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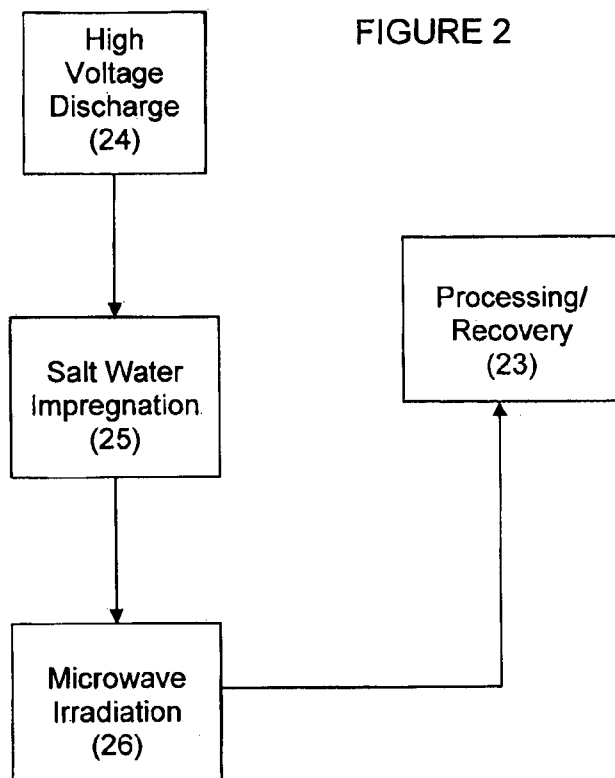
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(54) Title: METHOD FOR COMMINUATION OF A MATERIAL

FIGURE 2



(57) Abstract: A method for comminution of a material including: submerging the material in water and applying a high voltage discharge to the material, said high voltage discharge being applied at a voltage and energy sufficient to form cracks at grain boundaries within the material, thereby weakening the material at said grain boundaries; treating the material with salt water such that salt water is deposited in said cracks at the grain boundaries within the material; and applying electromagnetic radiation to the material, thereby fracturing the material along said grain boundaries.



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METHOD FOR COMMINATION OF A MATERIAL

FIELD OF THE INVENTION

5 The present invention relates to a method for comminution of a material. Particularly, the invention relates to a method of comminution of a material that includes pre-weakening of the material through application of high voltage discharge.

10 The method of the invention finds particular application in the comminution of rock and ore. Specific reference will be made to this application hereafter. However, it should be understood that the invention may find broader application.

15 BACKGROUND TO THE INVENTION

Mills are widely used in mineral processing operations around the world to reduce the size of ore particles that are generated by the basic mining operation. For example, blasting with an explosive will result in breakage of the native ore
20 body into pieces of rock. The size of rocks generated by blasting will differ from mine to mine and will depend on a number of factors such as rock type, the explosives used and the pattern of the explosives used.

Usually after blasting has taken place, the broken rock will have a mixture of
25 large and small particles. That is, the size of the blasted rock pieces will vary greatly. The fragments of rock or ore are generally subjected to a particle size reduction operation, typically in a mill. One object of milling the fragments is to reduce the mean size of the fragments for further processing downstream of the mill. A further object is to narrow the size distribution of the fragments or
30 particles so that the variation in particle size is not too great.

Generally, a mill comprises a mill shell that is typically cylindrical and that rotates about a substantially horizontal axis. The particles are contained within the mill

shell and tumble on rotation of the mill shell, while moving in a broadly longitudinal direction from an inlet of the mill to an outlet of the mill. In some mills the mill shell also contains steel balls that collide with the ore particles during tumbling and assist with breakage of the ore particles into smaller ore particles. In addition, in SAG and AG mills the ore particles themselves assist with breakage of the ore particles. In fact, in an AG mill the mill shell does not contain any mill balls and the rock and ore breakage occurs due to collisions between ore particles, and between ore particles and the inner wall of the mill shell.

Mills have a high capital running cost. Mill shells are generally driven to rotate by electrically powered motors and the electrical power required to run the mills is extremely high. The installed power of the largest mills is of the order of 10-20 MWatt. However, as a general statement, the milling process is very inefficient. A small fraction of the mill input energy actually goes into breaking the ore particles. A large part of the energy is just dissipated in the mill. As energy prices rise a greater imperative is being placed on engineers to run mills more efficiently and with reduced green house gas emissions.

SUMMARY OF THE INVENTION

According to one aspect of the invention there is provided a method for comminution of a material including:

applying a high voltage discharge to the material; and

comminuting the material to which the high voltage discharge has been applied,

wherein the high voltage discharge is applied at a voltage and energy sufficient to weaken the material at grain boundaries within the material.

As used herein, the term "comminution" includes any reduction in particle size of the material. The term is not intended to be limited to pulverisation and may include any degree of reduction in particle size. Likewise, the term "comminuting" as used herein includes within its scope any crushing or milling

operation used to reduce the particle size of the material. The term also includes alternative operations that are not necessarily mechanical for the reduction of particle size including, but not limited to, the application of electromagnetic radiation, for example microwave energy, to fracture the material thereby reducing particle size.

As used herein, the term "weaken" includes any weakening of the material at the grain boundaries within the material up to, but excluding, complete fracture of the material at the grain boundaries.

As used herein, the term "electromagnetic radiation" includes radio wave radiation, microwave radiation, terahertz radiation, infrared radiation, visible light, ultraviolet radiation, x-ray radiation and gamma ray radiation.

The high voltage discharge is applied at a voltage and energy and time period sufficient to weaken the material at grain boundaries within the material. Particularly, the intention is not to fracture the material at the grain boundaries. In terms of efficiency and economics, the parameters may vary depending on the material being comminuted. Ideally, a minimum amount of energy is employed that will provide for desired savings in the subsequent comminution step.

In most instances, it is envisaged that the high voltage discharge will have a voltage of from 60 kV to 200 kV, preferably from 80 kV to 150 kV, more preferably from 100 kV to 120 kV, and a specific energy of 1 kWh/t to 10 kWh/t, preferably from 1 kWh/t to 3 kWh/t, more preferably from 2 kWh/t to 3 kWh/t.

Likewise, in most instances it is envisaged that the high voltage discharge will include the application of from 1 to 200 pulses, preferably from 1 to 50 pulses.

Whilst it is envisaged that the high voltage discharge may be directly applied to the material, this will not usually be the case. Rather, it is preferred that the high voltage discharge be applied to the material when submerged in a dielectric

liquid, such as water, oil or other organic liquid. Most preferably, for convenience and economics, the dielectric liquid is water.

