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Fundamental investigation of charge injection type of electrostatic oil filter (effect of filter element on filtration speed)

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ABSTRACT

This paper deals with the effect of filter element on the filtration speed of a charge injection type of electrostatic oil filter proposed by Yanada and his coworkers. The effect of the filter elements that are inserted between the emitter and collector electrodes on the filtration speed is examined using several types of oil. In order to discuss the effect of the filter elements on the filtration speed, numerical simulations of electrostatic field are conducted and ion drag flow patterns are measured using two-dimensional filter models. An optimal filter configuration is proposed.

1. Introduction

The majority of the failures of machines utilizing lubricating oils results from the contamination of the oils and submicrometer-sized contaminants such as the oxidation products of additives have a strong influence on the failures [1]. While usual mechanical filters cannot remove such minute contaminants as submicrometer-sized ones, electrostatic oil filters can remove them from oils. By virtue of this characteristic, the electrostatic oil filters have contributed to decreasing the failures of machines, lengthening the lives of oils and to decreasing waste oil. However, the filtration speed of electrostatic oil filters is slow and it usually takes a long time for a contaminated oil to be purified.

Aiming to increase the filtration speed of the electrostatic oil filters, Yanada and his coworkers [2–4] have proposed a new type of electrostatic oil filter, named charge injection type of electrostatic oil filter. The new filter consists of one or more set(s) of an emitter electrode with many sharp projections and a smooth collector electrode and utilizes the charge injection phenomenon [5] to augment the charges on the surfaces of contaminants. Charges (ions) with the same polarity as that of the emitter electrode can be injected from the tips of the sharp projections into oils by applying a high DC voltage between the emitter and collector electrodes. The adsorption of part of the injected charges onto the contaminants' surfaces can increase the magnitude of Coulomb force exerted on the contaminants and, therefore, they can be removed from oils at a faster speed.

The filtration principle of this filter resembles that of an electrostatic precipitator used for the purification of gases. While the electrostatic precipitator utilizes the corona discharge phenomenon to generate ions, the charge injection type of electrostatic oil filter utilizes the charge injection phenomenon that takes place as a result of the movement of electrons at the interface between an electrode and some types of the molecules in liquid. The charge injection starts to occur at a lower electric field strength than that at which the corona discharge occurs in oil. However, both phenomena are seemingly the same and it is not easy to guarantee that no corona discharge takes place in the filter.

Previous investigations [2–4] have demonstrated that the filtration speed can be increased by injecting electric charges and that the degree of the increase in the filtration speed largely depends on the type of oil. Chemical analyses of the oil into which electric charges were injected for a long time have confirmed that the charge injection has no bad influence on the oil at all. It is

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believed that the latter result shows that no corona discharge takes place at least under the electric field strengths used in [2–4]. In addition, it has been shown that part of the contaminants captured on the collector electrode may be detached by the ion drag flow generated at the tips of the projections [4].

In general, both conductive and non-conductive contaminants are included in contaminated oils. Typical conductive and non-conductive contaminants are metallic wear debris and the oxidation products of additives, respectively. The filtration experiments have been conducted so far using only non-conductive particles, which can be captured on the electrode surfaces, to examine the effect of charge injection using a simple filter model. For charged conductive contaminants, they are attracted to the electrode surface of which polarity is opposite to their polarity but at the instant when they touch the electrode surface, they are strongly repelled from it. After that, they are again attracted to the electrode. Such a jumping motion is repeated and, therefore, conductive contaminants cannot be easily captured. In order to capture conductive contaminants, a filter element has to be inserted between the electrodes. The shape of the filter element and the position to be inserted between the electrodes may affect the filtration speed. However, the effects of those factors on the filtration speed have not been investigated yet.

In this paper, the effect of the filter element on the filtration speed is experimentally investigated using a filter model of which basic configuration is the same as the model used in the previous papers [2–4]. In order to discuss the effect of the filter element on the filtration speed, ion drag flow generated from the projection tips of the emitter electrode is observed using two-dimensional filter models and the three-dimensional electrostatic field is numerically analyzed.

