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Environment-friendly industrial cleaning agents incorporating plant-oil-based raw materials as chlorofluorocarbon (CFC) alternatives

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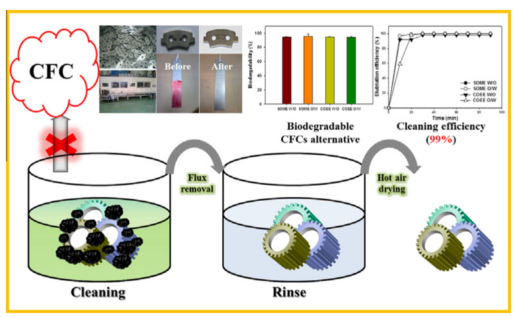
HIGHLIGHTS

- Bio-surfactants were synthesized using plant oils (soy bean and canola oils).
- Both O/W and W/O formulated bio-surfactants was prepared.
- Biodegradability of bio-surfactants was tested.
- Cleaning efficiency of bio-surfactants was investigated for flex removal.
- Degree corrosion of bio-surfactants for metals and polymers was tested.

GRAPHICAL ABSTRACT



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ABSTRACT

Chlorofluorocarbons (CFCs) are known to cause depletion of the stratospheric ozone layer and to contribute to global warming. For this reason, many researchers are investigating alternative CFCs. In the present study, bio-surfactants incorporating two oils, soy bean and canola, were prepared, and bio-surfactants in water in oil (W/O) and oil in water (O/W) types were produced, respectively. The phase behaviors of the as-prepared lauryl alcohol, caster oil, and oleic acid bio-surfactants were investigated under temperatures ranging from 4 to 60 °C to find the optimal single phase. The bio-surfactants additionally were analyzed for biodegradability, cleaning efficiency, and degree of corrosion of several metals and plastics, taking into due consideration the industrial cleaning process for chemical impurities. For removal of flux (i.e., abietic acid that constitutes most of rosin) from 25 to 60 °C temperature by sonication treatment, first, the biodegradability (%) of the four bio-surfactants, namely the W/O- and O/W-formulated soybean methyl ester (SME) and canola ethyl ester (CEE) types, were determined to be 94.66%, 95.60%, 94.43%, and 93.87%, respectively. Second, the cleaning efficiencies of the four bio-surfactants were 99%, 97%, 58%, and 15%, respectively, under the optimal cleaning conditions. Third, the degrees of maximal corrosion of caster iron and polyvinyl chloride (PVC) by W/O SME, O/W SME, W/O CEE, and O/W CEE were recorded as −0.11/−7.65, −0.44/−5.79, −0.11/−11.80, and −0.12/−2.84 $\Delta mg/cm^3$, respectively. Compared with trichloroethylene (TCE)'s cleaning performance for oil-contaminated brake pads, the W/O SME bio-surfactant showed better (~99%) cleaning efficiency in <5 min. Conclusively, the W/O SME bio-surfactant was judged to be a proper CFC alternative for application to industrial cleaning processes.

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1. Introduction

Chlorofluorocarbons (CFCs) are stable synthetic chemicals that were formulated commercially in the US beginning in 1931. They have been used extensively in solvent-cleaning applications, due to their especial effectiveness for degreasing of greases, oils, and waxes. CFCs accordingly can still be found in widespread use for cleaning electric motors, compressors, heavy metal parts, delicate precision metal parts, printed circuit boards, gyroscopes, guidance systems, as well as aerospace and aluminum parts [1,2]. However, CFCs cause depletion of the stratospheric ozone layer as well as global warming. Resultantly, many researchers are actively searching for safe alternatives to CFCs [3–9].

Among the alternatives, hydrofluoroethers (HFEs) have been considered the most promising candidates for use as refrigerants, blowing agents and cleaning solvents, owing to their zero ozone-depleting potential, low global warming potential, and favorable physical and chemical properties including low surface tension and non-flammability [10,11,3,12–18]. Thus, numerous methods of HFE production have been reported, including fluorination of ether with fluoride (F_2) [19] or with metal fluoride [20], electrochemical fluorination of ether [21], and alkylation of acyl halides using a sulfonic acid ester as an alkylating agent in the presence of anhydrous potassium fluoride (KF) [22]. Unfortunately, these methods suffer either from low product selectivity or the difficulty of handling hazardous and reactive raw materials. HFEs also can be obtained from the hydroalkoxylation reaction of commercially available fluorinated olefins (tetrafluoroethylene and hexafluoropropylene) in the presence of a base catalyst or free radical initiator [23]; however, these methods either require a long reaction time or produce relatively large amounts of unsaturated HFEs, which are difficult to remove by distillation due to the closeness of saturated and unsaturated HFEs' respective boiling points.

