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Effects of electrode and filter element shapes on characteristics of charge injection type of electrostatic oil filter

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A B S T R A C T

This paper reports on an improvement of the filtration speed of charge injection type of electrostatic oil filter. Numerical simulations of the ion drag flow field and electric field are performed to compare the charge density distribution, ion drag flow pattern, and electric field strength distribution for different electrode and filter element shapes. Filtration experiments are conducted and the experimental results are discussed in relation to the simulation results. It is shown that the numerical simulations used in this study can contribute in predicting a better structure for electrostatic oil filters.

Introduction

Particles in liquid are usually positively or negatively charged because of the preferential adsorption of ions in liquid and the dissociation of dissociative groups on the surfaces of the particles [1]. Applying a high electric field to an insulating liquid, such as oil, causes the particles to migrate in the liquid toward the electrode with a polarity opposite to that of the particles as a result of Coulomb force. This phenomenon is called electrophoresis and is the basic filtration principle of electrostatic oil filters. An electrostatic oil filter can separate not only coarse but also minute contaminant particles from oils, such as the minute oxidation products of additives, which cannot be removed by conventional mechanical filters. This is the most attractive characteristic of electrostatic oil filters. Unfortunately, the speed of electrostatic filtration is slow, and it takes a long time for a contaminated oil to be purified. However, the filtration speed can be increased if the quantity of charges on the particles is increased.

Yanada et al. applied the charge injection phenomenon [2] to electrostatic filtration and showed that the filtration speed can be increased by injecting charges into oils [3]. In addition, they examined the effects of mechanical factors, such as applied voltage, on filtration speed and demonstrated that an ion drag flow generated from the projection tips of the emitter electrodes may negatively influence filter performance [4]. They also investigated the effects of several electrode and filter element shapes and a few filter element positions between the electrodes on the filtration speed [5,6], determining the appropriate shapes and positions by trial and error.

There are many possible electrode and filter element shapes, as well as filter element positions between the electrodes. The electric field and ion drag flow field in the electrostatic oil filter may be strongly affected by the shapes and positions of the electrodes and filter element. If these fields are numerically simulated, the effects of the shapes and positions of the electrodes and filter element on filter performance may be quantitatively predicted. Therefore, a numerical simulation can contribute in finding a more optimal filter structure.

In the present work, the effects of the shapes of the electrodes and filter element on the electric field and ion drag flow field are first investigated by numerical simulation, and then the filtration experiments are conducted. The effects of the shapes of the

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electrodes and filter element on the filtration speed are discussed on the basis of the simulation results, and a desirable filter configuration is proposed.

The remainder of this paper is organized as follows. Section Filter models describes the filter models used. Section Numerical simulation describes the numerical simulation method, and the test setup and experiments are illustrated in Section Experimental apparatus and methods. Experimental and simulation results are presented and discussed in Section Results and discussion. Finally, the conclusion is given in Section Conclusion.

Filter models

Fig. 1 shows the two types of emitter electrodes used in this study. Fig. 1(a) is a standard type of emitter electrode with 72 triangular projections of 6 mm height; Fig. 1(b) is another emitter electrode with additional sub-projections of 2.5 mm height. As shown later in Figs. 4 and 5, the emitter and collector electrodes are separated by 10 mm. For an electrode separation distance of 10 mm, a projection height of 6 mm is the most appropriate from the standpoints of filtration speed and the avoidance of spark discharge. The reasons for machining the sub-projections are described later.

The two types of collector electrodes used in this study are shown in Fig. 2. One is a flat electrode (Fig. 2(a)) and the other is an electrode with rectangular fins (Fig. 2(b)). The reason for selecting the shape in Fig. 2(b) is described later in relation to Fig. 5(d).

Fig. 3 shows the two types of filter elements used. Fig. 3(a) is a standard type with rectangular holes, and Fig. 3(b) shows a new type of filter element modified by taking into account the results obtained in a previous paper [6]. It was shown in Ref. [6] that the filtration speed can be increased by placing the filter element at a slant position against the electrodes instead of placing it at right angles to the projections. The slanting filter element proposed in Ref. [6] could not be readily prepared because of its complicated structure. However, the filter element shown in Fig. 3(b) can be prepared from a stainless steel plate by laser beam machining and bending, although its production is more difficult than the standard type filter element shown in Fig. 3(a).

