

LEACHING DEVICE

Field of the Invention

The present invention relates in general to toxicity analysis of solid samples and more particularly to a leaching device.

5 Background of the Invention

Toxicity Characteristic Leaching Procedure, also known as TCLP testing, is an established standard to leach toxic components from solid samples such as, for example, solid waste and contaminated soil for further characterizations. TCLP testing is also used to determine whether a solid sample is suitable for direct disposal in a landfill or is
10 hazardous and requires detoxification or treatment.

The TCLP testing process is designed to simulate long-term leaching of toxic components such as heavy metals by time as solid waste is deposited or buried underground. In the TCLP testing process, at least 100 grams (g) of a solid sample are required to be leached in an acetic acid / sodium hydroxide solution at a 1:20 ratio by
15 weight and a bottle containing the solution is required to be tumbled continuously from top to bottom at a speed of 30 +/- 2 revolutions per minute (rpm) for 18 hours. The TCLP testing process takes 18 hours to leach the toxic components for each test and thus can only be conducted in a laboratory. Consequently, TCLP testing is not suitable for on-site identification of hazardous heavy metals in solid waste or soil or for users to make an
20 on-site decision on waste disposal or soil quality for food growth.

Currently, microwave and ultrasound have been investigated as alternative methods to accelerate the TCLP process. Microwave consumes high power and is therefore more suitable for laboratory scale usage. Ultrasonic is more suitable for on-site acceleration of the leaching speed of heavy metals and is widely used in leaching
25 processes to extract targeted elements from solid materials with a designated solution.

For ultrasonic leaching, there are generally two methods. One method is to insert an ultrasonic probe directly into a solution for metal leaching of a solid sample, but this may cause cross-contamination and/or layer depletion of the ultrasonic probe, resulting in efficiency reduction. The other method is to use a commercially available ultrasonic

bath to sonicate a bottle filled with a solid sample and solution so that the cross-contamination issue is eliminated. However, for this method, investigations have shown that tumbling is required to achieve good repeatability with low standard deviation among tested toxic heavy metal ion concentrations for replicated leaching experiments and to
5 achieve a similar pH value of the leachate obtained by ultrasonic leaching compared to that of TCLP leaching. Because the pH value of a leachate affects solubility of heavy metals in the leachate, it would be desirable to make the pH value of the leachate obtained by ultrasonic leaching close to that of TCLP leaching. However, it is inconvenient to bring an ultrasonic bath and also a tumbler on-site for leaching of toxic
10 heavy metals from solid waste or soil.

In view of the foregoing, it would be desirable to provide a compact leaching device for performing quick and reliable leaching of toxic heavy metals from solid samples on-site.

Summary of the Invention

15 Accordingly, in a first aspect, the present invention provides a leaching device. The leaching device includes a motor and a receptacle rotatably coupled to the motor, the receptacle being configured to receive a sample container. A plurality of ultrasonic transducers is attached to the receptacle. An ultrasonic generator is coupled to the ultrasonic transducers. When in use, the ultrasonic generator is configured to energise
20 the ultrasonic transducers to radiate ultrasonic waves to sonicate a sample in the sample container received in the receptacle. A controller is configured to control operation of the motor and the ultrasonic generator, the motor and the ultrasonic generator being simultaneously operable.

Other aspects and advantages of the invention will become apparent from the
25 following detailed description, taken in conjunction with the accompanying drawings, illustrating by way of example the principles of the invention.

Brief Description of the Drawings

Embodiments of the invention will now be described, by way of example only, with reference to the accompanying drawings, in which:

FIG. 1A is a schematic perspective view of a leaching device in accordance with an embodiment of the present invention;

FIG. 1B is a schematic side view of the leaching device of FIG. 1A;

FIG. 2 are photographs of a prototype of the leaching device and components
5 inside the leaching device;

FIGS. 3A and 3B are schematic diagrams illustrating user interfaces (UI) of the leaching device of FIG. 1A;

FIG. 4 is a graph comparing results from a Toxicity Characteristic Leaching Procedure (TCLP) against the leaching device of FIG. 1A for incineration bottom ash
10 (IBA);

FIG. 5 is a graph comparing results from a Toxicity Characteristic Leaching Procedure (TCLP) against the leaching device of FIG. 1A for slag; and

FIG. 6 is a graph comparing results from a Toxicity Characteristic Leaching Procedure (TCLP) against the leaching device of FIG. 1A for fly ash.

