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METHOD FOR THE ULTRASONIC CLEANING OF SURFACES

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2 Sheets-Sheet 2

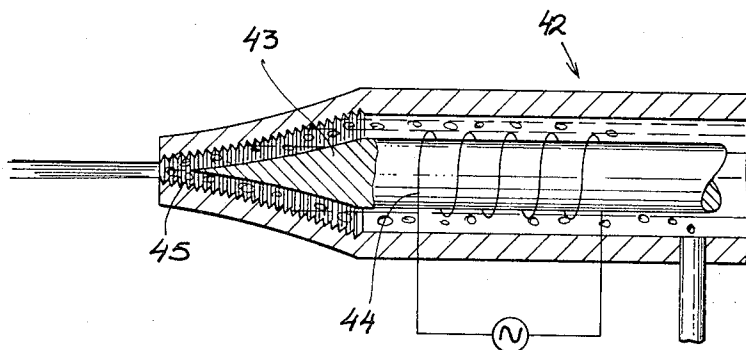


Fig. 4

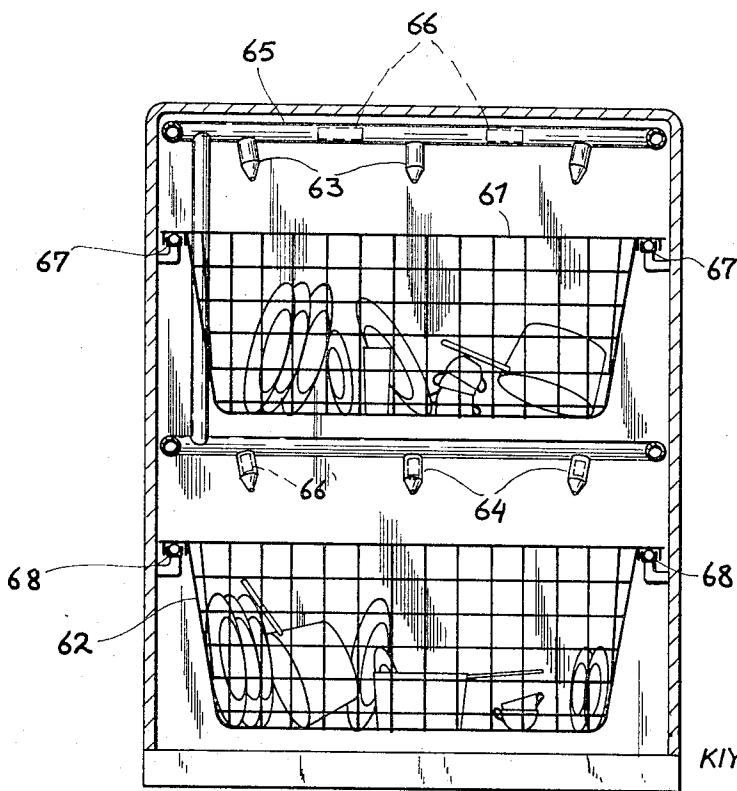


Fig. 6

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METHOD FOR THE ULTRASONIC CLEANING
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1 Claim. (Cl. 134—1)

ABSTRACT OF THE DISCLOSURE

Method for cleaning a surface by directing a high-pressure stream of liquid/gas mixture from a nozzle thereagainst, ultrasonic vibrations being imparted to the mixture in the nozzle by an electromechanical transducer cooperating with a resonant body downstream thereof and having a natural frequency of vibration of the order of that generated by the transducer, while serrated areas on the internal tapered wall of the nozzle and on the resonant body augment the turbulence in the nozzle.

My present invention relates to the removal of undesirable surface accumulations from metallic and non-metallic bodies by directing a stream of cleaning fluid thereagainst and, more particularly, to an improved method of carrying out this removal.

