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Ultrasonic system for continuous washing of textiles in liquid layers ☆

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ABSTRACT

The use of ultrasonic energy for washing of textiles has been tried several times without achieving practical development. In fact, the softness of the fibres makes the cavitation to produce small erosion effect and the reticulate structure of the fabric favours the formation of air bubble layers which obstruct wave penetration. In addition, a high proportion of water with respect to the wash load and a certain water degassing is required to assure efficiency and homogeneity in the wash performance. Such requirements have hindered the commercial development of the ultrasonic washing machines for domestic purposes. For specific industrial applications, a great part of these limitations may be overcome. This article deals with a new process in which the fabric is exposed to the ultrasonic field in a flat format. Such process has been implemented at laboratory and at semi-industrial stage by using specially designed power ultrasonic transducers with rectangular plate radiators. The cleaning effect is produced by the intense cavitation field generated by the plate radiator within a thin layer of liquid where the fabric is introduced. The homogeneity of such effect is achieved by the successive exposure of all the fabric areas to the intense acoustic field. In this paper the structure and performance of the developed system are shown.

1. Introduction

Cleaning of solid rigid materials is one of the most popular applications of power ultrasound. Nevertheless the use of ultrasonic energy for textile washing has been explored over several years without achieving commercial development. As well known, the cleaning action of ultrasonic energy is mainly due to transient cavitation. The implosion of small gas or vapour bubbles inside the cleaning liquid and near the surface to be cleaned imposes such stresses on the surface that erodes the contaminant coat and removes the impurities. Other phenomena, such as streaming and stable cavitation, may also contribute to the dispersion of the particles of contaminant removed from the surface. The strategies for ultrasonic domestic washing have been generally directed towards the production of cavitation in the entire volume of the bath in which the fabrics to be washed are placed [1–3]. Such systems offer significant inconveniences. In fact, it is difficult to achieve a homogeneous distribution of the acoustic field in the entire washing volume. Then in the areas of low acoustic energy the cavitation threshold is not reached and to avoid the washing to be irregular the fabric has to be continuously moved so that it passes through the areas of high acoustic intensity of the washing cavity. Other general difficulties come from the softness as well as from the reticulate structure of the fabric materials. The softness of the fabric makes cavitation to produce small erosion effect while its reticulate structure favours the formation of layers of big bubbles that obstruct wave penetration. Therefore the wash load has to be exposed to the ultrasonic field in the way to assure the production of "strong transient cavitation" on the fabric surface. That means the collective cavitation of a large number of bubbles in the gassy liquid [4].

During several years we investigated about the use of ultrasonic technologies for cleaning textiles in domestic washing machines. Although it was found out that by degassing the wash liquor in a certain proportion the ultrasonic washing resulted in a better wash performance than the conventional washing [5,6], the practical conditions required have made difficult the commercial development of ultrasonic washing machines for domestic use.

However, there exists a potential and a present interest for the applications of the ultrasonic energy in industrial textile treatments [7]. This is, for example, the case of the textile manufacturing industry [8]. Fabric processing in textile manufacturing is a wet processing to improve the appearance and serviceability of the fabric. It includes several operations that usually require washing the fabric. The use of ultrasonic energy in such operations may help in speeding up the process and in improving the quality of the final product. Looking for such industrial applications, a new process and a system has been developed and patented [9] in which the textiles are exposed to the ultrasonic field in flat format and within

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a layer of liquid of a few millimeters by applying specific plate transducers. Such process has been implemented at laboratory and semi-industrial stage. This paper deals with the structure and performance of the developed system.

2. Description of the procedure

The new washing procedure is based on the application of the ultrasonic energy to the textiles to be washed by means of special vibrating plate radiators that are in direct contact or very close to them. The textiles are submerged in a layer of liquid of a few millimetres in thickness and conveyed in a flat format through the ultrasonic radiator by means of a roller-type system (Fig. 1). The plate radiator is designed to vibrate with one of its simpler flexural vibration modes to avoid as much as possible great differences in the vibration amplitudes of the different areas of the plate.

The washing liquor used was a solution in standard tap water containing 1.75 g/l of SDBS (sodium dodecylbenzenesulphonate) surfactant and 3.5 g/l of STP (sodium triphosphate) a builder to enable surfactant to be more effective. The layer of washing liquor was frequently refreshed. The temperature of the washing solution was kept constant at about 25 °C. Such temperature was chosen for practical reasons (the main objective of the present development is to implement a simple and low energy consumption process) and because according to our experience and the technical literature [6] this value is within a range (20–30 °C) in which the cavitation intensity is kept relatively constant.

The new procedure offers notable characteristics to be underlined. The cleaning action is produced by the intense cavitation field generated by the plate radiator within the layer of liquid which is very favourable to produce high cavitation effect [10]. From the practical point of view, such liquid layer is very convenient for the low consumption of washing liquid required. The homogeneity of the washing effect is achieved by the fact that the fabric is passed along the plate surface in such a way that all its parts are exposed during the same time to the areas of intense acoustic field. Finally, the radiation force produced by the high intensity ultrasonic beam directed over the surface of the textiles helps to remove the big bubbles formed within the reticulate structure of the fabric and therefore the requirement of degassing the liquid is not essential in this process.