15 Detailed Description of Exemplary Embodiments

The detailed description set forth below in connection with the appended drawings is intended as a description of presently preferred embodiments of the invention, and is not intended to represent the only forms in which the present invention may be practiced. It is to be understood that the same or equivalent functions may be
20 accomplished by different embodiments that are intended to be encompassed within the scope of the invention.

The term "about" as used herein refers to both numbers in a range of numerals and is also used to indicate that a value includes the standard deviation of error for the device or method being employed to determine the value. The term "about" as used
25 herein can allow for a degree of variability in a value or range, for example, within 10%, within 5%, or within 1 % of a stated value or of a stated limit of a range.

Referring now to FIGS. 1A and 1B, a leaching device 10 is shown. The leaching device 10 includes a motor 12, a receptacle 14 rotatably coupled to the motor 12 and

configured to receive a sample container (not shown), a plurality of ultrasonic transducers 16 attached to the receptacle 14, an ultrasonic generator 18 coupled to the ultrasonic transducers 16 and operable to energise the ultrasonic transducers 16 to radiate ultrasonic waves to sonicate a sample in the sample container received in the
5 receptacle 14, and a controller 20 configured to control operation of the motor 12 and the ultrasonic generator 18, the motor 12 and the ultrasonic generator 18 being simultaneously operable.

The motor 12, the ultrasonic generator 18 and the controller 20 may be enclosed in a housing 22. An electronic system (not shown) may be provided in the housing 22 to
10 provide high power for the motor 12 and the ultrasonic transducers 16 as well as to control the leaching device 10 with the controller 20.

A temperature sensor 24 may be received in the housing 22, the temperature sensor 24 being operable to monitor an operational temperature within the housing 22.

A fan 26 may be received in the housing 22, the fan 26 being operable to cool an
15 interior of the housing 22 when the operational temperature exceeds a predetermined threshold temperature.

A touchscreen 28 may be electronically connected to the controller 20, the touchscreen 28 being configured to receive setting inputs to control the operation of the motor 12 and the ultrasonic generator 18. The touchscreen 28 may be used to control
20 operation of the leaching device 10 through a user-friendly user interface (UI). Advantageously, a digital touchscreen input provides better accuracy and precision control. Timing of the leaching device 10 may be up to 999 minutes and precision may be down to a second scale. Operating parameters may be set using the touchscreen 28 and may be saved in the leaching device 10. The digital touchscreen 28 also makes it
25 easier for users to operate the leaching device 10.

A memory 30 may be coupled to the controller 20, the memory 30 being operable to store earlier settings of the motor 12 and the ultrasonic generator 18.

The leaching device 10 provides a high-power ultrasonic-assisted tumbler (UAT) with ultrasonic leaching and tumbling processes running concurrently for rapidly leaching
30 toxic heavy metals from solid samples. Advantageously, the leaching device 10 is able

to simultaneously perform sonication and tumbling of the sample container filled with solid sample and solution, thereby shortening TCLP duration, which in turn has a significant impact on on-site solid waste toxicity detection and on-time disposal, as well as on-site checking of land quality for planting. Tumbling helps to make pH values of ultrasonic leaching closer to pH values of TCLP and standard deviation is also smaller. Multiple heavy metal elements may be leached at once with the leaching device 10. All electronic connections inside the leaching device 10 may be sealed with heat shrink tubes to protect against short circuit of the ultrasound or ultrasonic generator 18 or electrocution. The leaching device 10 may have a length of 532 mm, a width of 208 mm and a height of 264 mm.

The motor 12 may be operable to rotate the receptacle 14 via a first shaft 32. The purpose of the motor 12 is to make uniform mixing of samples by rotating the receptacle 14 and the sample container inside the receptacle 14 to gently leach ions from solid samples. The motor 12 may be operable to rotate the receptacle 14 at a rate of between about 0.1 revolutions per minute (rpm) and about 500 rpm. The motor 12 may be operable to rotate the receptacle 14 for a duration of between about 1 minute (min) and about 24 hours (hr).