It has been the practice heretofore, to descale metallic bodies, masonry and other surfaces and to effect a soil removal therefrom by subjecting the contaminated surfaces of the bodies to a high-pressure and/or high-velocity stream of a fluid (generally a liquid) in which the contaminants are soluble or otherwise entrainable with or without the aid of chemical solubilizing agents or solid particles entrained by the fluid stream to effect a loosening by impact of the contaminant. The considerable advantages of this method of cleaning or clearing a surface has led to many efforts to develop an apparatus for carrying out this technique with greater efficiency, such apparatus being primarily improved spray guns, means for feeding an adjuvant to the fluid stream, mechanism for concentrating the stream or insuring the maintenance of a predetermined impact angle on the surface etc. In all cases, however, the principle of operation remained the same and no marked increase in the cleaning efficiency was noted. A most significant drawback of the aforescribed system has been the relatively large volume of fluid employed as a consequence of the relatively long treatment periods necessary. This disadvantage becomes increasingly important when relatively expensive solvents (e.g. kerosene or trichloroethylene) are employed.

It is, consequently, the principal object of the present invention to provide an improved method of treating surfaces to remove contaminants therefrom, utilizing a stream of fluid directed against the surface.

These objects, and others which will become apparent hereinafter, are attained, in accordance with the present invention, by a method of removing undesirable matter from the surface of a body which comprises directing a stream of fluid at this surface in such manner that the kinetic energy of the fluid particles is at least partly transferred to the contaminants, and supplying to these particles a mechanical vibration substantially in the direction of the impact with the surface to increase the transferable energy of impact and thus the efficiency of contaminant removal. I have found, in this connection, that a fluid directed at relatively high pressure against a contaminated surface effects removal of the undesirable material as a consequence of a process which can be described, in simple terms, as repeated collision of par-

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ticles of the fluid with the contaminant material at the surface to loosen the adherent material and entrain it along with the fluid stream. I have further observed that the efficiency of soil removal by this repeated-impact mode can be strongly augmented when the impacting particles undergo vibration at supersonic frequencies substantially in the direction at which the particles collide with the surface, these vibrations being "superimposed" upon the impact velocity of the fluid stream.

According to an essential feature of the present invention, therefore, an ultrasonic vibration is supplied to the fluid stream in such manner that, at least at the nozzle of the cleaning apparatus, a vibrational mode is imparted to the discharged fluid particles. I have found that a marked improvement in the cleaning efficiency of a fluid stream can be achieved by providing an electromechanical transducer in the discharge conduit or the nozzle at the terminus thereof, this transducer being energized by a relatively high-frequency current to produce mechanical vibrations in the fluid stream. Alternatively, or as a supplement to these mechanical oscillations, the fluid stream can be relatively conductive (i.e. composed of an electrolyte) with the oscillations supplied by electromagnetic pulsing of the fluid stream. The transducer may be of a body of, for example, piezoelectric material which experiences a change of volume upon application of an electric field, so that a direct conversion of high-frequency electric current to mechanical oscillations is provided, it is also possible to achieve the conversion of electrical energy to mechanical energy indirectly (e.g. via magnetic effects). Magnetic oscillations need not be derived from complete mechanical displacement of an armature but can result from the application of a magnetic field to a magnetostrictive body in which the oscillations are generated just as direct conversion of high-frequency electrical energy to mechanical oscillations can be produced by electrostriction.

I have found that the transfer of vibrational energy to the liquid can be augmented by serrating the discharge conduit at least in the region of the nozzle and, preferably, constricting the latter at the mouth. Apparently these serrations, which may be annular or broken in the circumferential direction, increase turbulence at the nozzle and ensure an increased transfer of vibrational energy to the particles through a process of collision and rebound. In this connection it may be noted that excellent results are obtained when the nozzle is, in effect, tuned to the ultrasonic frequency. To this end I have found it convenient to provide the nozzle with a taper whose length is an integral number of half-wave lengths ($L=n\lambda/2$) or to provide a body in the constricted portion of the nozzle which oscillates substantially at the frequency of the supplied vibrations or an aiding harmonic thereof. Since the vibration is of a sonic type (i.e. alternate rarefaction and condensation), such harmonics may have half-lengths equal to an integral number of half-wave lengths of the supplied frequency. The resonating body may be a transducer in the sense previously described or merely an element suspended so that it vibrates at a frequency harmonically related to the original or supply frequency.

