ZESZYTY NAUKOWE POLITECHNIKI ŁÓDZKIEJ
Nr 1050 ELEKTRYKA, z. 119 2009

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INFLUENCE OF GASEOUS MINERAL COMPONENTS ON DC ELECTRIC ARC PARAMETERS

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Manuscript received 04.09.2009

The applications of electric arc plasma can be classified in two categories: electrical and thermal (chemical). In most cases plasma consists not only of inert gas but also inserted on purpose or in undesirable way metal. An additional element in electric arc plasma affects its equilibrium and thermo-chemical parameters, and in consequence the analysed process. The purpose of this work is to show influence of some selected metals on plasma composition parameters. A new way of estimating plasma properties without resorting very complex models has been developed and the results for electric arc metal plasma are presented.

1. INTRODUCTION

The electric arc in gas-metal vapour atmosphere appears in many applications. An example of the influence of metals on plasma is the plasma waste destruction whereas DC arc burns in neutral gas e.g. argon. As a result of high temperature the wastes are melted following gasification and ionization. Consequently, the metal atoms enter the arc channel changing its parameters. Metal plasma also appears in the circuit breakers where evaporating electrodes change the plasma conductivity, temperature, electron density etc. Another example of metal-gas atmosphere appears in metallurgical processes. In this case metal vapour considerably decreases the effective ionization potential of the plasma medium.

The conducted research focuses on the electric arc parameters. Experimental techniques in the arc plasma diagnostics are shown. Various detecting materials are analyzed and advantages of using copper are discussed. Spectroscopic measurements of electric arc temperature are presented. Plasma composition is calculated and compared to the measured results.

The influence on electric arc of such phenomena and factors as mineral oxides decomposition processes in high temperature, change of effective ionization potential, change of the partial pressure etc. is considered. The electric arc parameters i.e. voltage, current and resistance are measured.

To prove the main thesis a theoretical analysis of metal components influence on plasma was carried out. A spectral technique based on two spectral lines intensities ratio was chosen and usefulness of copper as a thermometer element was analyzed and two copper spectral lines to estimate the arc temperature were selected. A set-up for spectral, visual and electrical measurements was constructed.

2. COMPOUNDS OF FLY ASH

Fly ash is one of the residues generated in the incinerators of industrial, municipal, medical and hazardous plants as well as combustion of coal. Though the majority of ashes are raw materials for further production, particularly in the building industry most of the generated fly ash is still disposed of in landfills or storage landfills [1,2]. Fly ash consist of particles containing metals as Si, Ca, Al, Fe, Mg, K. Stored ash may also contain heavy metals that are harmful to health as nickel, vanadium, arsenic, beryllium cadmium, barium, chromium, copper, molybdenum, zinc, lead, selenium, uranium, thorium, radium [3]. Over 95% fly ash composition is formed by five oxides: SiO_2, Al_2O_3, Fe_2O_3, CaO and MgO [4].

Plasma is the best medium to achieve temperatures which enable efficient decomposition of waste compounds and to neutralize toxic compounds by vitrification.

3. RESEARCH CHAMBER

An electric arc burns between two 6 mm graphite electrodes. One of the electrode is hollowed. A metal sample is placed in this hollow with addition of detecting material – copper. The distance between electrodes is 3 mm. The research chamber enables pirometry, spectroscopy and visual process registration. Figure 1 shows a frame from high speed camera operating at 12000 frames per second.

