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Plasma arc for utilization of soils

***Abstract**. The paper presents the plasma arc method of solid state waste 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. The plasma arc utilization process has been described and examples of the end products have been presented. Conditions characteristic for the utilization of soils were determined.*

***Streszczenie.** W artykule przedstawiono metodę utylizacji odpadów stałych przy zastosowaniu plazmy łuku elektrycznego. W metodzie tej temperatura łuku początkowo wykorzystywana jest do stopienia odpadów prowadząc do ich witryfikacji. Dzięki wysokiej temperaturze szkodliwe substancje zamieniane są w bezpieczny produkt. Opisano proces utylizacji plazmowej. Określono warunki niezbędne do utylizacji. (**Zastosowanie plazmy łuku elektrycznego do utylizacji gruntów**)*

Słowa kluczowe: utylizacja gruntów, utylizacja plazmowa, plazma łuku elektrycznego, postępowanie z odpadami,
Keywords: soil treatment, plasma utilization, electric arc plasma, waste treatment

Introduction

Nowadays soil pollution is more common for environment than in the XX century. Contaminants get through the organic matter and surface soil into the subsoil ground waters from intentional or unintentional human activity. The most problematic are contaminants from damaged containers, oil leakage from electrical apparatus or chemical weapons residues. Surrounding environment itself may increase the pollution on a relatively wide area.

An electric arc plasma due to its high temperature is an effective tool for utilization of contaminated soil. A method using immersed arc can be an effective tool for smelting of mineral compounds followed by their vitrification. The average soil composition depends upon various factors, such as geology, cultivation, or atmospheric deposition. Usually soil consists of about 45% minerals, 25% of water, 25% of air, 5% of organics. The most popular components are iron, silicon, calcium, magnesium, aluminum etc. and their oxides [Fig. 1].

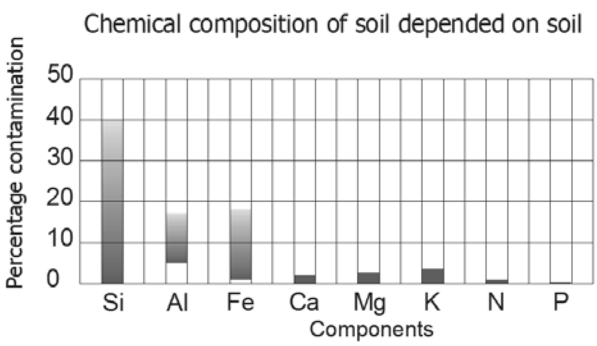

Fig.1. The safe vitrificate formed into ceramic tiles

It has been proved that it is possible to lead a continuous process of utilization using an electric arc [1].

Solid wastes treatment

Due to the diversified composition of wastes there is not only one universal method of waste disposal.

The management of solid waste is a major problem in many parts of the world. There are many techniques for waste treatment. EU regulations banning the disposal to communal landfill of toxic and hazardous waste are effective from the year 2002. One of the most popular method of waste treatment is incineration plant but presence of oxygen and low temperature leads to the formulation of more hazardous forms of wastes such as dioxins and furans.

The simplest way of solids utilization is to burn the waste in the licensed installation. However in this case some hazardous residues comes from the waste incinerators in the form of fly and grate ashes. Generally the following shortcomings of the waste burning process can be noticed:

- The thermal treatment of some wastes (e.g. industrial, medical, and military) through their incineration results in the formation of relatively highly toxic residues. The ash residue being a secondary waste is sometimes more toxic than the primary solid feed.
- Waste incineration leads to a decrease of the waste mass only. From 15 to 30 % of feed mass is still the ash residue.
- Dioxins, furans and heavy metals can be released as air borne pollutants in the ash, which needs to be land filled with special care (i.e. mixed with cement) due to a danger of ground water contamination.

The above disadvantages can be resolved by employing the plasma technology for thermal treatment of inorganic and/or hazardous organic wastes.

Thermal plasma is particularly attractive for treatment of solids and liquids containing hydrocarbons. Thus it is possible to convert wastes into valuable fuel. As an effect of plasma pyrolysis at temperature above 2000 K only high-caloric gases and molted inorganic ash fraction and metals appear. Non-leachable solids – vitrificate with structure and strength of basalt - can be used as building materials. Gaseous products, which contain hydrogen and oxygen, can be used in methanol production or as a fuel for the electric power generator.