2. Experimental apparatus and method

2.1. Electrodes and filter elements

If a metallic material such as stainless steel is used for filter elements, they can be repeatedly used after washing and never become waste. A nonmetallic material such as plastic can also be used for filter elements but the material has to possess a much larger permittivity than oil in order for lots of polarization charges to appear on the filter elements' surfaces. Plastics or other nonmetallic materials usually have much larger resistivities than oils. If nonmetallic filter elements are used, a relatively large potential drop may take place across them and the electric field strength in the oil is decreased. Taking these into consideration, a metallic material is adopted for the filter elements.

Fig. 1 shows schematics of the emitter electrode and filter element. Both were made of stainless steel plates with the dimensions of 100 mm × 100 mm. The emitter electrode was 0.3 mm thick and the filter element was 0.5 mm thick. Isosceles triangular projections were machined on the emitter electrode by laser beam; the length of the base and the height of the projections were 2 mm and 6 mm, respectively. The average radius of curvature of the tips of the projections was about 7 μm. The 78 projections in total were bent at right angles to either side at every longitudinal line as can be seen from the top view of Fig. 1(a). Because electric discharge is apt to take place if a conductive material exists in the vicinity of the tip of projection, circular holes were machined on the filter element at fixed pitches in the longitudinal and lateral directions to avoid the generation of electric discharge as shown in Fig. 1(b). The center of each hole of the filter element corresponds to the tip of each projection of the emitter electrode. The filter

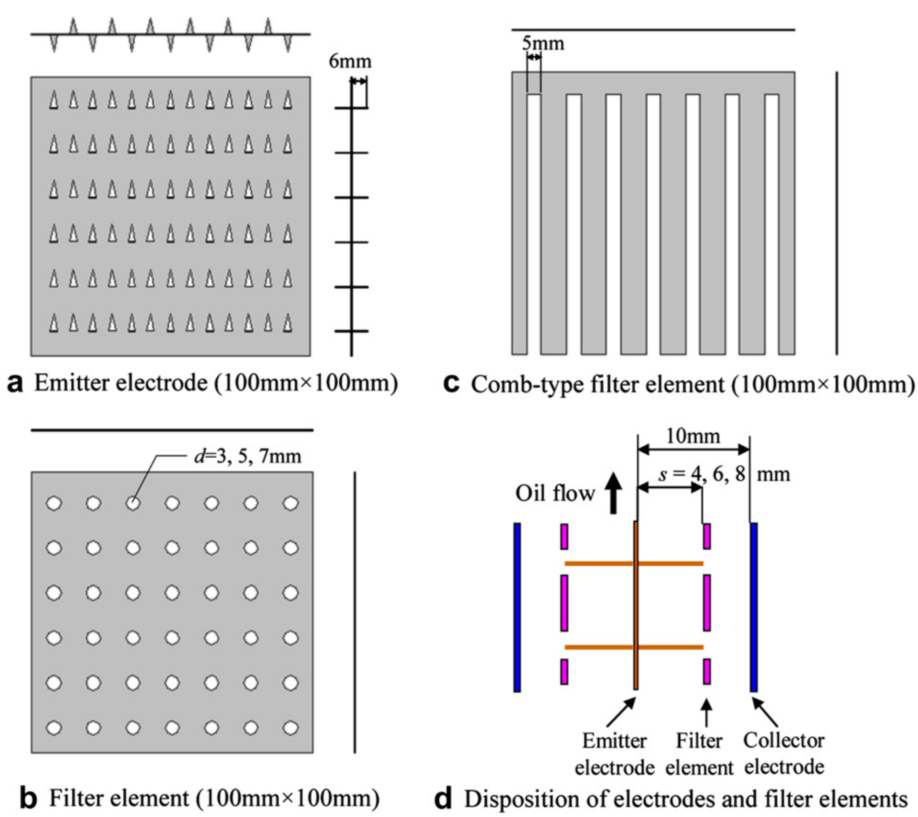

Fig. 1. Emitter electrode and filter element (a) Emitter electrode (100 mm × 100 mm) (b) Filter element (100 mm × 100 mm) (c) Comb-type filter element (100 mm × 100 mm) (d) Disposition of electrodes and filter elements.