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The Immersed Arc for Remediation of Contaminated Land

***Abstract**. The plasma arc utilization process has been described as a tool for contaminated land treatment. In this method high temperature of electric arc is used to melt, vaporize and decompose of wastes following to their vitrification. Due to this high temperature harmful elements are converted into a safe and a non-leachable product. Examples of the end products have been presented and its toxicity has been measured and compared.

Streszczenie.** W artykule została opisana plazmowa metoda mogąca mieć zastosowanie do procesu utylizacji skażonej gleby. W metodzie tej łuk elektryczny topi, a następnie doprowadza do parowania i rozkładu odpady, prowadząc w końcowym etapie do ich zeszklenia. W procesie tym, dzięki wysokiej temperaturze szkodliwe związki przetwarzane są w bezpieczny i niewymywalny produktu. W artykule zostały przedstawione także produkty końcowe procesu - witryfikaty. (**Zastosowanie łuku zanurzonego do utylizacji skażonej gleby)

Keywords: electric arc, waste treatment, soil treatment.
Słowa kluczowe: łuk elektryczny, utylizacja odpadów, utylizacja gruntów.

Introduction

Contamination of soil and ground water by organic and inorganic chemicals is a widespread problem around the world. Increasing amount of mineral components, produced by industry plants and agriculture determine a potential environmental risk of inorganic contamination. Also organic fraction might be there expected for example, unavoidable leaks from capacitors and transformers containing mineral oil with polychlorinated biphenyl's (PCB's). The thermal processing can be done by heating up the soil layer in-situ or by transporting the bulk of the soil into a furnace. The in-situ processing is high energy consuming and it has been already reported (1).

The economically viable solution applicable for most of toxic mineral residues is the use of plasma arc vitrification process.

The vitrification refers to inorganic substances containing oxides of silicon, aluminum etc. The vitrification process can be used for contaminated land treatment. Temperature of the electric arc transforms solid state of contaminated soil into a liquid state. Glassy product which is safe for the environment is formed by cooling. Figure 1 presents the vitrification process scheme.

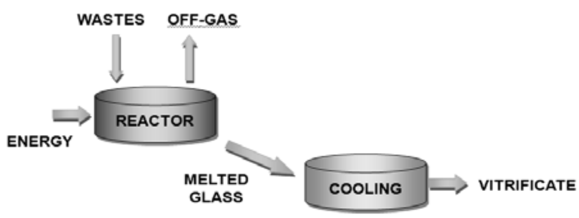

Fig.1. Vitrification process diagram

The main advantages of vitrification are: crystallization of inorganic materials, binding of toxic elements (metals and its oxides), mass and volume reduction, chemical resistance and high hardness of the product.

The whole process can be divided into several stages. At the beginning energy is supplied to the waste. The second phase is a liquid-glass phase transition (2). After casting the fluid is cooled. A final product is a glassy material with an amorphous structure (3).

Thermal plasma is also an efficient medium for breaking bonds of unwanted molecular chains so it can effectively destroy organic compounds together with the solid waste conversion into valuable materials or products. Limited oxidation of organic portion of waste decreases the energy consumption so the utilization cost.

The plasma technologies are implemented since the eighties of the last century. Despite of classification them to the advanced technologies, they have not become popular yet on the industrial scale.

The plasma systems can be divided into two groups. To transfer the energy from plasma to the feed the first one uses plasma torches and the second the electric arc. World wide are carried out research works aiming to demonstrate the most effective techniques of waste materials utilisation using plasma torches or an electric arc (1-15).

The plasma systems produced on an industrial scale are having now good reliability and endurance as the plasma furnaces and plasma torches are being successfully used from 30 years in plasma metallurgy.

In the last twenty years a few different approaches for efficient minerals smelting and decomposition of organics were demonstrated. The most of experiments were connected with plasma torches with steady and centrifugal crucibles (1) or with graphite open or shielded arc also with two electrodes in arc V mode. However, the most energy efficient system is such in which the electrode is immersed deeply in the feed allowing most of the heat generated by the arc to be transferred to the feed.