As the sample container is independent of the receptacle 14, the receptacle 14 does not need to be cleaned after leaching. The receptacle 14 may include a body 34 having a first screw thread (not shown) on an inner surface of an open end of the body 34, and a cover 36 in a separable threaded connection with the body 34. The first screw thread may be located outside or inside the receptacle 14 within a distance of 1 millimeter (mm) to 10 centimeters (cm) from a top of the receptacle 14. A pitch of the threaded connection may be between about 0.2 millimetres (mm) and about 10 centimetres (cm). By increasing the pitch of the threaded connection and moving the first screw thread location from outside to inside the receptacle 14, it is easier to tighten the cover 36 of the receptacle 14. This provides a hassle-free capping and tightening experience. In one or more other embodiments, the cover 36 may be secured to the body 34 via other types of water-tight fixtures such as, for example, a clip. The receptacle 14 may be a stainless-steel barrel and may be sized to accommodate a standard TCLP bottle as the sample container. In operation, a gap between the receptacle 14 and the sample container may be filled with water to reduce ultrasonic transmission loss from the ultrasonic transducers 16 to the sample container. In use, samples are placed inside the sample container, an

ultrasonic wave is applied to the receptacle 14, and water acts as a media to transmit the ultrasonic wave to the samples in the sample container. Advantageously, this saves the trouble of transferring the sample container from one machine to another.

5 The ultrasonic transducers 16 may be rotated together with the receptacle 14 via a second shaft 38. Advantageously, as there is non-direct contact between ultrasonic radiating surface and targeted solution as well as solid waste, cross-contamination is avoided, which is crucial in a TCLP process.

Although two (2) ultrasonic transducers 16 are shown in the present embodiment, it should be understood by persons of ordinary skill in the art that the leaching device 10 is not limited by the number of ultrasonic transducers 16. For example, in one or more alternative embodiments, the leaching device 10 may be provided with more than two (2) ultrasonic transducers 16.

As can be seen from FIGS. 1A and 1B, the ultrasonic transducers 16 may be distributed along a length of the receptacle 14. Advantageously, such an arrangement ensures ultrasound energy is evenly distributed across the receptacle 14 to leach samples homogeneously. Consequently, more uniform and consistent leaching results may thus be obtained. Consistent leaching results are obtained due to a more uniform distribution of the ultrasound energy to the targeted solution in the sample container. In the embodiment shown, the dual transducers 16 are located at or near both ends of the receptacle 14.

Each of the ultrasonic transducers 16 may be operable at a frequency of between about 10 kilohertz (kHz) and about 200 kHz. Each of the ultrasonic transducers 16 may have a power requirement of between about 0.01 watts (W) and about 1000 W. In one embodiment, the leaching device 10 may be provided with two (2) high-power (100 W each) ultrasonic transducers 16. The benefit of higher ultrasonic power is that the leaching device 10 leaches heavy metals more quickly. Each of the ultrasonic transducers 16 may be designed with protection against a short circuit of the ultrasound or ultrasonic generator 18 or electrocution. The ultrasonic transducers 16 may be operable to sonicate the sample for a sonication period of between about 1 second (s) and about 10 hours (hr). With two (2) ultrasonic transducers 16 having high power for

sonication, the ultrasonic transducers 16 need only be turned on for 1 min to 10 min in actual leaching.

The controller 20 may be a microcontroller. Advantageously, a microcontroller-based control unit with customised Hardware Attached on Top (HAT) provides greater flexibility in terms of add-ons or removal of functionalities.

Referring now to FIG. 2, a fabricated prototype of the leaching device 10 and components inside the leaching device 10 are shown.

A DC motor is selected to drive rotation of the receptacle 14. For ease of speed control, the DC motor may have a tunable speed of from 0 rpm to 60 rpm. The leaching device 10 may have an adjustable tumbling speed ranging from 0 rpm to 62 rpm.

An ultrasound generator, which may be purchased together with ultrasonic transducers, serves as a driver for piezoelectric materials inside the ultrasonic transducers to radiate ultrasonic waves.

An Arduino Mega 2560 microcontroller may be used to programme software for controlling operation of the leaching device 10 through a thin film transistor (TFT) touch screen user interface. The microcontroller sends low power transistor-to-transistor logic (TTL) digital signals to solid state switches connecting to the microcontroller through a customized home-designed adapter board or Hardware Attached on Top (customized HAT). The solid-state switches controlled by TTL signals turn on the high-power DC motor or the ultrasonic generator and tune the motor speed based on settings keyed in via the touch screen.