As mentioned above, the step of comminuting the material subsequent to the application of the high voltage discharge is not particularly limited. This may include, but is not necessarily limited to, a mechanical comminution step. For example, the step of comminuting the material may include a crushing or milling operation.

Alternatively, a non-mechanical operation may be employed. For example, the step of comminuting the material may include subjecting the material to electromagnetic radiation, for example microwave radiation. In this case, the microwave radiation applied must take into consideration the total energy required for the comminution of the material. If the microwave energy required to effect comminution in a particular application is relatively high, the total energy saving may be diminished or lost. As such, the energy input during microwave irradiation must be determined on a case by case basis.

In order to further encourage fracturing of the material, in one embodiment, prior to the application of the microwave radiation, the material is treated with salt water to deposit salt in cracks of the material. In an alternative embodiment, prior to the application of the microwave radiation, the material is treated with salt water such that the salt water enters cracks of the material. Preferably, the material is saturated with salt water prior to the application of the microwave radiation. In another alternative embodiment, prior to the application of the microwave radiation the material is treated with a mixture of a dielectric liquid and an organic liquid such that the mixture enters cracks of the material. While the organic liquid is not particularly limited, preferably the organic liquid is selected from the group consisting of methanol, ethanol and isopropanol. Preferred dielectric liquids are water or salt water. In any of these three alternative embodiments, the cracks of the material may be microcracks or otherwise. For instance, the cracks or microcracks may have been present in the material before application of the high voltage discharge to the material. However, it is preferred the cracks of the material will be formed along grain

boundaries of the material resulting from the application of the high voltage discharge to the material.

It has been found that the application of the high voltage discharge to the material is not particularly effective if the material has exposed conductive mineral deposits on surfaces thereof. Therefore, in certain embodiments the method includes sorting of the material prior to the application of the high voltage discharge to remove material having exposed conductive mineral deposits on the surface thereof. That is, the high voltage discharge is applied only to material that does not have an undesirable amount of exposed conductive material on surfaces thereof.

Sorting of the material is not limited to any particular method. In one embodiment, however, sorting includes applying electromagnetic radiation, such as microwave radiation, to the material and imaging the material to identify exposed mineral deposits on the surface thereof and removing said material with exposed mineral deposits on the surface thereof. Imaging of the material may include, for example, infrared imaging. Such a method is described in International Publication No. WO2007/051225 A1.

According to one particular aspect of the invention there is provided a method for comminution of a material including:

submerging the material in water and applying a high voltage discharge to the material, the high voltage discharge being applied at a voltage and energy sufficient to form cracks at grain boundaries within the material, thereby weakening the material at the grain boundaries;

treating the material with salt water such that salt is deposited in the cracks at the grain boundaries within the material; and

applying electromagnetic radiation to the material, thereby fracturing the material along the grain boundaries.

According to another particular aspect of the invention there is provided a method for comminution of a material including:

submerging the material in water and applying a high voltage discharge to the material, the high voltage discharge being applied at a voltage and energy sufficient to form cracks at grain boundaries within the material, thereby weakening the material at the grain boundaries;

5 treating the material with salt water such that the salt water enters the cracks at the grain boundaries within the material; and

 applying electromagnetic radiation to the material, thereby fracturing the material along the grain boundaries.

10 When the material is treated with salt water such that the salt water enters the cracks at the grain boundaries within the material, it is preferred that the material be saturated with salt water prior to the application of the microwave radiation.

 According to yet another particular aspect of the invention there is provided a method for comminution of a material including:

15 submerging the material in water and applying a high voltage discharge to the material, the high voltage discharge being applied at a voltage and energy sufficient to form cracks at grain boundaries within the material, thereby weakening the material at the grain boundaries;

20 treating the material with a mixture of a dielectric liquid and an organic liquid such that the mixture enters the cracks at the grain boundaries within the material; and

 applying electromagnetic radiation to the material, thereby fracturing the material along the grain boundaries.

25

In this particular aspect, preferred organic liquids are methanol, ethanol and isopropanol and preferred dielectric liquids are water or salt water.

 When the material is treated with a mixture of a dielectric liquid and an organic liquid such that the mixture enters the cracks at the grain boundaries within the material, it is preferred that the material is saturated with the mixture of the dielectric liquid and the organic liquid prior to the application of electromagnetic radiation.

30

In any of these three particular aspects of the invention, it is preferred the electromagnetic radiation is microwave radiation, as described above.

- 5 The term "cracks" as used herein includes within its scope cracks and microcracks and is not particularly limited to any degree of cracking of the material.

DETAILED DESCRIPTION OF THE INVENTION

10

A more detailed description of the invention will now be provided with reference to the accompanying drawings and experimental results. It will be appreciated that the drawings are provided for illustration only and should not be construed as limiting on the invention in any way. Likewise, the experimental results are
15 provided for exemplification only. In the drawings:

Figure 1 illustrates a flow chart of the process according to one aspect of the invention;

- 20 Figure 2 illustrates a partial flow chart of the process according to one embodiment of the invention;

Figures 3A and 3B illustrate surface images of rock treated with high voltage discharge and conventional crushing respectively;

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Figures 4A and 4B illustrate CBT images of rock treated with high voltage discharge and conventional crushing respectively;

- Figure 5 illustrates typical size reduction t_{10} in relation to specific energy E_{cs}
30 resulting from mechanical breakage;

Figure 6 illustrates typical size reduction t_{10} in relation to specific energy E_{cs} resulting from high voltage discharge; and

Figure 7 illustrates a graph of reduction of ore hardness ($A*b$) as a function of particle size.

5 Referring to Figure 1, a flowchart illustrating the invention is provided. The method includes an initial sorting step (10). This step involves sorting of material having exposed surface mineral deposits (11) from material having minimal or no exposed surface mineral deposits (12). It has been found that if the material has exposed surface mineral deposits, the application of high
10 voltage discharge to the material for pre-weakening may not be effective. Particularly, the discharge may travel around the outside of the material, rather than through the material. In that case, weakening of the material may not be sufficiently facilitated.

15 Material that includes excessive amounts of exposed surface mineral deposits, or high grade ore (11) may proceed direct to downstream processing and recovery (13). This is not particularly limited and may include any form of downstream processing.

20 Material having minimal or no exposed surface mineral deposits (12) is treated with high voltage discharge (14). Generally, it is envisaged that the material (12) will be fed into a chamber where it is submerged in water, or other dielectric liquid. Water is preferred, as mentioned above, as it is both economical and convenient when compared with other options. High voltage discharge is then
25 applied to the material (12) while submerged in the water. As there is minimal or no exposed surface mineral deposits, the discharge travels through the material (12) taking the path of least resistance. Generally, this is along grain boundaries of mineral within the material. As such, weakening of the material will be along those grain boundaries that have attracted the discharge.