According to a further feature of this invention, the pressure fluid is a liquid to which a gas has been added in a continuous stream, the gas apparently further increasing the turbulence necessary to promote transfer of vibrational energy to the particles of liquid or being present as a substance adapted to take up such energy temporarily while entrained in the liquid and subsequently transfer it to particles of the liquid; the use of the inert gas increases efficiency by at least 20% in most cases.

The above and other objects, features and advantages of the present invention will become more readily appar-

ent from the following description, reference being made to the accompanying drawing in which:

FIG. 1 is an axial cross-sectional view through the nozzle of a descaling device, in accordance with the present invention, using a magnetostrictive transducer;

FIG. 2 is an axial cross-sectional view of a nozzle employing an electrostrictive transducer;

FIG. 3 is a view similar to those of FIGS. 1 and 2, illustrating the use of electromagnetic oscillating means according to the invention;

FIGS. 4 and 5 are axial cross-sectional views illustrating further modifications of the invention; and

FIG. 6 shows, in cross-section, a portion of a dish-washing device embodying the invention.

In FIG. 1, I show a descaling device having a nozzle 10 into which a descaling liquid is passed axially (arrow 11) and is admixed with a gas stream fed transversely into the nozzle by tube 12. The interior of the nozzle tapers toward its mouth 13, which is shown to be inclined to the surface 14 to be descaled, whereby the liquid stream 15 emitted from the mouth 13 of the nozzle forcibly removes the scale 16. Within the nozzle 10 there is provided an electromechanical transducer 17 of the magnetostrictive type. This transducer comprises a body 18 of a material adapted to convert electromagnetic energy into mechanical vibrations, flexibly mounted by rods 19 on an inner wall of the nozzle in such manner as to be capable of oscillating at the vibrating frequency. Body 18 is surrounded by a coil 20 energized by a high-frequency alternating current source 21 at ultrasonic frequency.

Suitable transducer materials include barium titanium oxide (BaTiO_3), ferrite (Fe_2O_3), aluminum ferrides and nichrome alloys; the latter are capable of developing 15 watt/cm.² while the ferrites have power outputs of about 6 watt/cm.² and the barium titanium oxide of 3 watt/cm.² for corresponding masses. The BaTiO_3 is capable of developing frequencies of 10 to 500 kc./sec. without difficulty while ferrite is suitable for frequencies between 10 and 100 kc./sec.

Example I

With the device of the type illustrated in FIG. 1 using barium titanium oxide and a frequency of 47 kc./sec. and an acoustical power output of 6 watt/cm.², a stream of water emitted at a pressure of 5 kg./cm.² and a velocity of 100 liter/min. was able to descale a motor casting of iron for the body of a 10 HP motor. 3% by volume of alcohol (Skydrol) was added as a rust-inhibiting agent. The nozzle was composed of bronze and had a converging portion of 120 mm. in length tapering from a diameter of 30 mm. to a diameter of 10 mm. The distance between the mouth of the nozzle and the workpiece was 200 mm. and the temperature of the liquid 8° C. Under these conditions the casting face was cleaned of scale after a contact duration of 20 seconds with the liquid. Using the identical parameters, a steel body was degreased by substituting kerosene for the water. It was found that other conventional organic degreasing solvents were also effective. These solvents included Henkel P-3, Cleanall S and trichloroethylene.