The electronics part of the leaching device 10 also includes a temperature sensor to monitor an operational temperature inside an enclosure of the leaching device 10. A fan is turned on to cool down the electronics sealed in the enclosure when the temperature is high.

A DC power supply is integrated to supply 5V and 24V voltages to the microcontroller, the DC motor and the fan.

Two (2) transducers of 100W each, operating at 21.7 kHz, are selected to sonicate for solid sample leaching. This is because ultrasonic radiation at a lower

frequency is able to penetrate deeper inside the sample container with solid sample and TCLP buffer solution, which then more effectively leaches heavy metals from the solid samples.

Referring now to FIGS. 3A and 3B, touch screen user interfaces (UIs) of the leaching device 10 are shown. As can be seen from FIGS. 3A and 3B, there are two (2) pages: a "HOME" user interface as shown in FIG. 3A and "SETTINGS" user interface as shown in FIG. 3B.

In FIG. 3A, the "Home" user interface separately controls the "on" and "off" of ultrasonic power and tumbling time and displays the time left for sonication and tumbling. Tumbling speed may also be indicated on the screen. The user interface at the "Home" page also displays a temperature inside the enclosure to indicate whether the electronic components or the motor are overheated. Speed of the fan to dissipate heat automatically adjusts based on the temperature read. An "ORIGIN" button when activated moves the receptacle 14 to an upright position for loading or unloading of the sample container. Functions of the "RUN" and "STOP" buttons are synchronized to ensure that sonication and tumbling are started or stopped at the same time.

In FIG. 3B, the "Settings" user interface page allows users to set time of sonication and tumbling and tumbling speed, respectively, through a key panel. A default setting for the leaching device 10 is to run both sonication and tumbling for 1 min with a tumbling speed at 30 rpm. This default setting may be reset through a software update and may be further identified by experiments on leaching of different solid samples.

Experimental Results

Verification of the ultrasonic-assisted tumbler (UAT) or leaching device 10 for different samples was performed. Protocols for leaching different types of solid waste samples including incineration bottom ash (IBA), slag and fly ash using the ultrasonic-assisted tumbler (UAT) or leaching device 10 are described. For all three types of solid waste during the leaching process using the ultrasonic-assisted tumbler (UAT) or leaching device 10, both sonication and tumbling are started together when the "RUN" button was pressed. The IBA was sonicated for 10 min, whereas the slag and the fly ash were only sonicated for 1 min. All three samples were kept tumbling for 30 min.

In order to verify efficiency as well as consistency of end leaching products (i.e., leachates) of the UAT or leaching device 10, pH values (a critical indicator of TCLP tumbling leachates) and concentrations of trace heavy metals between the UAT or leaching device 10 and a standard TCLP leaching process were compared. Three (3) types of solid waste were tested: (i) incineration bottom ash (IBA), (ii) slag, and (iii) fly ash. Total leaching time of each sample was 30 minutes (min) and trace heavy metal concentrations for the samples were determined by inductively coupled plasma optical emission spectrometry (ICP-OES) and/or inductively coupled plasma mass spectrometry (ICP-MS). More particularly, the concentrations of heavy metals in the leachates were determined by ICP-OES first, and then further verified by ICP-MS. In most cases, for concentrations above 1 ppm, ICP-OES results were recorded and for concentrations below 1 ppm, ICP-MS results were recorded. All statistical analyses of the results were performed using GraphPad. Unpaired t-tests with unequal variance were performed to provide the p-values. If $p > 0.05$, it was considered a statistically insignificant difference; if $p < 0.05$, it was considered a statistically significant difference.

Referring now to FIG. 4, a comparison of heavy metal concentrations detected in incineration bottom ash (IBA) from SembCorp EFW plant using a standard Toxicity Characteristic Leaching Procedure (TCLP) (18 h) and the ultrasonic-assisted tumbler (UAT) or leaching device 10 with different ultrasonic times (1 min, 5 min and 10 min after beginning of tumbling; total tumbling time of 30 min) is shown. Error bars were based on three (3) replicates per sample. According to the results, the ultrasonic-assisted tumbler (UAT) or leaching device 10 with an ultrasonic time of 10 min best matched with the TCLP and thus the ultrasonic-assisted tumbler (UAT) or leaching device 10 with 10 min results was chosen for further analysis. 20 kinds of heavy metals were detected, 10 of which had no significant differences as shown in Table 1 below.