Plasma arc for treatment of soils

One of the most effective methods of soil utilization is thermal plasma waste treatment. The plasma technology offers many benefits. The utilization process can be conducted in a closed system and does not emit harmful chemicals into the environment.

The thermal plasma is a source of high energy density with temperature of a few thousand Kelvins and high ultraviolet radiation. These result in fast reaction rates, and high throughput in smaller reactors. The heat generation is independent of the chemical composition. Avoidance of dioxins and furans is guaranteed due to oxygen free environment. Moreover it is possible to select optimum chemistry for the destruction process, smelting of high melting point inorganic wastes, easy control, rapid start-up and shut down and also the treatment process is relatively flexible.

The process of vitrification, that means solidification in glass-like form (from Latin: vitrum - the glass), concerns the inorganic compounds including silicon or aluminium oxides and similar glass creating elements. It consists of thermal fluidisation of the material followed by cooling it to obtain the vitrificate.

However the plasma process on an industrial scale is a quite sophisticated and know-how packed technological system. Presently, the target applications of the thermal plasma systems are:

- the treatment of the most toxic and hazardous industrial wastes [2, 3],
- clean fuel generation from organic hazardous wastes [2, 4],
- vitrification of solid leftovers from incineration plants,
- vitrification of contaminated soil [1, 5].

The main advantages of thermal plasma waste treatment are:

- complete pyrolysis of organic and hazardous wastes without oxygen, vitrification of inorganic toxic leftovers high temperature,
- high calorific value of gas fuel generated,
- smaller size of installation - high energy density
- minimum total gas throughput - no excess gas for combustion required,
- rapid start-up and shutdown - easy automatic control.

The average soil composition is a mixture of minerals such as Si, Al, Fe, Ca, Mg, K, N, P and their oxides. Their temperature of decomposition is much higher than the temperature in classic incinerator. We used thermodynamic program CHEMSAGE to predict variety and amount of different products after heating fly ashes in a plasma arc. Our aim is to determine temperature of total decomposition of ash. Figure 2 shows phase equilibrium for SiO_2 as the major component of soil.

The calculation results showed that all compounds are in gas phase when the temperature reaches 4000K [6]. There are the following gas compounds during the ash components decomposition:

- Al, AlO, AlO_2, Al_2O, Al_2O_2, Al_2O_3, Al_2,
- Ca, CaO, Ca_2,
- Fe, FeO, FeO_2,
- Mg, MgO, Mg_2,
- Na, Na_2, NaO, Na_2O, Na_2O_2,
- O, O_2, O_3,
- SiO, SiO2, Si, Si3, Si2O2.

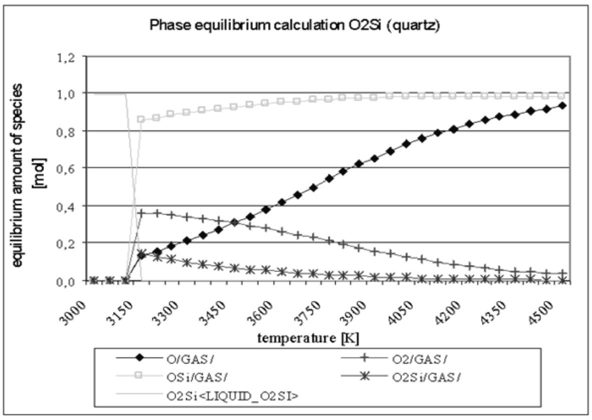

Fig.2. Phase equilibrium for SiO_2

From waste to useful product

In Technical University of Lodz DC plasma furnace has been designed as an Immersed Arc Furnace (IAF) and applied to treat the inorganic wastes (Fig.3) [7]. The furnace is water-cooled and the transferred arc-plasma system has a maximum output power of 250 kW. In axially - symmetrical configuration of an anode - the crucible and a cathode the rod electrode the mineral feed charge files a space between them. Initially (in solid state) the feed does not conduct an electric current. Anode has a hole in its bottom, which enables 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).

Fig.3. The plasma arc furnace.