30 The introduction of electrical field by high voltage discharge concentrates at the boundaries of different minerals with different electrical properties, such as permittivity and electrical conductivity. This leads to multiple electrical

breakdowns in a form similar to a tree with one main trunk and many branches. The main trunk bridges the electrodes via water. The expansion of plasma through the tree branches helps cracks/microcracks to grow up to a certain length, depending on the energy selection for the high voltage discharge. In the present invention, the number of pulses is selected to sufficiently expand the cracks/micro cracks, but not to bridge the ground electrode.

It is important to note that the intention is not to completely fracture the material along the grain boundaries. Rather, it is to weaken the material. The energy required to effectively induce complete fracture of a material along grain boundaries, for example to completely fracture an ore to liberate mineral deposits, would be too great in a commercial setting. Complete fracture of the material, such as an ore body, is not considered within the ambit of the present invention.

Once the material (12) has been subjected to high voltage discharge (14), it may be comminuted (15). As mentioned above, this step is also not particularly limited and may include any processing that reduces the particle size of the material and results in complete fracture of the material along the weakened grain boundaries. It has been found that the amount of energy required in the comminution step (15) is significantly reduced due to the prior application of high voltage discharge (14) to the material. Effectively, the amount of energy saved during comminution (15) exceeds that required during high voltage discharge (14). Thus, the method results in a net saving of energy.

Once the material (12) has been comminuted (15), it may be subjected to downstream processing and recovery (13), as was the case with material having exposed surface mineral deposits (11). Further downstream processing may be improved by conducting a sorting stage (not shown) prior to processing and recovery (13), for example through the application of microwave radiation and subsequent infrared imaging. Fragments without any valuable minerals exposed may be considered barren and, therefore, may be discarded rather than be subjected to processing and recovery (13).

Turning to Figure 2, a flow chart is provided illustrating one option for comminution of the material following application of high voltage discharge (24). Particularly, as was the case in the previous flow chart, high voltage discharge (24) is applied to the material while it is submerged in water. This induces weakening of the material along grain boundaries within the material as previously mentioned. Weakening generally takes the form of cracks along the grain boundaries. The water is then drained and the material impregnated with salt water (25). The salt water is then drained from the material leaving salt water in the cracks along the grain boundaries within the material. Electromagnetic radiation such as microwave radiation (26) is then applied to the material resulting in rapid heating of the salt water and / or the salt deposits at the grain boundaries. This effectively results in complete fracture of the material along the grain boundaries. The material may then proceed to downstream processing and recovery (23).

Figures 3A and 3B are surface images of rock treated with high voltage discharge and conventional crushing respectively. It is apparent on viewing these images that the rock treated with high voltage discharge includes a number of cracks along grain boundaries within the rock. Conversely, the rock that has been treated with conventional crushing does not include such cracks. This is even better illustrated in Figures 4A and 4B which include CBT images of rock treated with high voltage discharge and conventional crushing respectively. Here, the cracks are clearly evident in the rock imaged as Figure 4A.

Preliminary investigations for at least one ore type have indicated that the rock sample treated with high voltage discharge has a porosity volume of 13.7%, while the crushed rock has a porosity volume of 3.2%. It will be appreciated that this illustrates a substantial increase in porosity, which will have a weakening effect on the rock. Increased porosity will also increase efficacy of microwave induced rock damage and breakage, if such techniques are employed.

EXPERIMENTAL RESULTS

The following provides a discussion of experimental results obtained using a high voltage discharge apparatus developed by selfFrag AG of Kerzers, Switzerland.

Selective fragmentation, or selfFrag, employs high voltage discharge on inhomogeneous, non-conducting solids to effect their fragmentation, disintegration or disaggregation. The discharge, which is generally about 400 kV with an energy of 10-100 J/cm, is deposited in a discharge plasma channel. The discharge results in pressures of up to 1010Pa at temperatures of about 104 K within the solids, causing the destruction of the solids. Reference is made to United States Patent Application Publication No. US 2009/0236142 and United States Patent Application Publication No. US 2010/0025240, the contents of which are incorporated herein in their entirety.

Initial Testing

Initial testing has been conducted on three drill cores of 65 mm that were saw-cut in half along the axis of the cores. The cores were obtained from a copper-gold deposit lying within a breccia system developed in a sequence of altered, porphyritic, intermediate volcanic rocks. Valuable minerals mainly consisted of magnetite, chalcopyrite, pyrite, gold, cobalt, molybdenum, rare earth elements and, to a lesser extent, uranium. A 1mm under screen was employed.

High voltage pulses were continuously discharged to the samples until nothing remained on top of the discharge screen. The specific energy required to disseminate the cores was from 63-67 kWh/t.

Subsequent Testing

Subsequent testing has included the evaluation of the effects of high voltage discharge on various ore types, including a copper/gold ore, a gold ore and a platinum ore.

Tests were conducted using the selfFrag apparatus to determine the pre-weakening effect on particles (only tested with the copper/gold ore).

For the pre-weakening experiment, one size (-45+37.5 mm) of the copper/gold ore was tested at about 1 and 2 kWh/t energy levels. Crushing tests using a laboratory scale jaw crusher were conducted at similar energy levels.

In the following discussions, JKRBT tests (Shi and Kojovic 2007) were used to determine hardness of various samples. These tests are described in International Patent Publication Nos. WO2008/006151 and WO2007/134367, which are incorporated herein by reference.

JKBRT tests were conducted on four narrowly sized products (-37.5+26.5 mm, -26.5+19 mm, -19+13.2 mm and -13.2+9.5 mm) derived from the selfFrag apparatus and crusher respectively to compare the residual hardness of the products after treatment with the two breakage mechanisms. The JKRBT products were further crushed by a jaw crusher to generate sufficient -3.35 mm materials for Bond ball mill tests to estimate the potential energy saving using the selfFrag apparatus compared with mechanical breakage, such as using a crusher.

Results

Size reduction-energy relationship

It has been found that the selfFrag product exhibits a different energy-size reduction pattern compared with conventional mechanical breakage. Figure 5

illustrates a typical size reduction-energy relationship from the mechanical breakage (Shi and Kojovic, 2007). The parameter t_{10} is defined as cumulative percentage passing 1/10th of the parent size in the product. The t_{10} can be regarded as a 'fineness index' with larger t_{10} values indicating a finer product size distribution. Ecs is a specific input energy in a unit kWh/t. The mechanical breakage data shows that there is a plateau on the t_{10} -Ecs plots and that at higher energies little additional size reduction occurs as the Ecs is increased, which indicates that the comminution process becomes less efficient once exceeding a necessary Ecs.