Table 1: Comparison of results of IBA between TCLP and UAT without significant differences ($p > 0.05$)

	TCLP	UAT (10 min)	
	Value	Value	p-value
Cd	0.184 ± 0.076 ppm	0.189 ± 0.11 ppm	0.948

Ti	4.737 ± 0.094 ppm	4.233 ± 0.436 ppm	0.122
V	0.018 ± 0.005 ppm	0.099 ± 0.093 ppm	0.205
Fe	4.672 ± 0.215 ppm	4.99 ± 3.07 ppm	0.867
Zn	19.320 ± 5.039 ppm	18.153 ± 2.699 ppm	0.742
Se	0.227 ± 0.164 ppm	0.45 ± 0.037 ppm	0.083
Mo	0.278 ± 0.098 ppm	0.124 ± 0.035 ppm	0.063
Ag	0.734 ± 0.54 ppm	0.833 ± 0.42 ppm	0.816
Hg	0.395 ± 0.265 ppm	0.106 ± 0.008 ppm	0.132
Ba	0.585 ± 0.005 ppm	0.664 ± 0.07 ppm	0.120

- Calibration factor, which is a ratio of leached metal concentration obtained by the ultrasonic-assisted tumbler (UAT) or leaching device 10 to leached metal concentration obtained by the TCLP, is calculated to indicate an under-leaching scenario or an over-leaching scenario for the ultrasonic-assisted tumbler (UAT) or leaching device 10. A calibration factor of less than one (1) means a targeted trace metal ion is under-leaching with the ultrasonic-assisted tumbler (UAT) or leaching device 10, whereas a calibration factor of greater than one (1) implies over-leaching with the ultrasonic-assisted tumbler (UAT) or leaching device 10. Calibration factors are crucial for inversion calculations to obtain results that are comparable to results produced with a standard TCLP leaching process. Calibration factors for the other 10 elements with significant differences are shown in Table 2 below.

Table 2: Comparison of results of IBA between TCLP and UAT with significant differences ($p < 0.05$)

	TCLP	UAT (10 min)		
	Value	Value	p-value	Calibration factor (TCLP/UAT)
pH	6.94 ± 0.305	5.157 ± 0.111	0.001	1.346
Pb	0.299 ± 0.002 ppm	1.613 ± 0.328 ppm	0.002	0.185

Mg	91.46 ± 6.085 ppm	56.387 ± 3.317 ppm	0.001	1.622
Al	9.129 ± 0.407 ppm	17.937 ± 3.042 ppm	0.008	0.509
Cr	0.155 ± 0.01 ppm	0.36 ± 0.079 ppm	0.011	0.431
Mn	2.73 ± 0.521 ppm	1.52 ± 0.151 ppm	0.018	1.796
Co	1.249 ± 0.14 ppm	1.01 ± 0.028 ppm	0.045	1.237
Ni	1.042 ± 0.098 ppm	0.674 ± 0.006 ppm	0.003	1.546
Cu	24.618 ± 0.718 ppm	7.1 ± 1.715 ppm	< 0.0001	3.467
Sr	3.405 ± 0.07 ppm	2.508 ± 0.103 ppm	< 0.001	1.358
Sb	0.202 ± 0.049 ppm	0.349 ± 0.02 ppm	0.009	0.578

The four (4) remaining elements, namely beryllium (Be), arsenic (As), tin (Sn) and thallium (Tl), in the IBA were too low to be detected. In these samples, magnesium (Mg), copper (Cu) and zinc (Zn) had higher concentrations (over 10 ppm).

- Referring now to FIG. 5, with similar processes as the IBA samples, a comparison of heavy metal concentrations detected in slag from a waste-to-energy (WTE) facility using a standard Toxicity Characteristic Leaching Procedure (TCLP) (18 h) and the ultrasonic-assisted tumbler (UAT) or leaching device 10 with different ultrasonic times (1 min, 5 min and 10 min after beginning of tumbling; total tumbling time of 30 min) is shown. As the ultrasonic-assisted tumbler (UAT) or leaching device 10 with an ultrasonic time of 1 min best matched with the TCLP, the ultrasonic-assisted tumbler (UAT) or leaching device 10 with 1 min results was chosen for further analysis. 14 kinds of heavy metals were detected, 6 of which had no significant differences as shown in Table 3 below.