Immersed gas-mineral-arc (GMA)

Our research has been focused on immersed arc technologies. The main assumptions for a model of arc furnace were: requirement of a continuous process of utilization and conversion of mineral waste material using an electric arc and that the energy transferred to the feed should be as high as possible. To avoid the use of plasma torches we assumed that the arc might be generated inside the waste material between an immersed electrode and the crucible. It means that the principle of this process is the arc submergence in the feed charge and also in its solution. Plasma utilization process might be a continuous one if the feeding of charge and collection of product are continuous.

Detailed requirements concerning the design principles of the furnace were as follows:

- the arc initiation is caused by short-circuiting of the electrode and the crucible following by the electrode enhancement,
- the continuous casting of the bath starts as soon as the feed is liquefied,
- the tap hole should be at sufficiently high temperature all the time, what makes impossible coagulation of the bath,

- tapping should be hold without the furnace move.

Hitherto existing technical solutions in this field have been analyzed on the ground patents and publications. The literature being close to the above-mentioned assumptions is very poor and it concerns mainly metallurgy of alloy steel (16, 17, 18) and production of the metallic silicon (19).

In our design we assumed axially symmetrical configuration (Fig. 2) of an anode - the crucible 1 and a cathode – the rod electrode 3. The contaminated mineral feed 2 is charged in a space between electrodes. Initially (in solid state) the silica and alumina based feed does not conduct an electric current. Anode has got in its bottom a hole enabling flowing out of excess of gas as well as tapping of the melt (bath). A DC arc, burning in the environment formed by gaseous mineral substance was named here the gas-mineral-arc (GMA). In Fig. 2a first phase of GMA burning is presented.

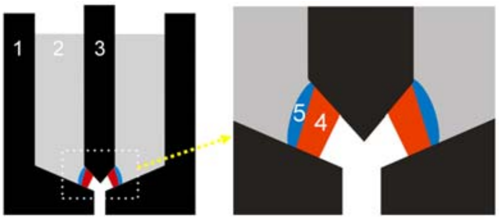

Fig.2. Draft of first phase of the GMA burning (whole object and its enlarged fragment)

The idle current starts to flow following the short-circuiting of the cathode and anode. After electrodes separation to a short gap (usually below 1mm) a stable arc discharge named here the idle arc is initiated 4 using a gas matter (argon, nitrogen or air) from side of the hole. The increase of the feed temperature effects in the gas coming to the arc - plasma atmosphere from gradually evaporating compounds according to reaching their boiling points. The arc discharge produces a gas sheath 5 from the side of charge which is of mineral origin. The other wall of the gas sheath is the melted mineral material layer. It has been proved that this layer is having electrical conductivity comparable to this of some metals [20].

Melted material gravitationally driven over the crucible bottom to the hole causes an increase of the anode spot resistance. The arc anode spot will then change its position, moving to a place, where the anode voltage fall is the lowest. The electrical arc temperature will cause in this new place more intensive melting of the charge material, what in turn causes the next move of the anode spot for looking of the place with a minimum anode fall. Finally, all these make the anode spot chaotic move around the hole. This phenomenon of effective arc drive around the crucible can be treated as "rotation” in the macroscopic scale. Such coupling makes all angular position of arc placement with the same statistical probability. The symmetry of thermal process allows supposing that the plasmas collar occurring among cathode and crucible is separated from solid charge (as powder) by the sheath of gas and the layer of liquid (melted charge).

Waste composition has a significant influence on the electric arc plasma properties. An influence of mineral vapors in the plasma arc channel is essential for plasma arc technologies, including waste treatment. Elements from waste decomposition cause usually lowering of the gas ionization potential. For example ionization potential for iron is 7.9 eV, for copper - 7.73 eV, for silver silver - 7.58 eV whereas for working gas as nitrogen is equal to 14.53 eV, and for oxygen - 13.62 eV. In plasma technologies even slight contamination of the metal in plasma arc channel (about 1%) significantly changes the electron density in the discharge over a wide temperature range.

Measurements of melted material resistivity showed [20] that fluid layer connecting electrodes could shunt the arc, leading to take over the current and extinguish the arc. The resistance of fluid layer depends on its local resistivity, the cross section and the length. It is also probable, that resistivity of this layer near electrodes grows up sufficiently as a result of electrode cooling. It can prevent current shunting leading to arc breaking. In every case however the arc voltage fall should be as high as possible so the arc can be elongated to the length assuring its stable regime called working arc regime. In these experimental investigations it does not encounter any arc instability problems. However before working arc would be applied the idle arc was burning for the time up to 30 s. After such "conditioning” of the system the arc was elongated to 5 mm and it was burning always steadily, until the tapping of the full charge. The arc stable discharge with the voltage fall of 200V has been reached also in large plasma furnace (250kW power).