Example II

Following the steps outlined above, using water, approximately 2 to 4 liter/min. of inert gas (i.e. nitrogen) was admixed with the liquid stream within the nozzle. A period of only 15 seconds was required for treatment of the face in contrast with a treatment time of 20 seconds in the absence of the nitrogen adjuvant.

Example III

The process using water in Example I was carried out without the superimposition of ultrasonic vibrations upon the velocity of the liquid stream for a period of one minute. The nozzle had a taper length of 120 mm. from a diameter of 30 mm. to a diameter of 10 mm. as previ-

ously described and the water pressure was 5 kg./cm.², with a flow velocity of 100 liter/min. The nozzle/work-piece distance was 200 mm. During the time indicated, no descaling was observed. When the transducer was again energized at a frequency of 47 kc./sec., descaling was accomplished in 20 seconds. When the same test was carried out in the absence of an ultrasonic vibration but with addition of gas to the liquid, there was no noticeable improvement.

In FIG. 2 there is illustrated a modified nozzle 22, according to the invention, wherein the tapered portion has a length L which is an integral number of half wavelengths of the sonic frequency developed by the electro-sonic transducer 23. The latter can comprise a body 24 of barium titanium oxide between conductive layers 25, 26. It may be noted at this point that it is an essential feature of this invention that the resulting vibrations be in the direction of the liquid flow. An alternating current source 27 is connected across the transducer 23 to provide the electric energizing pulses of a frequency at which the transducer is designed to operate. A tube 28 supplies an adjuvant gas to the nozzle, whose tapered interior 30 is provided with annular serrations 31 which augment the transfer of vibrational energy to the liquid.

Example IV

The process of Example I was followed with the apparatus of the type shown in FIG. 2. The transducer 23 had an output power of 3 watt/cm.² at 47 kc./sec. and resulted in a descaling of the casting surface in a period of 18-20 seconds. When the output power was increased to 6 watt/cm.², the descaling was accomplished in 10-15 seconds. In this case, the length of the tapered portion L of the nozzle was approximately 80 mm., i.e. an integral number of half wavelengths (80 Angstrom units). The serrations had a depth of about 10 microns and an apex angle of 60°.

In FIG. 3 I show another nozzle 32 in which the transducer includes a magnetic armature 33, the latter being oscillated (arrow 34) in the direction of mouth 35 by a magnetizing coil 36 and an alternating-current source 37 connected therewith. Armature 33 has a narrow extension 38 projecting into a serrated passage 39 of small cross-section adjacent the mouth 35 of the nozzle. The main interior portion of the latter is also serrated as shown at 40. Gases admixed with the liquid stream at 41. The use of the extension 38 or another element partly filling the discharge cavity apparently increases the transfer of vibrational energy to the liquid as a consequence of the elimination of laminar flow by holding the Reynolds number above that at which turbulence commences.

Using the device of FIG. 3, a basketful of screw-machine parts was descaled by passing the nozzle over the parts at a distance of about 15 cm. and supplying kerosene through the nozzle at a rate of about 25 liters per minutes and a pressure of 7 kg./cm.² at room temperature. The armature 33 is vibrated at a frequency of 20 kc./second with a maximum stroke of about 10 microns. The main portion of the nozzle had an internal diameter of 40 mm. whereas the passage 39 had a diameter of 10 mm. The parts were cleaned by a single pass of the nozzle over them. When no ultrasonic frequency was applied, there was a noticeable retention of grease upon the metal (brass). An ultrasonic frequency ranging from 10 kc./second to about 10 megacycles was found most effective. It may be noted that this method of degreasing differs sharply from earlier degreasing techniques using ultrasonics wherein the vibrations are supplied to a body of liquid in contact with the material to be degreased or to the parts themselves.