Table 3: Comparison of results of slag between TCLP and UAT without significant differences (p > 0.05)

	TCLP	UAT (1 min)	
	Value	Value	p-value
Pb	0.169 ± 0.005 ppm	0.229 ± 0.062 ppm	0.171
Al	1.580 ± 0.474 ppm	1.583 ± 0.070 ppm	0.991

Ni	0.267 ± 0.066 ppm	0.257 ± 0.002 ppm	0.808
Cu	11.323 ± 0.030 ppm	11.420 ± 0.090 ppm	0.151
Zn	4.151 ± 0.150 ppm	3.964 ± 0.243 ppm	0.320
Co	0.572 ± 0.002 ppm	0.565 ± 0.005 ppm	0.082

Calibration factors for the other 8 elements with significant differences are shown in Table 4 below.

Table 4: Comparison of results of slag between TCLP and UAT with significant differences ($p < 0.05$)

	TCLP	UAT (1 min)		
	Value	Value	p-value	Calibration factor (TCLP/UAT)
Mg	8.507 ± 0.540 ppm	1.903 ± 0.377 ppm	< 0.0001	4.469
Ti	1.090 ± 0.038 ppm	0.677 ± 0.018 ppm	< 0.0001	1.610
Cr	0.123 ± 0.007 ppm	0.094 ± 0.001 ppm	0.002	1.302
Mn	2.554 ± 0.361 ppm	1.042 ± 0.027 ppm	0.002	2.451
Fe	27.049 ± 3.268 ppm	5.745 ± 0.522 ppm	< 0.001	4.709
Se	0.248 ± 0.025 ppm	0.371 ± 0.035 ppm	0.008	0.669
Ba	1.724 ± 0.083 ppm	0.888 ± 0.018 ppm	< 0.0001	1.942
Sr	0.614 ± 0.036 ppm	0.303 ± 0.003 ppm	< 0.001	2.026

- 5 In these samples, the concentrations of Fe and Cu were over 10 ppm. The remaining 10 elements in the slag: Be, V, As, Mo, Ag, Cd, Sn, Sb, Hg and Tl, were too low to be detected.

- 10 Referring now to FIG. 6, a comparison of heavy metal concentrations detected in fly ash from the waste-to-energy (WTE) facility using a standard Toxicity Characteristic Leaching Procedure (TCLP) (18 h) and the ultrasonic-assisted tumbler (UAT) or leaching device 10 with different ultrasonic times (1 min, 5 min and 10 min after beginning of

tumbling; total tumbling time of 30 min) is shown. All three results by the ultrasonic-assisted tumbler (UAT) or leaching device 10 matched well with the TCLP. In order to reduce unnecessary energy consumption, the ultrasonic-assisted tumbler (UAT) or leaching device 10 with 1 min results was chosen for further analysis. 15 kinds of heavy
 5 metals were detected, 13 of which have no significant differences as shown in Table 5 below.

Table 5: Comparison of results of fly ash between TCLP and UAT without significant differences ($p > 0.05$)

	TCLP	UAT (1 min)	
	Value	Value	p-value
pH	12.507 $\pm$ 0.006	12.527 $\pm$ 0.025	0.251
Pb	5.933 $\pm$ 1.497 ppm	6.467 $\pm$ 0.325 ppm	0.579
Al	17.120 $\pm$ 0.569 ppm	17.435 $\pm$ 1.650 ppm	0.770
Ti	8.508 $\pm$ 0.179 ppm	8.551 $\pm$ 0.091 ppm	0.727
Cr	0.331 $\pm$ 0.025 ppm	0.313 $\pm$ 0.005 ppm	0.289
Mn	0.345 $\pm$ 0.012 ppm	0.331 $\pm$ 0.018 ppm	0.315
Fe	10.189 $\pm$ 0.551 ppm	9.167 $\pm$ 0.770 ppm	0.135
Co	1.853 $\pm$ 0.023 ppm	1.571 $\pm$ 0.256 ppm	0.130
Ni	1.064 $\pm$ 0.071 ppm	1.010 $\pm$ 0.023 ppm	0.277
Cu	46.533 $\pm$ 0.406 ppm	46.481 $\pm$ 0.149 ppm	0.847
Zn	8.940 $\pm$ 2.422 ppm	5.620 $\pm$ 0.295 ppm	0.078
Se	1.883 $\pm$ 0.080 ppm	1.836 $\pm$ 0.264 ppm	0.784
Ag	0.235 $\pm$ 0.015 ppm	0.240 $\pm$ 0.018 ppm	0.718
Ba	2.507 $\pm$ 0.358 ppm	2.067 $\pm$ 0.121 ppm	0.114

