Sustainable Cutting Fluids: Thermal, Rheological, Biodegradation, Anti-Corrosion, Storage Stability Studies and its Machining Performance

Kishor K Gajrani and Mamilla R Sankar, Indian Institute of Technology, Guwahati, India

© 2018 Elsevier Inc. All rights reserved.

Introduction

The demand for energy is increasing day by day due to ever-going development, modernization and industrialization. The energy consumption by world is estimated to increase by 33.5% from 2010 to 2030 (Saidur et al., 2011). Fossil fuels are one of the most commonly used sources of energy. In general, fossil fuels are used in the form of fuel and lubricant to fulfill worlds soaring energy demand. Survey estimation says that 30–40 million tons of lubricants are used every year. Out of these, 20 million tons come back to the environment after usage (Mang and Dresel, 2017). Most of these lubricants (over 95%) that end up in the environment are based on petroleum products (Schneider, 2006).

Petroleum-based cutting fluids are subdivided into two categories; straight oils and neat oils. Both consists performance enhancer additives to improve its various properties. Additives such as fatty material, free sulphur, chlorinated paraffin, sulphurized oils and phosphorus compounds are present in petroleum-based cutting fluids (Dixit et al., 2012). At higher temperature these additives react with work material and form metal chloride, phosphates as well as sulphides, which are hazardous and harmful to the environment (Trent, 2000; Gajrani and Sankar, 2017a). In long run, inappropriate disposal of used petroleum-based cutting fluids can cause serious damage to environment. Moreover, prolong exposure to emissions of the cutting fluids causes several types of cancers as well as respiratory diseases (Sankar and Gajrani, 2017). Also, petroleum-based lubricants are non-renewable. A global concern has aroused due to environmental hazard and gradual depletion of petroleum source.

Nowadays to minimize these concerns, several alternative measures such as development of environment friendly cutting fluids and green energy systems are focused (Nagendramma and Kaul, 2012; Bart et al., 2013; Somashekaraiyah et al., 2016). Therefore, bio-based cutting fluids or bio-cutting fluids (BCF) are derived using bio-based raw materials such as animal fats, vegetable oils, unsaturated acids, etc., (Salimon et al., 2010). From recent past, BCF production is growing with agricultural advancement. As per the estimation of United States Department of Agriculture (USDA), 185.72 million metric tons vegetable oil will be produce in 2016/17 (USDA, 2016). Most BCF have almost similar molecular structure. They mainly consist of triglycerides. Triglycerides have number of long unsaturated fatty acids chains (Fox and Stachowiak, 2007; Mongkolwongrojn and Arunmetta, 2002), which are renewable and readily biodegradable. In addition, BCF have high viscosity index and high flash point than that of petroleum-based mineral oils (MO) (Son and Agarwal, 2014). High viscosity index of BCF ensures better stable lubricity, which means with the increase in temperature viscosity of BCF drops slowly as compared to petroleum based MO (Woods, 2005). Also, high flash point of BCF reduces possibilities of fire hazard and smoke formation. Moreover, BCF have higher boiling point and heavier molecular weight that reduces vaporization and mist formation (Khan and Dhar, 2006). Further, BCF is capable of reducing friction and wear between two mating surfaces. It is due to ability of polar and long carbon unsaturated acid chain to strongly interacting with intermetallic surface. Apart from above mentioned characteristics, BCF is sustainable, biodegradable and highly renewable source. Therefore, BCF can be a viable alternative to petroleum-based cutting fluids. Fig. 1 illustrates life cycle of renewable resources based products (Willing, 2001).

In spite of numerous merits, usage of BCF is still limited today. It is due to major issues regarding their cost and performance. However, most of the researchers have used BCF with minimum quantity lubrication (MQL) also known as minimum quantity cutting fluid (MQCF) technique to reduce cost by minimizing its consumption (Boswell et al., 2017; Khandekar et al., 2012; Heinemann et al., 2006). As per the performance is concern, these insufficiencies can be improved by the addition of proper additives and chemical modifications. These additives and modification changes the properties of BCF. With proper knowledge, BCF properties can be altered and controlled in a desired way. Therefore, it is necessary to investigate various properties of BCF. Furthermore, constant activities among government organizations, environmental agencies and manufacturer will results in development of procedures for the implementation of bio-technologies that can benefit ecological, social and economic aspects. In long run, there hard work can lead in sustainable environmental management and assessment (Walters, 1986).

In this study, physical properties of BCF are characterized. Also, thermal, rheological, apparent activation energy, biodegradable potential, anti-corrosion and storage stability characteristics of BCF are investigated. For comparison, similar studies are also conducted with MO. Afterwards, machining experiments using minimum quantity cutting fluids (MQCF) technique are carried out to examine the relative machining performance of both cutting fluids in terms of cutting force, feed force, coefficient of friction and surface roughness.

Physical Characterization of Cutting Fluids

The cutting fluids used for this study are petroleum-based MO and sustainable BCF. The MO used in this study was supplied by Servo Lubricants and Greases, Indian Oil Corporation Limited, India and BCF by CORTEC Corporation, India. BCF and MO are...