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Ultrasonic cleaning: An historical perspective

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ABSTRACT

The development of ultrasonic cleaning dates from the middle of the 20th century and has become a method of choice for a range of surface cleaning operations. The reasons why this has happened and the methods of assessing the efficiency of ultrasonic cleaning baths are reviewed.

1. Introduction

Ultrasonic cleaning is nowadays regarded nowadays as a conventional technique for industry and also in both scientific and medical laboratories. Its origins date back to the 1950s and it was beginning to become established around 40 years ago. In a series of reviews on the uses of power ultrasound in industry "Macrosonics in Industry" Neppiras suggested that ultrasonic energy performed a physical function in the process of cleaning which could not be obtained by any other industrial tool. He further maintained that its ultimate success depended on the selection of proper equipment and materials, a knowledge of both cavitation and chemical cleaning techniques together with process control [1]. A later review in the series dealt exclusively with cleaning and in it Bulat claimed that this was probably the commonest use of power ultrasound and one which was being improved continually [2]. Nevertheless we seldom give a thought as to why ultrasonic cleaning has proved to be so widely accepted.

In terms of its historical development it is reasonable to ask what factors have made it important? In other words what are its advantages over more traditional cleaning methods? To help answer these questions we can explore the alternatives that were available in the 1950s when ultrasonic cleaning first emerged as a technology. Many of the cleaning methods available then are still in use today and so if we consider these then it will become easier to appreciate the reasons why surface cleaning with ultrasound has gained such prominence.

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2. Survey of non-ultrasonic cleaning technologies

The need for large scale and heavy-duty washing and cleaning has existed since the industrial revolution or even before. There are several different approaches to these more traditional cleaning processes but they can be grouped in terms of the ones used in each of the various types of manufacturing industries.

2.1. Heavy industry

After machining and/or assembly of individual parts most engineering products must be cleaned free of cutting oil residues and swarf. This will also be true when parts are dismantled and recycled because ingrained debris must be removed. For degreasing the most common method in the past was immersion in a hot chlorinated solvent. In the days before health and safety concerns precluded such materials from common use these methods were certainly more effective than the use of aqueous or semi-aqueous immersion processes [3]. An alternative to total immersion is vapour degreasing where the object to be cleaned is placed in a heated vapour tank above a chlorinated solvent. The vapour combines with the grease to form droplets that fall back into the solvent tank. Vapour degreasing is ideal for reaching into small crevices in parts with convoluted shapes and also to remove more stubborn soiling. An additional benefit is that parts degreased in chlorinated solvent or vapours come out of the process dry; there is no need for an additional drying stage, as required in water based technologies.

The major drawback to such processes is of course the health and environmental problems associated with the use of chlorinated solvents such as carbon tetrachloride (CTC), tetrachloroethylene (PCE), trichloroethylene (TCE) and 1,1,1-trichloroethane (TCA) which were four of the most widely used cleaning and degreasing solvents. The history of the production and use of these four compounds can be linked to the development and growth of the synthetic organic chemical industry in the USA [4]. In the early years of the 20th century, CTC and TCE were used as a replacement for petroleum distillates in the dry-cleaning industry. The latter became the solvent of choice for vapour degreasing in the 1930s. But in the 1960s TCA became increasing popular [5]. During the 1980s environmental and safety issues led to the banning of chlorinated solvents for parts cleaning and in the 1990s, CTC was phased out under the Montreal Protocol due to its role in stratospheric ozone depletion.

It became clear that aqueous systems should replace chlorinated solvents but methods were then needed to make the water based cleaning more efficient. One route was to improve the performance of detergents for immersion cleaning and this required considerable chemical development. Mechanical methods were also required to ensure that detergent solutions would reach all parts of the surface of the object to be cleaned. Two alternatives emerged which have remained popular to this day: pressure jetting and parts washing. The two differ in that pressure jetting involves a pressurised jet of water plus detergent directed, often manually, at the item to be cleaned. In contrast a parts washer is used to clean smaller engineering items generally placed on some form of carousel contained within an enclosed cabinet. The cleaning is achieved by spraying or immersing the parts in aqueous detergent.