The electrodes and filter elements described above are combined to make four types of filter models. A schematic of the Type 1 filter model is shown in Fig. 4. The collector electrode is in the center, and two filter elements and emitter electrodes are placed symmetrically with respect to the collector electrode. The distance between the emitter and collector electrodes is 10 mm, and the filter element is placed in the center between the electrodes. All the

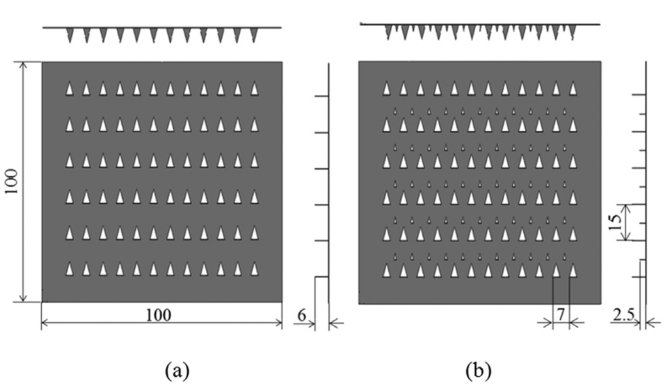

Fig. 1. Emitter electrodes (unit: mm), (a) standard type (b) emitter with sub-projections.

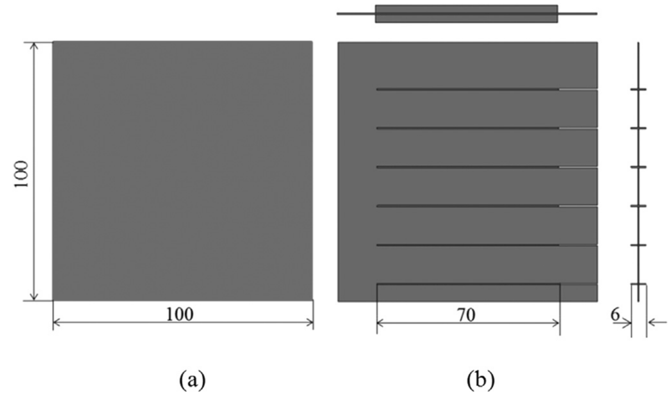

Fig. 2. Collector electrodes (unit: mm), (a) standard type (b) collector with rectangular fins.

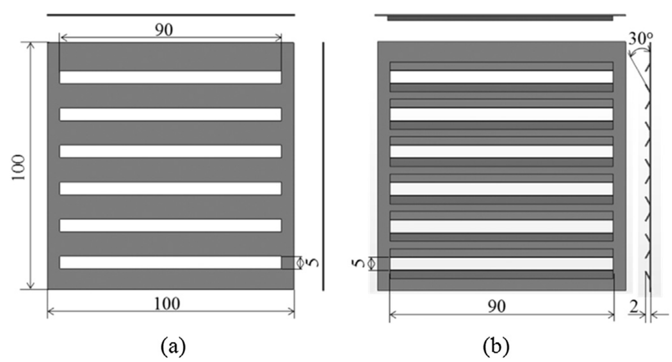

Fig. 3. Filter elements (unit: mm), (a) standard type (b) filter element with symmetrical slanting fins.

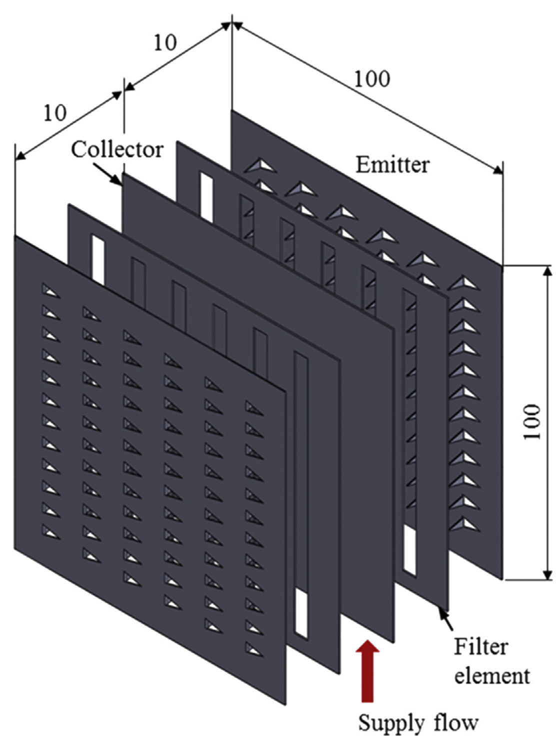

Fig. 4. Arrangement of electrodes and filter elements (Type 1 filter, unit: mm).