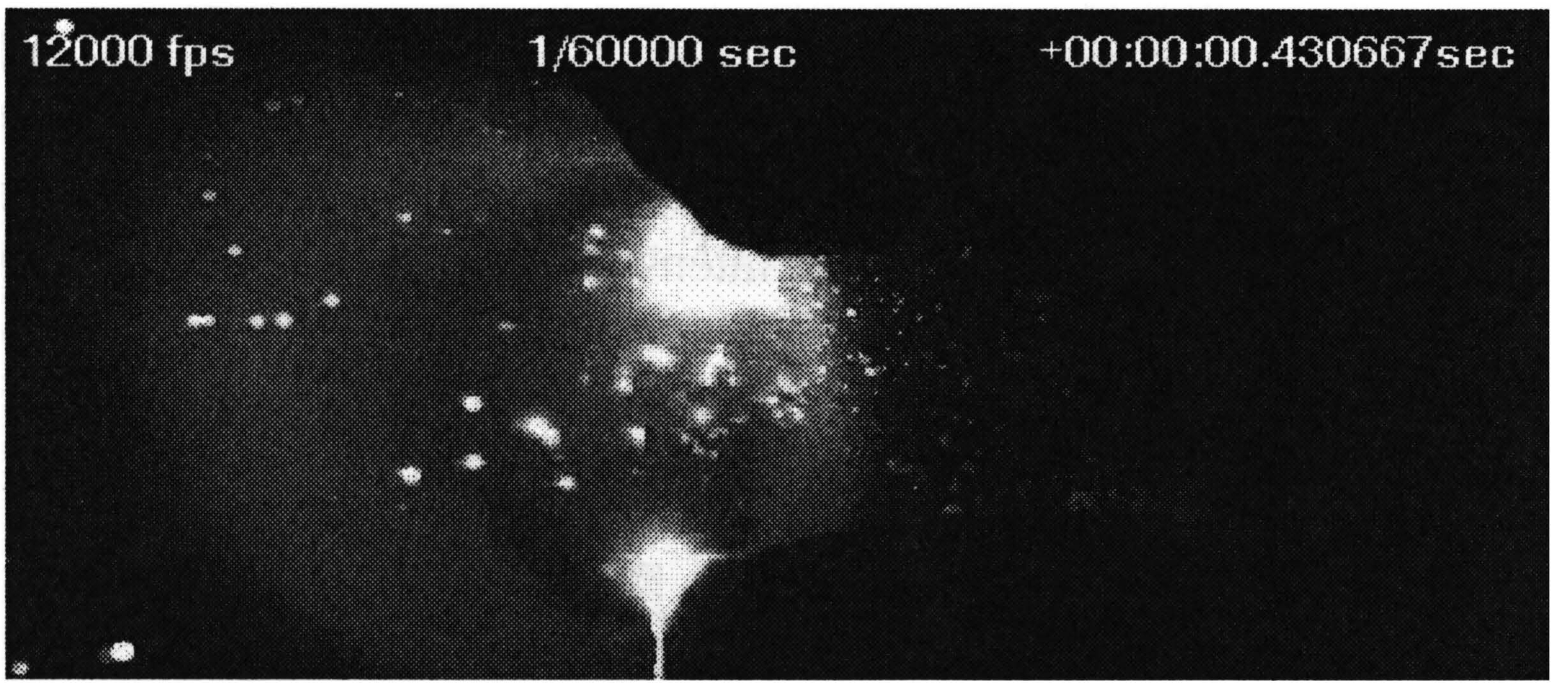

Fig. 1. Image from high speed camera

The main parts of the measuring arrangement are: the optical set-up and the data collecting equipment. To measure time-dependent temperature profiles at an arc cross-section, a special scanning technique was used. The optical set-up was composed of two main units: the scanning device and the spectrograph (Fig. 2).