In the nozzle 42 of FIG. 4 the transducer is again an armature 43 vibrated by a magnetic coil 44 at an ultrasonic frequency and cooperating with the serrated and tapered interior 45 of the nozzle, the latter having the configuration of the nozzle of FIG. 2. It should be ob-

served that the use of a vibrating pointed element 43 whose configuration is substantially complementary to the configuration of the nozzle at its outlet permits a 5-10% increase in the cleaning efficiency and reduces the cleaning time by a similar proportion. In the nozzle 46 of FIG. 5, the electromagnetic transducer 47 is suspended for oscillatory motion within the nozzle on flexible rods 48 and is provided with a serrated periphery composed of an array of annular grooves. Additionally, a resonant body 50 is suspended in a compartment 51 of the nozzle adjacent to the mouth 52 thereof and is serrated to vibrate in step with the supplied frequency. The suspension means may be a vibratile reed 53. The distance *d* between the constricted passage 54 of the nozzle and the resonating body 50 as well as the distance between the body and the constricted mouth 52 is so selected as to be an integral number of half wavelengths so that the passage 51 constitutes, in effect, a resonating cavity. If desired, body 50 may itself be a transducer vibrated via an alternating-current source 55 in step with transducer 47, care being taken to ensure that the distance between the transducers is equal to an integral number of wavelengths of the supplied current. A further increase in cleaning efficiency of about 10% over that of the device of FIG. 3 can be achieved by this construction.

In FIG. 6 there is shown a dishwashing machine 60 in which the articles to be washed are retained in the usual baskets 61, 62 or upon suitable trays in the path of the liquid jets from a plurality of nozzles 63, 64. As shown in this figure, the supply conduit 65 for nozzle 63 is provided with a plurality of spaced transducers 66 adapted to provide ultrasonic frequencies for increasing the washing efficiency. The nozzles 64 of the lower array have the transducers built into them in the manner illustrated in FIG. 2. The baskets 61 and 62 can be withdrawn from the machine, upon termination of the cleaning operation, on rails 67, 68. A device of this type, incorporating electrosonic transducers to augment the cleaning action, was found to give 25-50% better results in removing greasy substances from table articles. The improvement in cleaning efficiency permitted a reduction in the washing time by at least 25% and enabled a reduction in the total volume of water employed.

Example VI

A plurality of nozzles of the type illustrated in FIG. 2 were arranged radially about a common center through which a stainless steel wire was passed at a rate of 0.5 m./min. The wire had a diameter of 5 mm. and was composed of 18/8 stainless steel. Two nozzles were employed, using chromium oxide (CrO₂) as the transducer material with a power output of 5 watt cm.² with a frequency of 100 kc./second, a flow rate of 50 liter/min. and a liquid pressure of 5 kg./cm.². The steel wire was found to have a bright appearance after passing through the spray.

A series of tests were made using a device of the type illustrated in FIG. 5 without the aid of any electromechanical transducer element. In this test, the transducer 47 was dispensed with and the resonant body 50 provided upon the reed 53 without any external source of activation. With the configuration illustrated in FIG. 5 it was found that there was a tendency for body 50 to vibrate at a frequency determined by the Youngs modulus of the system. It was thus possible to supply a vibrating mode to the particles without the use of any external source. Vibration control was effected by varying the modulus of the vibratile element.

The invention described and illustrated is believed to admit of many modifications within the ability of persons skilled in the art, all such modifications being considered within the spirit and scope of the appended claims.

I claim:

1. A method of cleaning a surface, comprising the steps of:
 - (a) directing a stream of liquid against said surface from the mouth of a nozzle at an elevated pressure;
 - (b) admixing with said liquid in said nozzle a gas admitted to the nozzle at a location upstream of said mouth;
 - (c) imparting ultrasonic vibrations to the mixture of gas and liquid passing through said nozzle by operating at ultrasonic frequency an electromechanical transducer between said location and said mouth; and
 - (d) augmenting the vibrations imparted to said nozzle by disposing a resonating body in said nozzle between said mouth and said transducer, said body having a natural frequency of vibration of the order of the frequency of the vibrations generated by said transducer.

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