Calibration factors for another 2 elements with significant differences are shown
 10 in Table 6 below.

Table 6: Comparison of results of fly ash between TCLP and UAT with significant differences ($p < 0.05$)

	TCLP	UAT (1 min)		
	Value	Value	p-value	Calibration factor (TCLP/UAT)
Mg	5.156 ± 0.128 ppm	4.873 ± 0.092 ppm	0.036	1.058
Sr	2.587 ± 0.077 ppm	2.173 ± 0.084 ppm	0.003	1.190

In these samples, the concentrations of Al, Fe and Cu were over 10 ppm. The remaining 9 elements in the fly ash: Be, V, As, Mo, Cd, Sn, Sb, Hg and Tl, were too low to be detected.

The measurement results on concentrations of the leached heavy metals demonstrate that for solid waste samples including incineration bottom ash (IBA), slag and fly ash, leaching performed with the ultrasonic-assisted tumbler (UAT) or leaching device 10 is efficient and consistent with good correlations and satisfactory respectabilities demonstrated as compared to the standard TCLP leaching process.

As noted from the experiments, different types of solid waste have different calibration factors and have observable influences on leaching rates of individual trace heavy metals. The leaching results of the ultrasonic-assisted tumbler (UAT) or leaching device 10 demonstrate uniform and consistent leaching for targeted heavy metals in IBA, slag and fly ash.

In summary, the heavy metal concentrations of the leachates detected by inductively coupled plasma optical emission spectrometry (ICP-OES) and/or inductively coupled plasma mass spectrometry (ICP-MS) showed that most of the leached metal concentrations detected using the ultrasonic-assisted tumbler (UAT) or leaching device 10 do not have significant difference compared with those of the standard TCLP leaching process. For some heavy metals over-leached or under-leached by the ultrasonic-assisted tumbler (UAT) or leaching device 10, these exhibited low standard deviations among leaching replication experiments and thus can be reliably corrected with a calculated calibration factor for each ion. The experiments demonstrated that 30 min of a leaching process using the ultrasonic-assisted tumbler (UAT) or leaching device 10 is

able to obtain equivalent results to TCLP leaching. In other words, the ultrasonic-assisted tumbler (UAT) or leaching device 10 reduced the leaching process time from 18 hours in the standard TCLP leaching process to 30 min, thereby providing a device with capability to quickly leach toxic heavy metals on-site for further toxic heavy metal
5 detections. Ultrasonic time is shorter for all three types of solid waste tested: sonication time for IBA, slag and fly ash are 10 min, 1 min and 1 min, respectively. The leaching time may even be further shortened with additional optimizations for different solid waste samples by varying, for example, ultrasonic time, tumbling time and tumbling speed.

As is evident from the foregoing discussion, the present invention provides a
10 leaching device in the form of an ultrasonic-assisted tumbler (UAT) to accelerate standard toxicity characteristic leaching procedure (TCLP) for rapidly leaching toxic components in solid samples for further on-site detection, reducing TCLP leaching time from 18 hours to 30 minutes or even shorter times. The leaching device of the present invention integrates high-power multiple ultrasonic transducers with a tumbler for quick
15 and consistent leaching of heavy metals from solid samples. The leaching device of the present invention is a stand-alone device that is able to simultaneously sonicate and tumble a bottle filled with 100 g solid sample in a 2 L solution (the weight and volume are as specified in TCLP requirements) to accelerate the leaching of toxic components (such as heavy metals) from the solid samples. In other words, the leaching device of the
20 present invention is compatible with the TCLP process and is able to handle a large sampling size (100 g of solid sample in 2 L of leaching solution). The leaching device of the present invention, integrated with multiple ultrasonic transducers (demonstrated with two (2) transducers for 200W of ultrasonic power in total) to generate high ultrasonic power, radiates ultrasonic waves to the bottle filled with the solid sample and solution
25 and tumbles the bottle at the same time. The leaching device of the present invention allows individual setting of ultrasonic time and tumbling time and tuning of tumbling speed for different samples to optimize the leaching process; ultrasonic time, tumbling time and tumbling speed may be adjusted and optimized. With digital control, a microcontroller, a user interface and a touch screen for users to save setting protocols,
30 the leaching device of the present invention is easy to use. The leaching device of the present invention is also inexpensive to produce, compact, smaller in size and light-weight (e.g., a mass of about 9 kg) with a neat outlook without messy wires.