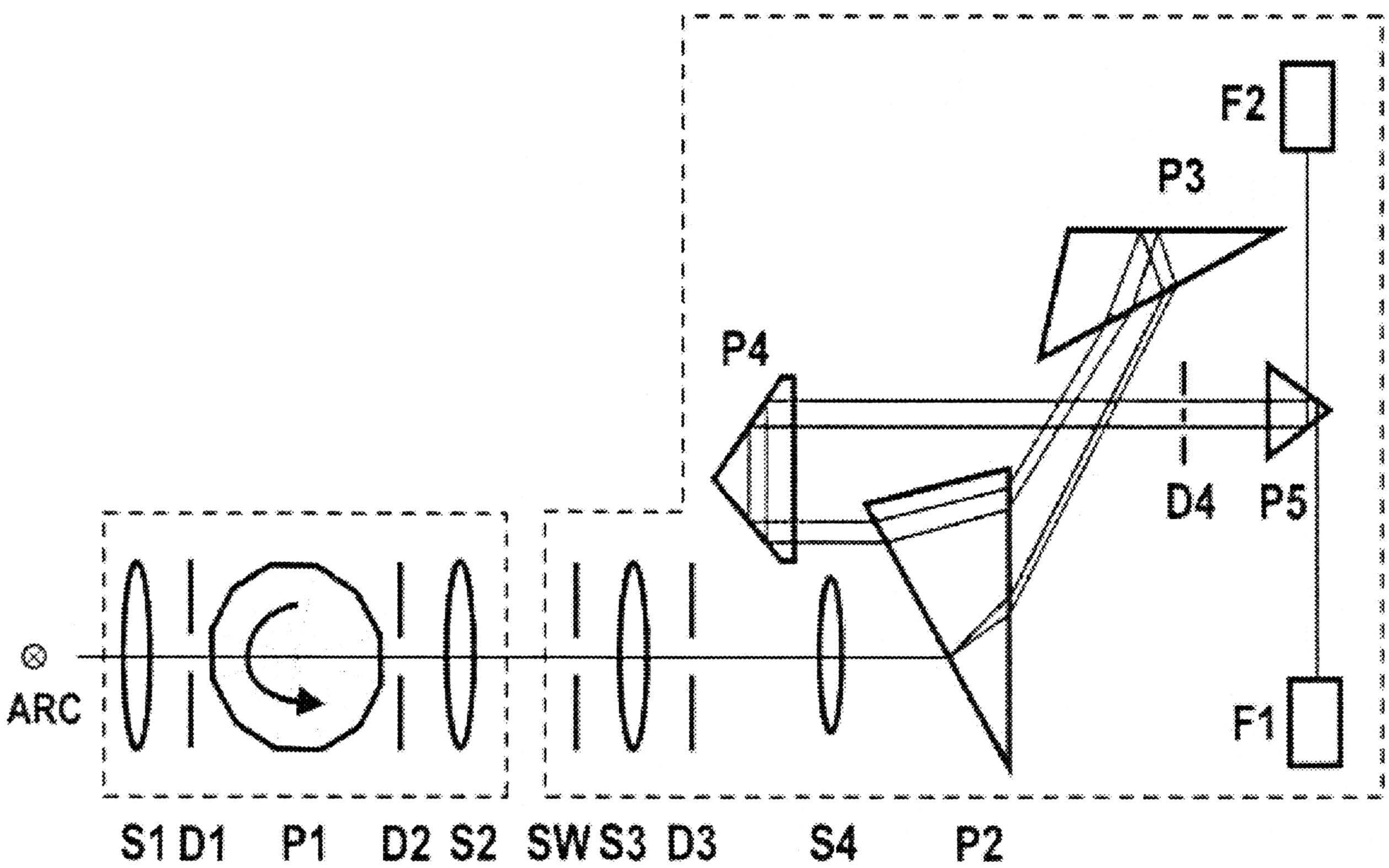

Fig. 2. D – diaphragmas, P – prisms, S – lenses, ES – entrance slit, F – photomultipliers, SW - entrance slit

The polycone prism of the scanning device unit was driven with a compressed-gas propelled turbine up to 1000 revolutions per second. It was possible to reach a scanning time of $5x10^{-5}$ with the scanning frequency 12000 full profile scans/s. Therefore only a single test was necessary to obtain time variation of the temperature profiles in an arc cross-section. The arc image focused on the entrance slit SW of the spectrograph was scanned. A diaphragm D4 was designed to select spectral lines characteristic for copper – 510,55nm and 521,82nm. Two spectral lines selected by the D4 diaphragm and split by the P5 prism were detected by two photomultipliers F1 and F2. Signals from photomultipliers are recorded by oscilloscope. Measurement of the plasma channel temperature are based on the relative line intensities spectroscopic technique.