For usage as solvent-cleaning agents in the semi-conductor industry, the surfactant types for cleaning of dirty metals contaminated with lubricants, oils, and waxes are generally classified into halogen, alcohol, fluorine, carbon, and silicon [24–28]. The surfactants specifically required as CFC alternatives have higher cleaning efficiency as well as biodegradability, low corrosiveness, low toxicity, and low production cost [29,30]. Plant-oil-based bio-surfactants therefore, unlike synthetic surfactants, are potential CFC replacements.

Generally, according to the nature of their chemical structures, bio-surfactants are categorized by chemical composition and microbial origin. Microorganism-metabolized bio-surfactants have demerits, such as costly downstream processes, low productivity, and intense foaming formation, that are currently barriers to their commercialization [31,32]. Therefore, in the development of bio-surfactants, researchers have been focusing on increasing productivity yields, reducing raw-material costs and devising oxygenation strategies to reduce foaming formation [32–34]. Despite the considerable effort, the cost of bio-surfactant production is still approximately three to ten times that of chemical surfactants [35–42]. Resultantly, much attention has been paid to the mass-production of plant-oil-based bio-surfactants, particularly given their high biodegradability and surface activity and low toxicity. In the present study, potential CFC-alternative bio-surfactants synthesized from plant oils were evaluated for their biodegradability, cleaning efficiency, and degree of corrosiveness to metals and plastics. Specifically, they were demonstrated to possess merits in terms of overall mass-production feasibility, biodegradability and non-toxicity. Ultimately, the brake-pad cleaning efficiency of the

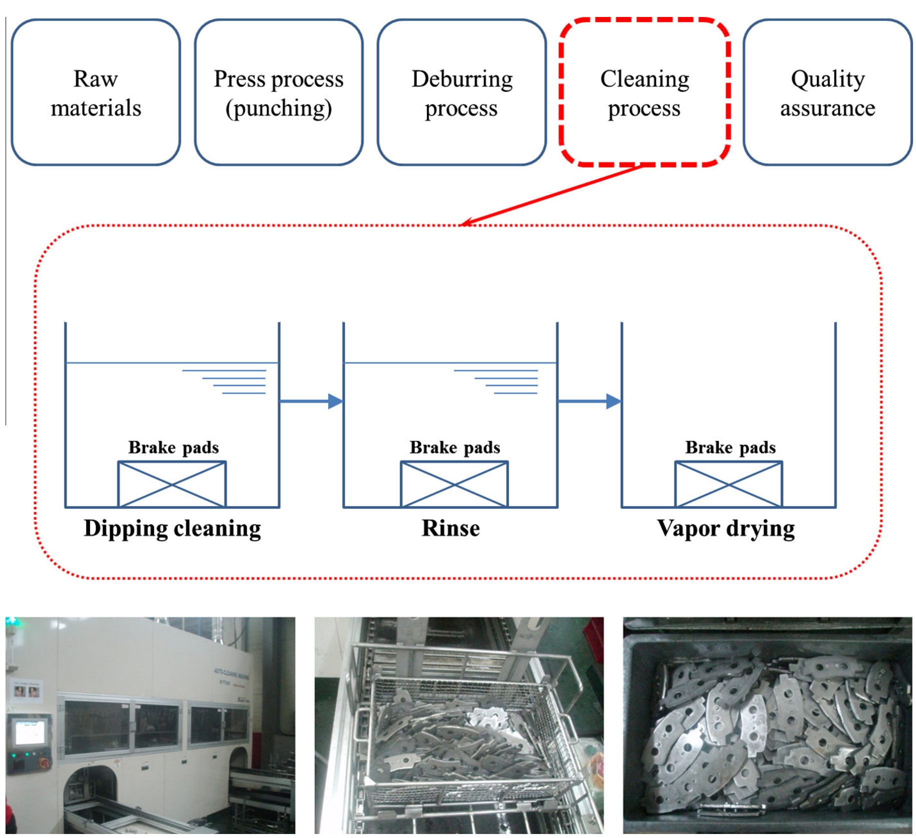

Fig. 1. Schematic illustration (flowchart) of industrial cleaning process.