The ultrasonic-assisted tumbler (UAT) or leaching device of the present invention may be used in incineration or gasification facilities, industry and civilian sewage water treatment systems, mining fields, pollution assessment of agricultural land, slag content assessment of indoor aquaculture waste and any other fields where a solid sample is
5 involved.

While preferred embodiments of the invention have been described, it will be clear that the invention is not limited to the described embodiments only. Numerous modifications, changes, variations, substitutions and equivalents will be apparent to those skilled in the art without departing from the scope of the invention as described in
10 the claims.

Further, unless the context clearly requires otherwise, throughout the description and the claims, the words "comprise", "comprising" and the like are to be construed in an inclusive as opposed to an exclusive or exhaustive sense; that is to say, in the sense of "including, but not limited to".

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CLAIMS

1. A leaching device, comprising:
 - a motor;
 - 5 a receptacle rotatably coupled to the motor and configured to receive a sample container, the receptacle rotatable via a first shaft;
 - a plurality of ultrasonic transducers attached to the receptacle and rotatable via a second shaft arranged opposite to the first shaft across the receptacle, such that the ultrasonic transducers are rotatable with the receptacle;
 - 10 an ultrasonic generator coupled to the ultrasonic transducers and operable to energise the ultrasonic transducers to radiate ultrasonic waves to sonicate a sample in the sample container received in the receptacle; and
 - a controller configured to control operation of the motor and the ultrasonic generator, wherein the motor and the ultrasonic generator are simultaneously
 - 15 operable.
2. The leaching device according to claim 1, wherein the ultrasonic transducers are distributed along a length of the receptacle and perpendicularly to the second shaft.
- 20 3. The leaching device according to claim 1 or 2, wherein each of the ultrasonic transducers is operable at a frequency of between about 10 kilohertz (kHz) and about 200 kHz.
4. The leaching device according to any one of the preceding claims, wherein each
- 25 of the ultrasonic transducers has a power requirement of between about 0.01 watts (W) and about 1000 W.
5. The leaching device according to any one of the preceding claims, wherein the ultrasonic transducers are operable to sonicate the sample for a sonication period of
- 30 between about 1 second (s) and about 10 hours (hr).
6. The leaching device according to any one of the preceding claims, wherein the motor is operable to rotate the receptacle at a rate of between about 0.1 revolutions per minute (rpm) and about 500 rpm.

7. The leaching device according to any one of the preceding claims, wherein the motor is operable to rotate the receptacle for a duration of between about 1 minute (min) and about 24 hr.
- 5
8. The leaching device according to any one of the preceding claims, further comprising a touchscreen electronically connected to the controller and configured to receive setting inputs to control the operation of the motor and the ultrasonic generator.
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9. The leaching device according to any one of the preceding claims, further comprising a memory coupled to the controller and operable to store earlier settings of the motor and the ultrasonic generator.
- 15
10. The leaching device according to any one of the preceding claims, further comprising:
- a housing enclosing the motor, the ultrasonic generator and the controller;
 - a temperature sensor received in the housing and operable to monitor an operational temperature within the housing; and
 - a fan received in the housing and operable to cool an interior of the
- 20
- housing when the operational temperature exceeds a predetermined threshold temperature.
11. The leaching device according to any one of the preceding claims, wherein the receptacle comprises:
- 25
- a body having a first screw thread on an inner surface of an open end of the body;
- and
- a cover in a separable threaded connection with the body.
12. The leaching device according to claim 11, wherein a pitch of the threaded
- 30
- connection is between about 0.2 millimetres (mm) and about 10 centimetres (cm).