4. TEMPERATURE MEASUREMENTS

Temperature measurements of plasma channel are based on two relative spectral line intensities (the Ornstein method). The integrated line intensities belonging to the same kind of plasma are side-on optically observed and recorded. The temperature is evaluated from the expression [5]:

$$T = \frac{E_1 - E_2}{\ln\left(\frac{A_1 \cdot g_1}{A_2 \cdot g_2}\right) - \ln\left(\frac{\lambda_2}{\lambda_1}\right) - \ln\left(\frac{\varepsilon_1}{\varepsilon_2}\right)} \qquad (1)$$

where:

E_1, E_2 – excitation energy for level 1 and level 2 respectively;
g_1, g_2 – statistical weight of excitation for level 1 and level 2 respectively;
A_1, A_2 – transition probabilities;
λ_1, λ_2 – wavelength for spectral lines 1 and 2 respectively;
$\varepsilon_1, \varepsilon_2$ – line intensities computed from Abel's transformation;

To obtain sufficient results a method that is independent of the plasma chemistry must be used. Due to a two spectral lines method the temperature is independent of plasma composition. Thus it is possible to use an additional element - thermometer. Assuming that we could introduce a certain amount of detecting element to the minerals mixture we selected copper for this purpose as it can be easily added as copper oxide to the waste being prepared as the mineral powder and two copper lines 521,8 nm and 510,5 nm were chosen.

Table 1. Average temperatures of electric arc in different time after ignition

component	temperature [K]			
	t = 3 sec.	t = 4 sec.	t = 5 sec.	t = 10 sec.
MgO	5130	5101	5204	4801
Al2O3	5429	5404	5148	5368
Fe2O3	5415	5439	5402	5366
SiO2	5672	5545	5541	5515
CaO	5369	5677	5768	5517
Cu	7023	6827	6971	7085

Even 20% amount of copper causing no side effect in measurements up to 7000K were established [6].

In Table 1 there are results of temperature measurements for electric arc in different gas-metal atmosphere. The 3 mm gap between electrodes, current 15 A. Figure 2 presents electric arc resistance for different plasma atmosphere.