The size reduction-Ecs data from mechanical breakage can be modelled with an equation (Napier-Munn, et al, 1996):

$$t_{10}=A(1-e^{-b.Ecs}) \quad (1)$$

where A and b are model parameters fitted to the breakage data. The value of parameter A is the limiting value of t_{10} . The product $A*b$ is used as ore hardness index widely accepted by mining companies and researchers. The typical $A*b$ values in the JK database, which consists of more than 2000 breakage testing data for ore particles, are between 20 to 300, $A*b$ values less than 40 indicating very hard ore, and larger than 100 very soft.

Figure 6 shows the size reduction in relation to specific energy input from selfFrag treating the copper/gold ore. The other ores show a similar trend. The graph demonstrates that there is no plateau in the plots as normally observed using mechanical breakage. In the high voltage pulse breakage, size reduction continuously increases as the specific energy is increased, even at an energy level more than six times larger than in the mechanical breakage (30 kWh/t in Figure 6 vs 5 kWh/t in Figure 5). The size reduction-Ecs relationship appears linear within the data range.

It is interesting to note that Figure 6 presents two particle size fractions treated with selfFrag. At the same specific energy input by selfFrag, large particles

experience a much greater size reduction compared with small particle. The difference is quite significant, and statistically valid. The particle size effect in mechanical breakage is well known, as evidenced in Figure 5. That is, larger particles produce larger t_{10} values. However, the particle size effect on mechanical breakage is not as significant as in the selfFrag breakage.

The JKRBT data was re-processed to produce size-by-size A^*b values for the products from selfFrag and the crusher, and the percent reduction in hardness by selfFrag was plotted against particle size as shown in Figure 7. This clearly illustrates that at the coarse particle sizes, the hardness reduction by selfFrag is much more significant than for the small particles. From this investigation, the implication is that the selfFrag technology may be more energy efficient when applied to large ore particles.

15 Preliminary investigation of particle weakening effect

The JKRBT breakage tests show that the product generated by selfFrag using similar specific energy (1 kWh/t) has higher A^*b values compared with the crusher product (Table 1), indicating that the selfFrag product is weaker than the crusher product. The standard deviations determined from duplicate JKRBT tests illustrate that the differences in A^*b values are statistically significant. The implication from this observation is that in downstream processes, such as a ball mill grinding circuit, the energy required to process the selfFrag product to a desired product size would be less compared with a crusher product.

To estimate the energy saving in the downstream ball milling process, a simplified relationship (Napier-Munn, et al., 1996) between the Bond Work Index and the A^*b value was used to calculate the Bond Work Index, as given in Table 1. From the estimated Bond Work Indices, it was assumed that 23.9% energy saving may be realised due to the pre-weakening effect of the selfFrag high voltage discharge breakage technology.

Breakage mode	selfFrag	Crusher
A*b (Hardness indicator)	55.6±2.5	36.6±2.8
Estimated Bond Work Index (kWh/t)	17.5	23.0
Energy saving by selfFrag (%)	23.9	

Table 1: Comparison of particle hardness of the products treated with selfFrag and crusher.

5 Further investigation of particle weakening effect

Large scale experiments were extended to another three ores to further investigate the particle weakening effect. Two copper ores and one lead/zinc ore were used. Two particle size fractions of each ore were selected: 45x37.5 mm and 19x16 mm. Particles were rotary divided into two parts. One was subjected to the high voltage pulse discharge at a specific energy 2 kWh/t, followed by Bond rod mill tests to determine Bond Work Indices. Another was treated by the conventional crusher at similar specific energy. The crusher products were tested in the same Bond rod mill. Direct comparison of the Bond Work Indices of ores treated with the two comminution methods is given in Table 2. The Bond Work Index is a typical ore parameter of energy requirement for a desired size reduction, large values indicating high resistance to comminution, or requiring more energy to achieve the desired size reduction. Table 2 shows that an energy saving from 6% to 18% may be achieved using high voltage discharge, depending on the ore type.

Ore	Mine A (Cu)	Mine B (Pb/Zn)	Mine C (Cu)
High voltage discharge	16.5	17.9	9.7
Conventional breakage	20.1	19.1	10.9
Energy saving by selfFrag(%)	18	6	11

Table 2: Comparison of Bond Work Indices (kWh/t) of the products treated with selfFrag and crusher.

A parallel experiment was conducted using a JKRBT to determine the residual ore hardness of the three ore samples treated with the two comminution methods. The ore hardness parameter A^*b values are given in Table 3. As stated above, a smaller A^*b value indicates harder ore particles. Clearly, the selfFrag products become weaker than the conventional crushed products.

Ore	Mine A (Cu)	Mine B (Pb/Zn)	Mine C (Cu)
High voltage discharge	46.3	55.4	73.9
Conventional breakage	35.0	50.7	61.1

Table 3: Comparison of ore hardness A^*b of the products treated with selfFrag and crusher.

Conclusion

In summary, the following trends were observed in the preliminary investigation:

- The size reduction – energy relationship of the ores subjected to high voltage pulse breakage is different from the traditional mechanical breakage;
- Significant pre-weakening effect of particles treated by selfFrag was observed. For the four ore samples tested, this pre-weakening effect was estimated to result in 6%-24% energy saving in the downstream comminution processes, depending on the ore type; and
- It has been observed that the selfFrag is more efficient for larger particles in terms of reduction of ore hardness.

Unless the context requires otherwise or specifically stated to the contrary, integers, steps, or elements of the invention recited herein as singular integers, steps or elements clearly encompass both singular and plural forms of the recited integers, steps or elements.

Throughout this specification, unless the context requires otherwise, the word "comprise", or variations such as "comprises" or "comprising", will be understood to imply the inclusion of a stated step or element or integer or group of steps or elements or integers, but not the exclusion of any other step or element or integer or group of elements or integers. Thus, in the context of this specification, the term "comprising" is used in an inclusive sense and thus should be understood as meaning "including principally, but not necessarily solely".

It will be appreciated that the foregoing description is has been given by way of illustrative example of the invention and that all such modifications and variations thereto as would be apparent to persons of skill in the art are deemed to fall within the broad scope and ambit of the invention as herein set forth.