Mineral waste treatment

Many plasma waste treatment tests were done for soil contaminated with some ashes, asbestos and medical incinerator residues also with addition of mineral oil with PCB [21]. Some simple products are presented in Fig. 3. However more advanced colored ceramic tiles (Fig.4) and porous insulation bricks (Fig.5) were also made [22].

Fig.3. The products of the immersed arc treatment of contaminated minerals [22]. The crashed frozen lava like and cake like casts

The simplest product received from the plasma furnace is a lava-like flow which after cooling and crashing can be used as a road aggregate (Fig.3).

This product was reach in silica and allumina and also in many metal oxides as presented in Table 1. Leaching tests (Tab. 2) done for the samples from Table 1 proved that all samples of product are having leaching bellow the regulatory limits so they are environmentally friendly.

Table 1. Composition of original slag samples

% mass	Sample 1	Sample 2	Sample 3
SiO_2	50.28	55.75	53.80
Al_2O_3	17.15	9.42	8.22
Fe_2O_3	9.18	6.020	4.07
Na_2O	3.77	6.34	4.03
K_2O	1.10	0.70	0.24
CaO	13.01	18.60	20.62
MgO	2.70	2.56	1.97
TiO_2	0.76	0.77	1.67
P_2O_5	0.44	0.51	0.63
MnO	0.28	0.28	0.17

Very useful and much required application is producing the chemically resistant refractory bricks and balls (Fig.5) replacing asbestos in various applications. This however requires post treatment i.e. graining and sinterring.

The characterization tests [22] proved that all the products are resistant to leaching and they are wholly friendly to the environment.

Table 2. Leachability of metals (mg/dm^3) of samples as in Table 1

	Sample 1	Sample 2	Sample 3
Ni	0*	0*	0*
Co	0*	0*	0*
Pb	0*	0*	0*
Mn	0*	0*	0*
Cr	0*	0*	0*
Mg	0.087	0.680	0.380
Ca	3.790	3.910	3.810
K	0.518	0.289	0.489
Na	3.122	2.720	2.920

However it is easy to make shape ready elements such as tiles (Fig.4).

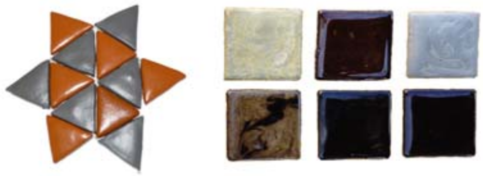

Fig.4. Samples of ceramic tiles [22]

Fig. 5. Porous insulation bricks and balls [22]

Energy efficiency

The balance of energy of a plasma furnace is generally related to such parameters as heat source, flow of energy and heat losses. The heat is mainly generated by electricity in the arc channel and in the electrode spots. The energy distribution in an arc furnace is on the way of the conductivity, radiation and convection. Heat losses follow in result of cooling the furnace body and the electrode. In the arc furnace worked out here we had to deal with initiating and generating the heat inside the feed. So “almost whole” of the energy was captured by the charge. Qualification „almost whole” classifies as useful all the energy produced in the arc channel and absorbed by the charge on the way of convection and radiation. This way the charge can consume up to 98% of delivered electrical energy. The efficiency of thermal process depends on the value of losses to the ambient. These losses depend on temperature distribution on surface of external sheath of the furnace and the uncovered part of electrode. Simulations results showed, the distribution of temperature on these surfaces mainly depend on the process duration.

The cost of waste disposal strongly depends on the system size. It means that cost decreases when the size increases from small to large system. If there is a medium size system (processing of 50 tons per day) and the inorganic waste is rich in a calorific waste (for example PCB transformer oil from10 to 20% in mass) the total cost of utilization can go bellow 50 €/t in some cases.

Conclusions

In the paper, a new approach to utilization of mineral wastes using electric arc has been presented. A model of mineral arc-plasma immersed in the furnace feed charge has been elaborated for this purpose. Experimental tests in the laboratory furnace presented some end products – vitrified slag.

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