2.2. Food industry

In the food industry baked on deposits or residues on moulds or cutting tools need to be hygienically removed. Traditional methods involve simply soaking in a water/detergent/bactericide mixture together with agitating and heating which is followed by a rinse cycle. The choice of detergent is key to this and so is the operating temperature with higher cleaning temperatures being more effective. As with industrial cleaning pressure jetting or a form of parts washing are sometimes used to help in the removal of heavily adherent material [6].

2.3. Medical instruments

More specific methods are needed for the cleaning of surgical instruments, medical implants and dental implements. The cleaning method must both remove dirt and sterilise the surface. The former can be done with an automated washer-disinfector to carry out the process of cleaning and disinfection consecutively. Generally though for full sterilisation an autoclave is required.

2.4. Clothing and textiles

Traditionally clothing and textiles were cleaned in stirred hot water with detergent. The process temperature depends on the fabric but the overall process is one of tumbling with hot aqueous detergent followed by rinsing and drying. Not much has change here except that newer detergents are produced and the washing can be done at significantly lower temperatures down to 30 °C.

3. The origins of ultrasonic cleaning

It is difficult to trace the actual "eureka" moment when ultrasound was applied to cleaning technology. The original discovery that ultrasound could be used to improve cleaning does not appear to be published as any kind of authenticated fact. Indeed it is not at all obvious why one would want to apply ultrasonic irradiation to a cleaning system. What is clear however is that by the 1950s there were a number of companies who had developed ultrasonic cleaning systems. Amongst these in the USA were the Bendix Corporation in Davenport, Iowa, Branson Cleaning Equipment Co., Danbury, Connecticut and Zenith Ultrasonics, Norwood, New Jersey while in the UK there were Mullard in Redhill, Surrey and Kerry, Hitchin, Hertfordshire.

In a report on the 20th Engineering, Marine and Welding Exhibition held at Olympia in London the Engineer magazine reported on a development in cleaning by Mullard Ltd. [7]. The company had on show a mechanised ultrasonic cleaning plant built in conjunction with Kerry Ltd. suitable for removing loose contamination (e.g. swarf, lapping compounds, oil and grease) from engineering parts. The parts to be cleaned were in baskets that passed through three tanks in succession first, through two tanks containing trichlorethylene a pre-wash tank and then an ultrasonic cleaning bath powered by a 2 kW ultrasonic generator and finally through a hot vapour zone for drying. The ultrasound was at a continuously variable frequency between 10 and 30 kHz. Apart from the solvents used the basic set up is much the same as with today's automated ultrasonic cleaners.

Ultrasound is particularly useful for surface decontamination because of two factors related to cavitation in a liquid medium:

- Above the cavitation threshold non-symmetric collapse of a cavitation bubble near to a surface results in the formation of a powerful jet directed at the surface which can dislodge dirt and bacteria. This is an effective mechanism for conventional cleaning systems operating in the 40 kHz range.
- When acoustic waves pass through the cleaning fluid acoustic streaming occurs which reduce the thickness of hydrodynamic boundary layer on any immersed surface. As a result tiny particles on the surface become more exposed to the liquid streaming which can overcome the adhesion force between particle and surface. This process becomes important in high frequency 1 MHz megasonic cleaning.

The particular advantage of ultrasonic cleaning in this context is that it can reach crevices that are not easily accessible using conventional cleaning methods. Objects that can be cleaned range from large crates used for food packaging and transportation to delicate surgical implements such as forceps. The use of ultrasound allows the destruction of a variety of fungi, bacteria and viruses in a much reduced processing time when compared to thermal treatment at similar temperatures. The removal of bacteria from various surfaces is of great importance to the food industry and can be efficiently accomplished with the combined use of sonicated hot water containing biocidal detergent [8].

For small and delicate items such as computer components, silicon wafers and printed circuit boards the method of choice is megasonic cleaning and this will be dealt with later in this article.

4. The development of ultrasonic cleaning – a consideration of parameters that affect efficiency

4.1. Cleaning fluid

The cleaning fluid plays an important part in determining the effectiveness of an ultrasonic cleaner. In the early days, as with conventional cleaning, chlorinated solvents were used e.g. perchloroethylene, trichloroethylene, 1,1,1-trichlorethane, carbon tetrachloride. For ultrasonic cleaning Colclough emphasised that the solvent was not only as the cleaning medium but also as an organic liquid used to transmit the ultrasonic vibrations from the