15

CLAIMS:

1. A method for comminution of a material including:
applying a high voltage discharge to the material; and
5 comminuting the material to which the high voltage discharge has been applied,
wherein the high voltage discharge is applied at a voltage and energy sufficient to weaken the material at grain boundaries within the material.
10
2. A method according to claim 1, wherein the high voltage discharge has a voltage of from 60 kV to 200 kV, preferably from 80 kV to 150 kV, more preferably from 100 kV to 120 kV, and a specific energy of 1 kWh/t to 10 kWh/t, preferably from 1 kWh/t to 3 kWh/t, more preferably from 2 kWh/t
15 to 3 kWh/t.
3. A method according to claim 1 or 2, wherein the high voltage discharge includes the application of from 1 to 200 pulses, preferably from 1 to 50 pulses.
20
4. A method according to any one of claims 1 to 3, wherein the high voltage discharge is applied to the material when submerged in a dielectric liquid, such as water, oil or other organic liquid.
- 25 5. A method according to any one of claims 1 to 4, wherein the step of comminuting the material includes a crushing or milling operation.
6. A method according to any one of claims 1 to 4, wherein the step of comminuting the material includes subjecting the material to
30 electromagnetic radiation.
7. A method according to claim 6, wherein the step of comminuting the material includes subjecting the material to microwave radiation.

8. A method according to claim 7, wherein prior to the application of the microwave radiation the material is treated with salt water to deposit salt water in cracks of the material.
- 5 9. A method according to claim 7, wherein prior to the application of the microwave radiation the material is treated with salt water such that the salt water enters cracks of the material.
- 10 10. A method according to claim 9, wherein the material is saturated with salt water prior to the application of microwave radiation.
11. A method according to claim 7, wherein prior to the application of the microwave radiation the material is treated with a mixture of a dielectric liquid and an organic liquid such that the mixture enters cracks of the material.
- 15 12. A method according to claim 11, wherein the organic liquid is selected from the group consisting of methanol, ethanol and isopropanol.
- 20 13. A method according to claim 11 or claim 12, wherein the dielectric liquid is selected from water or salt water.
14. A method according to any one of claims 8 to 13, wherein the cracks are formed along grain boundaries of the material resulting from the application of the high voltage discharge to the material.
- 25 15. A method according to any one of claims 1 to 14, including sorting of the material prior to the application of the high voltage discharge to remove material having exposed conductive mineral deposits on the surface thereof.
- 30 16. A method according to claim 15, wherein sorting of the material includes applying microwave radiation to the material and imaging the material to

identify exposed mineral deposits on the surface thereof and removing said material with exposed mineral deposits on the surface thereof.

5 17. A method according to claim 16, wherein imaging of the material includes infrared imaging.

18. A method for comminution of a material including:
submerging the material in water and applying a high voltage discharge to the material, said high voltage discharge being applied at a
10 voltage and energy sufficient to form cracks at grain boundaries within the material, thereby weakening the material at said grain boundaries;

treating the material with salt water such that salt water is deposited in said cracks at the grain boundaries within the material; and
applying electromagnetic radiation to the material, thereby
15 fracturing the material along said grain boundaries.

19. A method for comminution of a material including:
submerging the material in water and applying a high voltage discharge to the material, the high voltage discharge being applied at a
20 voltage and energy sufficient to form cracks at grain boundaries within the material, thereby weakening the material at the grain boundaries;

treating the material with salt water such that the salt water enters the cracks at the grain boundaries within the material; and
applying electromagnetic radiation to the material, thereby
25 fracturing the material along the grain boundaries.

20. A method according to claim 18 or claim 19, wherein said electromagnetic radiation is microwave radiation.

30 21. A method according to claim 19 or claim 20, wherein the material is saturated with salt water prior to the application of electromagnetic radiation.

22. A method for comminution of a material including:
submerging the material in water and applying a high voltage
discharge to the material, the high voltage discharge being applied at a
voltage and energy sufficient to form cracks at grain boundaries within the
material, thereby weakening the material at the grain boundaries;
treating the material with a mixture of a dielectric liquid and an
organic liquid such that the mixture enters the cracks at the grain
boundaries within the material; and
applying electromagnetic radiation to the material, thereby
fracturing the material along the grain boundaries.
23. A method according to claim 22, wherein the material is saturated with
the mixture of the dielectric liquid and the organic liquid prior to the
application of electromagnetic radiation.
24. A method according to claim 22 or claim 23, wherein the organic liquid is
selected from the group consisting of methanol, ethanol and isopropanol.
25. A method according to any one of claims 22 to 24, wherein the dielectric
liquid is selected from water or salt water.
26. A method according to any one of claims 22 to 25, wherein said
electromagnetic radiation is microwave radiation.

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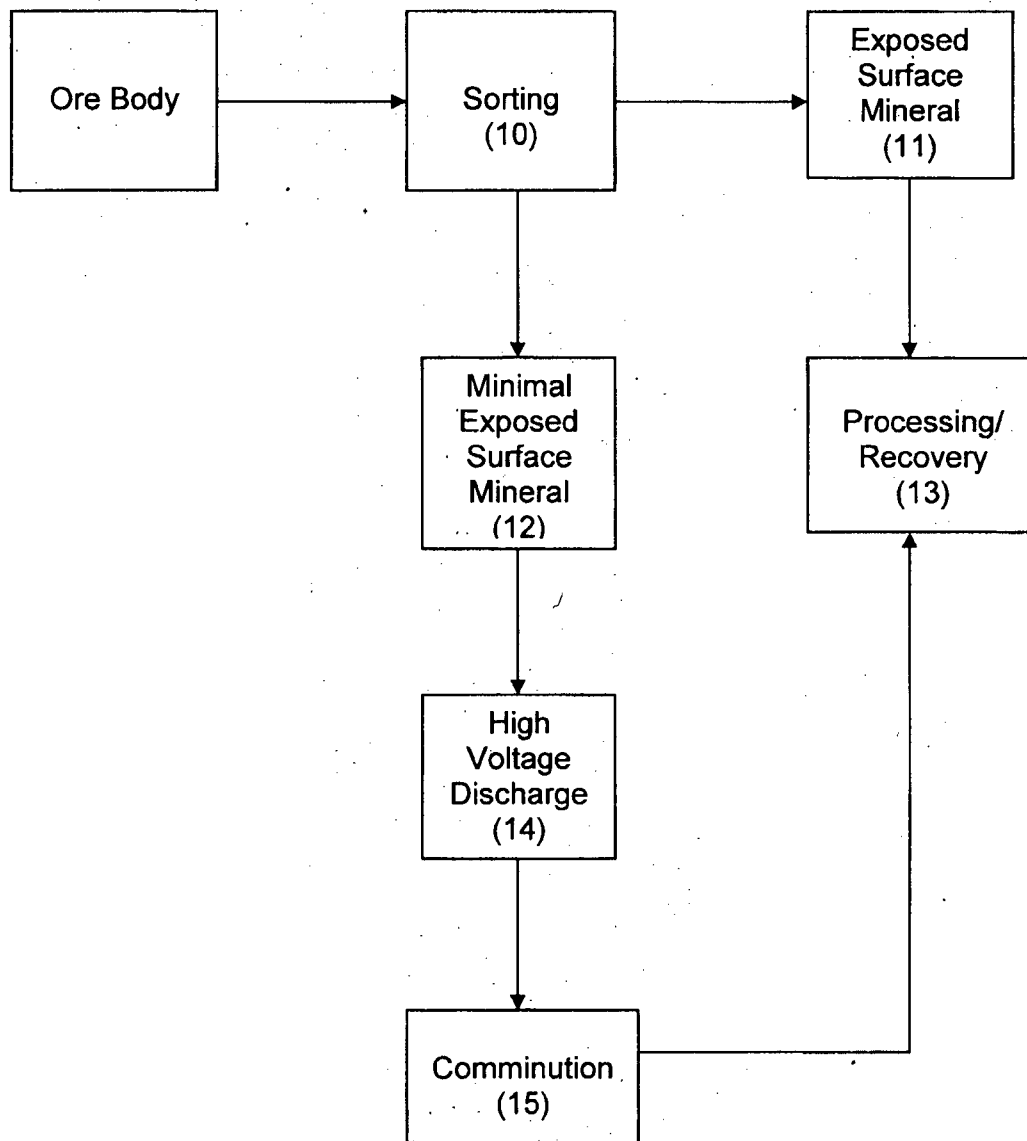


