tian Yow Tsang: Electroporation of Cell Membranes. Mechanisms and Applications. http://link.springer.com/chapter/10.1007/978-1-4899-2528-2_9#page-1, grudzień 2014.
16. Maged E.A. Mohamed and Ayman H. Amer Eissa : Pulsed Electric Fields for Food Processing Technology. http://dx.doi.org/10.5772/48678, grudzień 2014.

System do dezynfekcji cieczy obróbkowych z wykorzystaniem pulsacyjnego pola elektrycznego

Słowa kluczowe

Skażenie cieczy obróbkowej, komórka mikroorganizmu, pulsacyjne pole elektryczne (PEF), elektroporacja.

Streszczenie

W obróbce powierzchniowej metali stosuje się ciecze obróbkowe (chłodziwa), w których w trakcie ich użytkowania rozwijają się drobnoustroje. Efektami rozwoju mikroorganizmów w układzie chłodzenia są: skrócenie żywotności chłodziw, zwiększenie kosztów eksploatacji, przestoje produkcyjne związane z wymianą chłodziwa oraz narażenie pracowników na szkodliwe dla zdrowia oddziaływanie zarażonej mgły olejowej na skórę, wzrok czy górne drogi oddechowe.

W artykule przedstawiono możliwość innowacyjnego zastosowania metody pulsacyjnego pola elektrycznego do dezynfekcji cieczy obróbkowych. Skażone chłodziwo poddawane jest działaniu pulsacyjnego pola elektrycznego, w efekcie

czego następuje szybkie zniszczenie żyjących w nim mikroorganizmów, a także ich zarodników.

Przedstawiono laboratoryjny system wyposażony w generator wysokiego napięcia i układ sterowania umożliwiający między innymi zmianę parametrów impulsowego pola elektrycznego oraz laboratoryjny model celi dezynfekcji o zmiennej odległości elektrod. Przedstawiono stanowisko badawcze wykonane według przyjętych założeń.

Wykonane stanowisko badawcze umożliwi przeprowadzenie badań skuteczności zmniejszania stopnia skażenia biologicznego chłodziwa w funkcji parametrów pulsacyjnego pola elektrycznego oraz odniesienie otrzymanych rezultatów do wyników prac uzyskanych w zadaniu badawczym Programu Strategicznego pt.: „Systemy wspomagania proekologicznej eksploatacji olejów przemysłowych i cieczy technologicznych". Uzyskanie obiecujących wyników badań pozwoli na opracowanie urządzenia do dezynfekcji cieczy obróbkowych w skali technicznej.