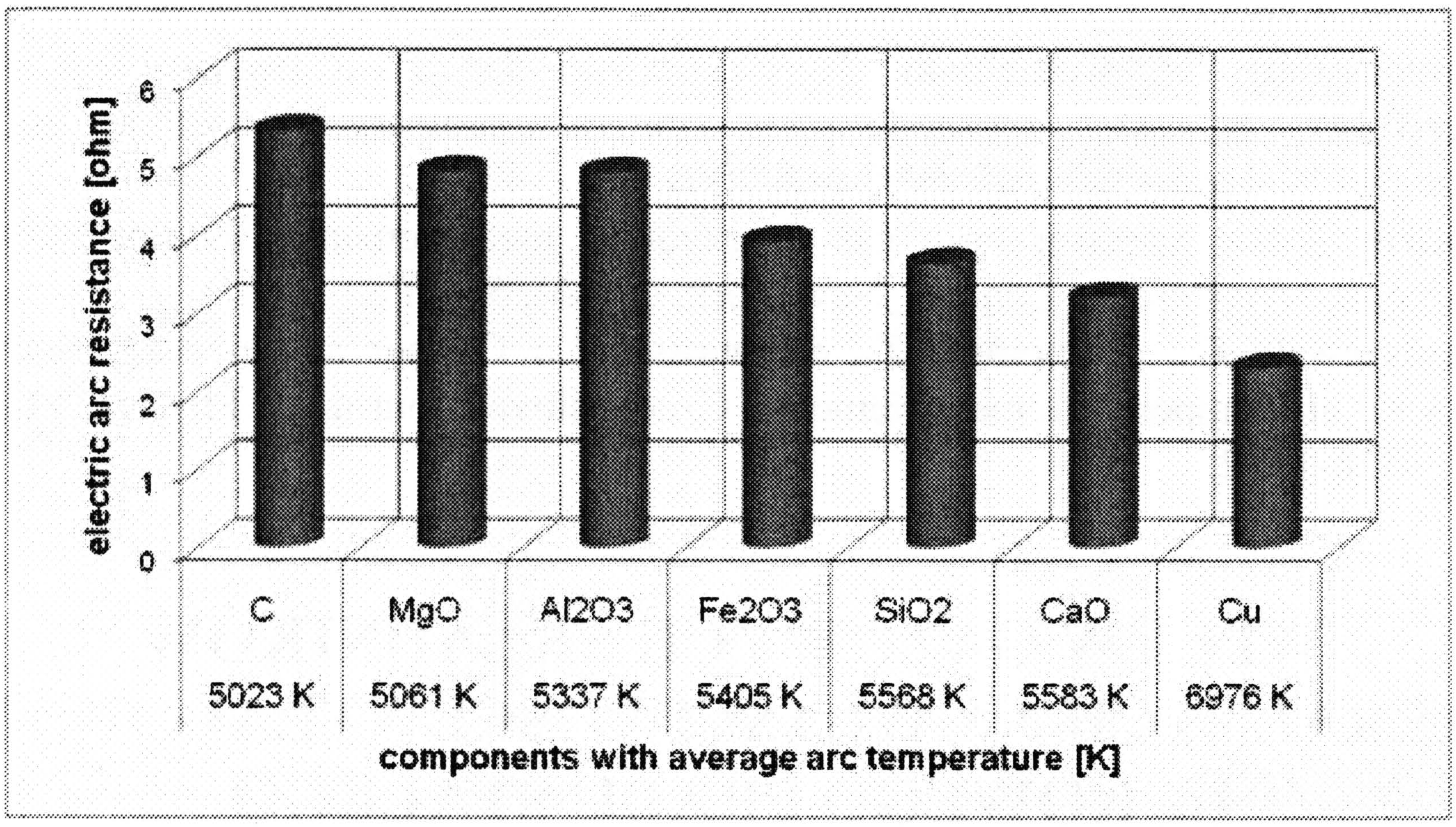

Fig. 3. Arc resistance for different metal-gas mixtures

5. CONCLUSIONS

The electric arc stability depends on two factors namely, source quality parameters and changes of resistance during the process. The influence of electrode material is discussed in literature. Additions of mineral compounds change the effective ionization potential and in effect - conductance. It has been estimated that minimal addition of metal vapour strongly changes plasma composition and results in a change of plasma properties. Even 0.5% of metal vapour determine electron quantity in temperature up to 7000 K. The number of electrons affects the electric parameters and thermodynamic state. Electric arc burns in argon as a working gas where the considered compounds are melted, following gasification and ionization. There are dosed into the arc channel series of properties changing heat transport conditions due to their thermal conductivity. It was proved that as the metal contents in the mixture rises the plasma electrical conductivity also increases. The electric arc in mineral environment shows lower resistance of the arc channel when compared to the arc in air or common technological gases as argon or nitrogen. It positively influences stabilization of the arc. To sum up, this feature enables discharge continuity under unstable plasma component concentration e.g. waste vitrification.

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WPŁYW GAZOWYCH SKŁADNIKÓW MINERALNYCH NA WŁAŚCIWOŚCI WYŁADOWANIA ŁUKOWEGO PRĄDU STAŁEGO

Streszczenie

Zastosowania plazmy łuku elektrycznego można podzielić na: zastosowania w elektrotechnice oraz zastosowania w procesach termicznych (lub termochemicznych). W większości przypadków w skład plazmy – poza gazem, w którym pali się łuk występuje metal wprowadzony celowo lub występujący jako składnik niepożądany. Celem niniejszej pracy jest określenie wpływu wybranych metali na skład plazmy. W pierwszej części krótko scharakteryzowano plazmę metaliczną. Następnie zaprezentowano metodykę obliczania składu plazmy. Na koniec przedstawiono zastosowany układ badawczy oraz wyniki obliczeń.

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Recenzenci pracy doktorskiej:
1. prof. dr hab. inż. Henryka D. Stryczewska
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