FIGURE 1

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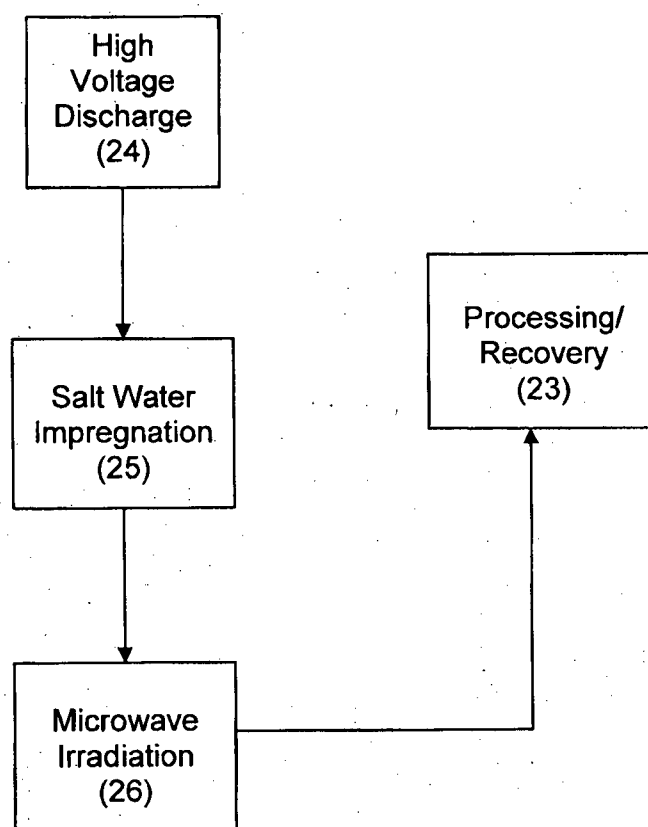


FIGURE 2

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FIGURE 3A

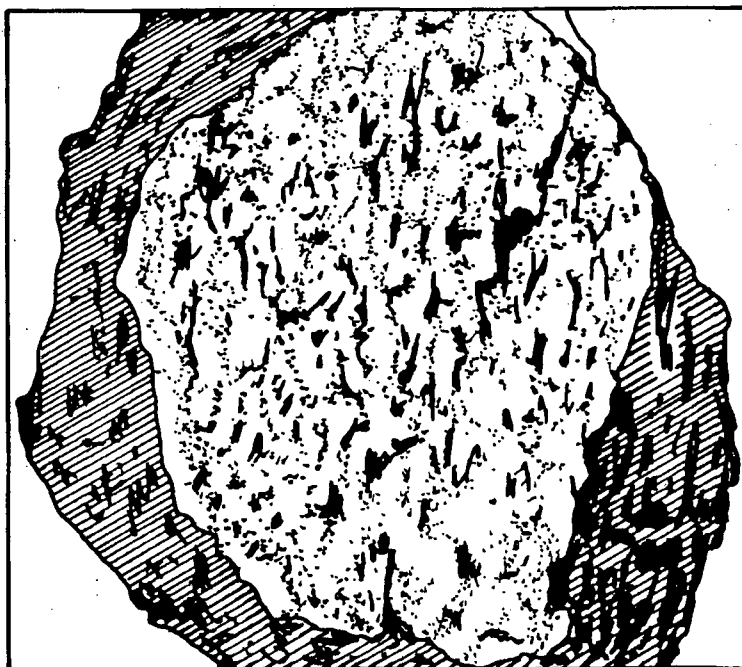


FIGURE 3B

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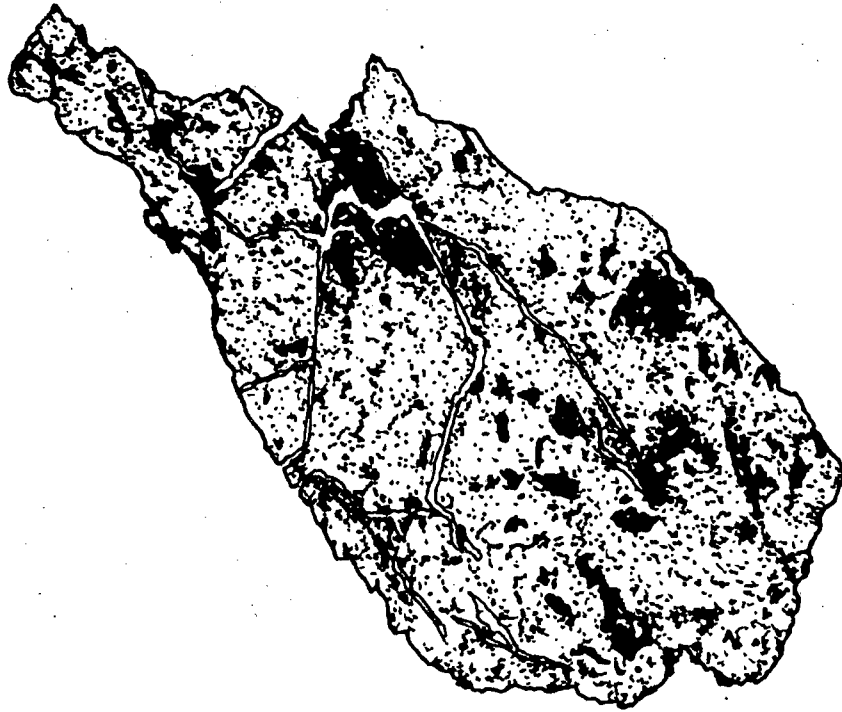