No chemical changes in the components of the washing solution due to the ultrasonic action were detected.

3. Experimental laboratory set-up

The washing procedure previously described was initially implemented at laboratory stage by means of the set-up shown in Fig. 2. The plate transducer developed for this laboratory set-up basically consisted of a rectangular aluminium flat-plate of about 22×5 cm^2 flexurally vibrating, driven by a composite length expander piezoelectric vibrator (Fig. 3a). The plate radiator was designed to operate at about 20 kHz with a flexural mode of two nodal lines parallel to the longer side of the plate (Fig. 3b). This transducer has a maximum power capacity of about 200 W which, according to the electroacoustic efficiency of the transducer (over 90% in water) and the amplitude distribution, corresponds to an applied acoustic intensity of about 1.5 W/cm^2.

By using this set-up the influence of the ultrasonic energy on the washing performance was studied for a number of representative standard test pieces: EMPA-101 (cotton soiled with carbon black and olive oil), AS9 (polyester/cotton soiled with fatty material and solid particles) and WFK30D (polyester soiled with skin fat and pigments). Fig. 4 shows the cleaning results obtained by using the ultrasonic system compared with those achieved with a conventional washing machine. The equally good results

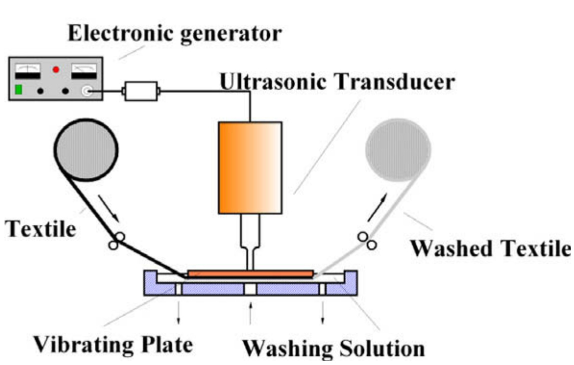

Fig. 1. Basic scheme of the process.

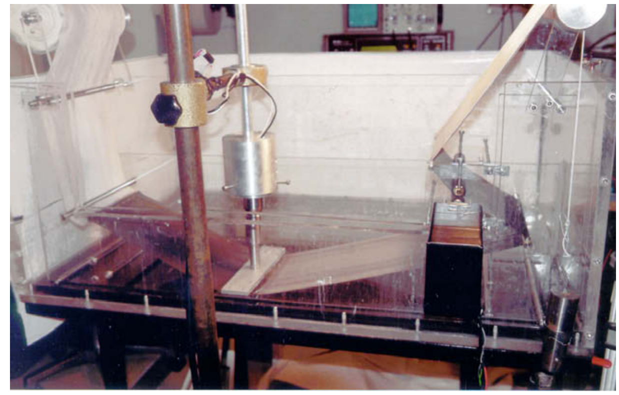

Fig. 2. Laboratory set-up.

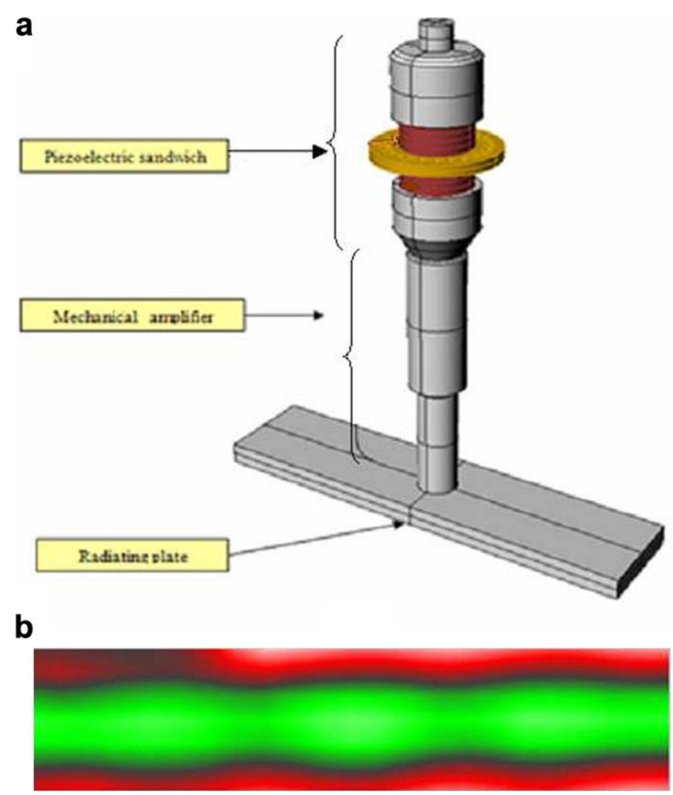

Fig. 3. Basic scheme of the plate transducer (a), and operating vibration mode of the plate radiator (b).