The idle current starts to flow following the short-circuiting of the cathode and anode. After electrodes separation to a short gap a stable arc discharge named here the idle arc is initiated using a gas matter (argon, nitrogen or air) from side of the hole. The increase of the feed temperature effects in entering to the arc evaporating mineral compounds. The arc discharge produces a gas sheath from the side of charge, which is of mineral origin. The other wall of the gas sheath is a melted mineral material layer. After that the arc is elongated to allow tapping of the full charge. The immersed arc configuration as the heat source within the charge means, that almost whole (up to 98%) of energy is captured by the charge [1].

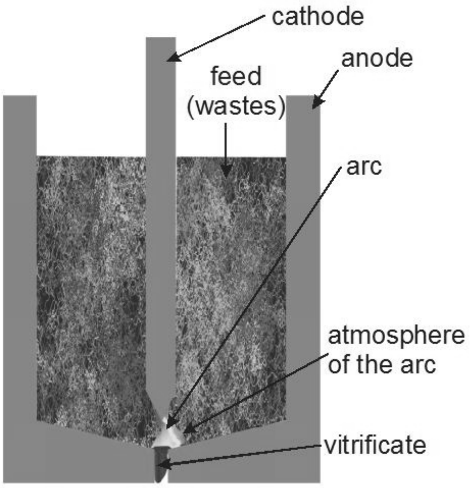

Fig.4. A model of vitrification by immersed arc plasma [8]

In this system it is possible to utilize and recycle mineral wastes in continuous way into vitrificate by electric arc generated inside the utilized material (Fig.5). The safe vitrificate can be formed into the ceramic tiles and can be used as a building material (Fig.6).

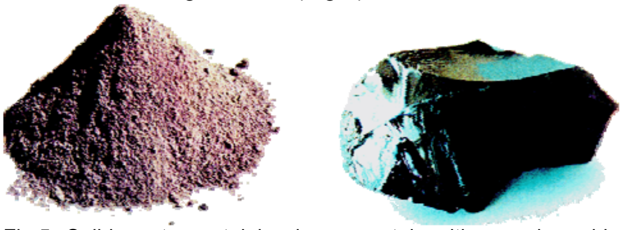
Fig.5. Solid waste containing heavy metals with organic residues compared to non-leachable vitrificate in plasma furnace


Fig.6. The safe vitrificate formed into ceramic tiles.

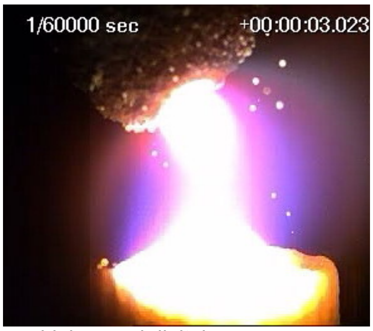

Fig.7. Image from high speed digital camera

Arc-plasma burns between electrode immersed in charge and crucible The arc starts to burn in neutral gas (i.e. argon) and then melts mineral compounds and their oxides followed by their gasification, thermal decomposition, ionization and formation of the mineral arc plasma. In our research 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. The theory of utilization of materials by electric arc has been verified by experimental tests in the laboratory furnace. To make calculations and measurements of the arc, a small model of a large system has been constructed (Fig. 7).

Determination of the mineral feed influence on electric arc for maximal usage of power system is associated with many equilibrium and thermodynamic parameters. In the case of completely immersed arc it burns only in mineral elements vapor and cannot be shunted by the conducting current melt. Metal arc plasma consists of atoms, ions and electrons. Argon has been used as a working gas. It was assumed that unbounded metal occurs in the argon atmosphere and that multiple ionization below 10000 K is negligible. Local thermodynamic equilibrium (LTE) has been assumed to calculate arc plasma composition. To determine electron density, atoms density, ions density system of non-linear equation have been solved. We used Saha-Eggert equatiuons, Dalton's law, charge equilibrium in LTE conditions, percentage of metal vapor in gas. Atomic data for considered elements has been calculated by Drawin [9]. Exemplary result is shown on Figure 8.