FIGURE 4A

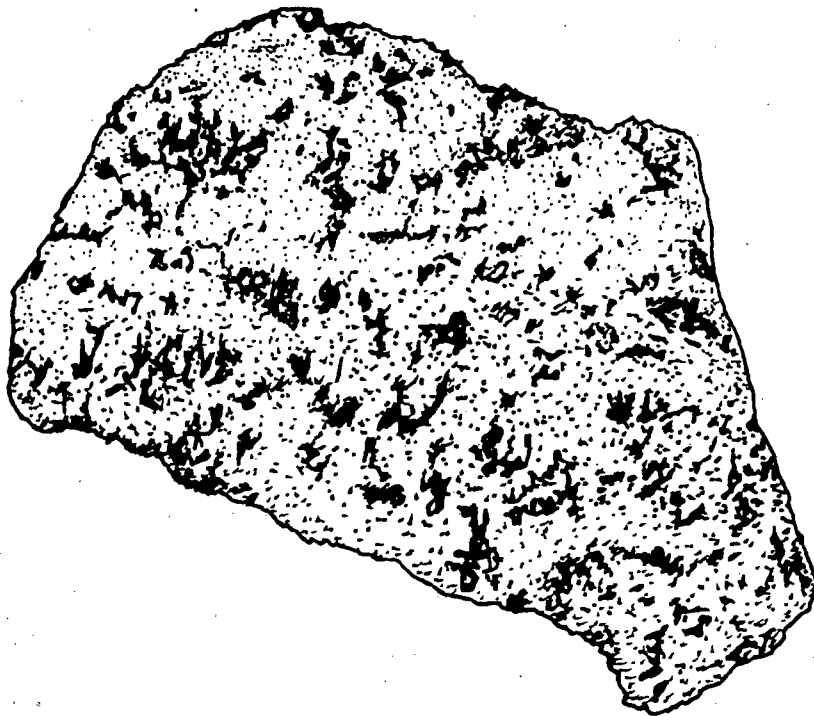


FIGURE 4B

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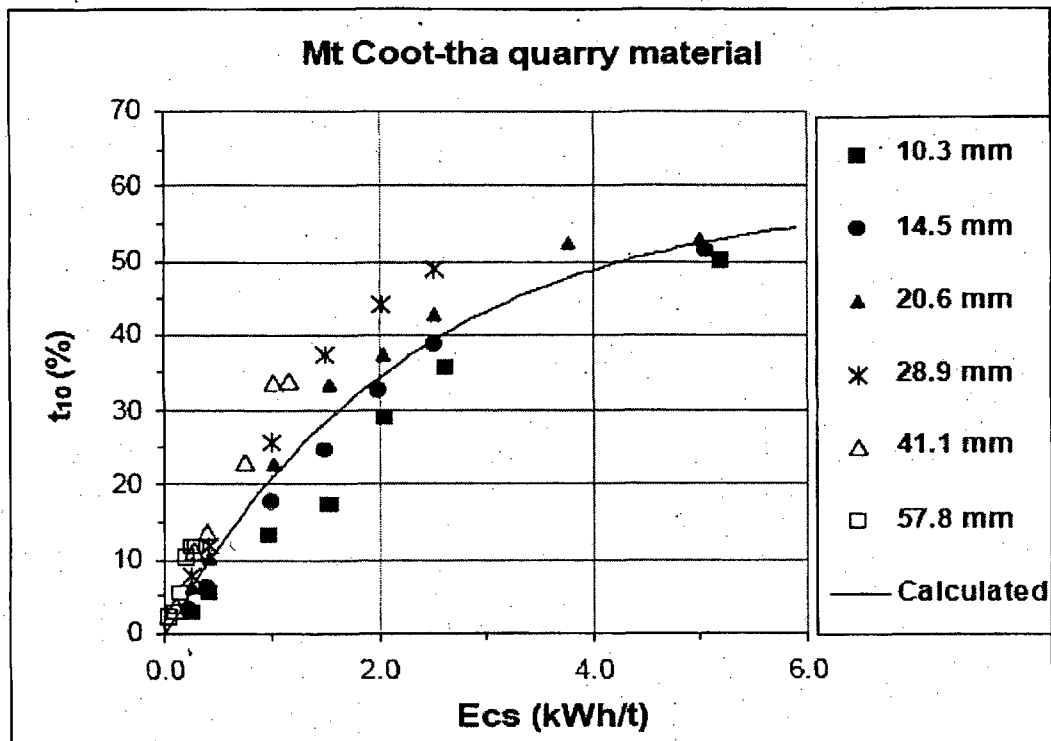


FIGURE 5

R(-13.2+9.5mm) vs R(-3.35+2.36mm)