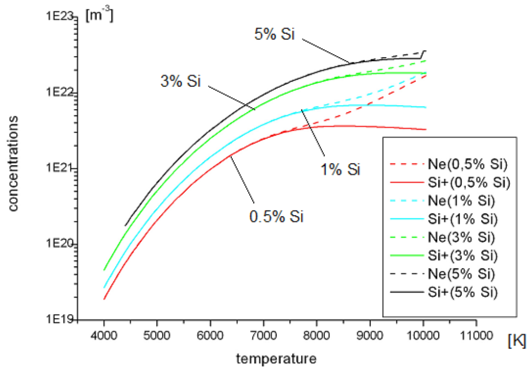

Fig.8. Electron densities for different silicon concentrations

Calculations for Mg, Si, Al, Ca, Fe have been conducted for 0,5 up to 5% mineral ratio in argon plasma. For each examined compound the electron concentration mainly depends of concentration of ions of examined element. Even 1% addition of metal determines electron densities in plasma. Measurements of the plasma channel temperature are based on the relative line intensities spectroscopic technique [10].

Figure 9 show a part of two lines intensities recorded by oscilloscope and calculated temperature for arc burning between graphite and copper 6mm electrodes, current 20 A, voltage 60 V. Distance between electrodes: 3 mm. The arc unit volume is computed from Abel's transformation.

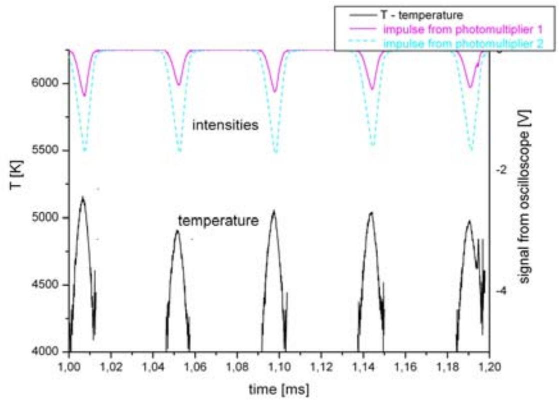

Fig.9. An example of temperature calculation

On Fig. 10 there are results of temperature and resistance measurements for electric arc in plasma arc furnace model.

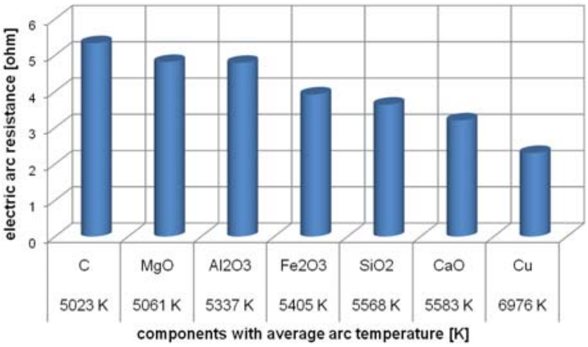

Fig.10. Arc resistance for different plasma composition

Conclusions:

The design and building of arc plasma systems for thermal treatment of materials is economically viable if its thermal efficiency is as high as possible. The laboratory tests proved that the use of the arc discharge generated inside the material among electrode submerged and crucible can function well and effectively. The thermochemical calculation allowed to define the best range of temperature for utilization of considered materials. The properties of the vitrificate qualify it as an acceptable building material.

The electric arc is able to decompose thermally any organic fraction and to melt an inorganic fraction of the material, what in turns leads to its vitrification in the cooling process.

It is possible to utilize and recycle mineral wastes in continuous way into vitryficate by electric arc generated inside utilized material.

The electric arc stability depends on two factors:

- parameters of source quality;
- changes of resistance.

Addition of mineral compounds changes effective ionization potential and in effect – conductance:

- minimal addition of mineral (less than 1%) strongly changes plasma composition what results by changing plasma properties such as resistance and electrical conductivity,
- even 20 % of copper in the Cu-Me mixture does not influence on electron density in metal plasma for a temperature up to 7000 K so copper can be used as a detecting element,
- electric arc plasma with atmosphere generated by waste vaporization has lower resistance of the arc channel comparing to the nitrogen or argon atmosphere,
- continuity of discharge under temporary minerals concentration increase is guaranteed.

This could be a step forward to elaborate and control an effective technological vitrification process of inorganic toxic or dangerous wastes.

It should considerably increase the energetic efficiency of waste treatment.

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