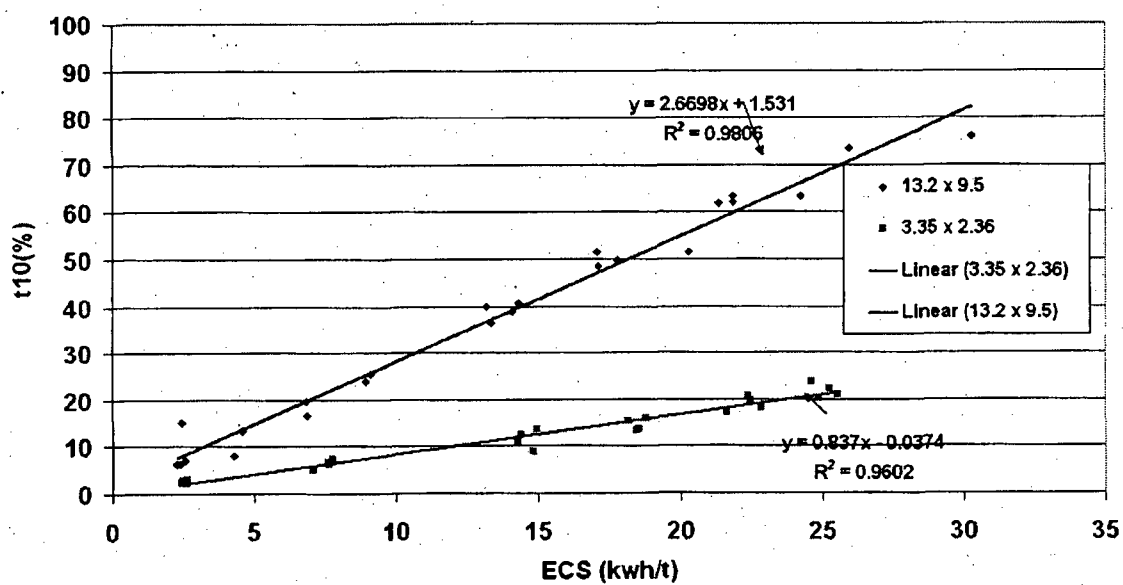


FIGURE 6

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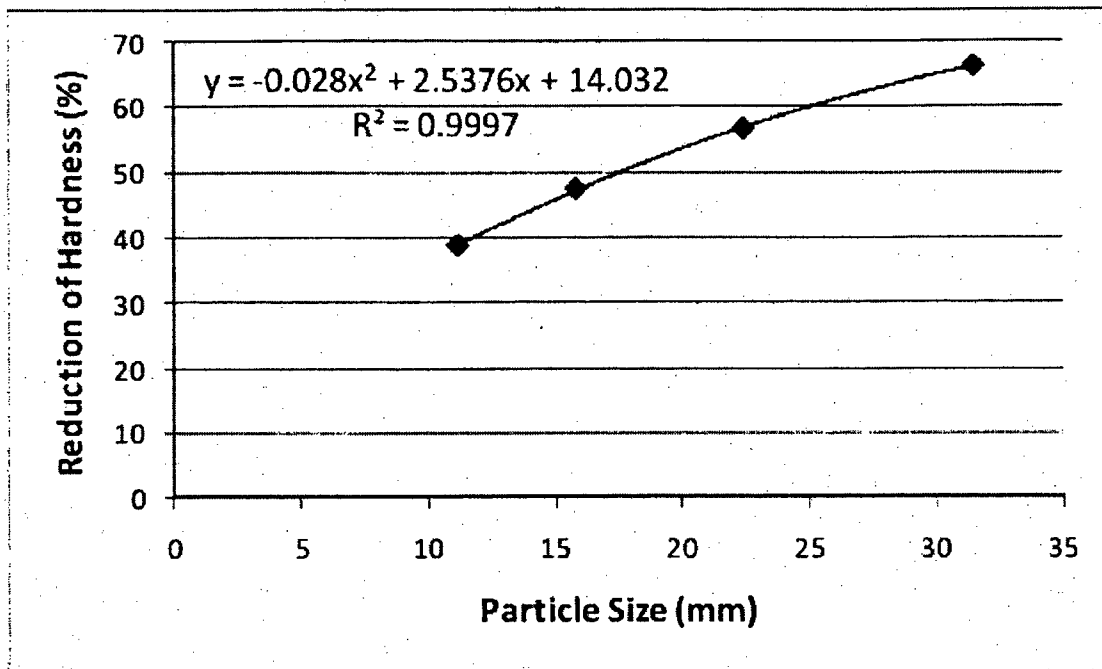


FIGURE 7

INTERNATIONAL SEARCH REPORT

International application No.

PCT/AU2011/000367

A. CLASSIFICATION OF SUBJECT MATTER

Int. Cl.

B02C 17/00 (2006.01)

B02C 19/18 (2006.01)

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

WPI, EPODOC databases (EPOQUE): B02C17/IC/EC OR B02C19/18/IC/EC; ENERG+ OR +VOLT+ OR DIS_CHARG+ OR +PULS+ OR ARC+ OR SPARK+ OR ELECTRIC+ OR SHOCK+; DIS_INTEGRAT+ OR WEAK+ OR COMPROMIS+ OR FRACTUR+ OR +CRACK+ OR BREAK+ OR FRAGMENT+ OF DIS_AGGREG+ OR COMMUNUT+ OR REDUC+

Esp@cenet, Google Patents, Internet Keyword Search, USPTO: volt+ or voltage or energy or pulse+ or shock; weaken or fracture or break or fragment; salt or salty or NaCl; and electromagnetic or microwave or gamma or radio or infrared and similar keywords.

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 4313573 A (GOLDBERGER et al.) 2 February 1982. See abstract; figures 1 and 2; column 1, lines 5- 15; column 1, line 45- column 2, line 50; column 2, line 53- column 4, line 6; column 4, line 23- column 5, line 53; examples 1 and 2; and claims.	1, 3- 7, 15- 17
Y		11- 14, 22- 26
X	WO 2009/026647 A1 (THE UNIVERSITY OF QUEENSLAND [AU]) 5 March 2009. See abstract; page 1, line 4- page 9, line 31; page 11, line 24- page 12, line 6; claims; and figures 1 and 2.	1- 4
Y		11- 14, 22- 26

☒ Further documents are listed in the continuation of Box C☒ See patent family annex

* "A"	Special categories of cited documents: document defining the general state of the art which is not considered to be of particular relevance	"T"	later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"E"	earlier application or patent but published on or after the international filing date	"X"	document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"L"	document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"Y"	document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"O"	document referring to an oral disclosure, use, exhibition or other means	"&"	document member of the same patent family
"P"	document published prior to the international filing date but later than the priority date claimed		

Date of the actual completion of the international search
20 July 2011

Date of mailing of the international search report 22 JUL 2011

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INTERNATIONAL SEARCH REPORT

International application No.

PCT/AU2011/000367

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 4540127 A (ANDRES) 10 September 1985. See abstract; figure; column 1, line 5- column 4, line 57; and claims.	1- 4
A	GB 905555 A (HADEN, THOMAS) 12 September 1962. See whole document.	

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/AU2011/000367

This Annex lists the known "A" publication level patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Patent Document Cited in Search Report			Patent Family Member				
US	4313573	NONE					
WO	2009026647	NONE					
US	4540127	AU	14810/83	CA	1207376	GB	2120579
		ZA	8303696	ZW	11783		
GB	905555	NONE					
Due to data integration issues this family listing may not include 10 digit Australian applications filed since May 2001.							
END OF ANNEX							