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PROSPECTS FOR THE APPLICATION OF THE PLASMA TECHNIQUE IN THE POLISH ENERGY SECTOR

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Abstract: This paper presents a short review of the plasma technologies used in the commercial power industry. The most common thermal plasma sources for the pulverized coal burners and reactors used in solid fuel conversion processes are described. The authors' own experience in the use of the plasma technique in energy applications is briefly presented. Proposals for the use of thermal plasma in the process of fuel conversion in pulverized-fuel power boilers, especially when operating at a lower technical minimum, are formulated.

Key words: thermal plasma, plasma reactor/burner, plasma start-up, technical minimum.

1. INTRODUCTION

Research on the application of plasma in technology began in the 19th century, but it significantly intensified towards the end of the last century. Recently there has been quite a lot of information about the use of plasma technologies in the production of energy from waste, biomass and coal [1-6].

Experimental and theoretical studies have shown that the use of plasma in energy production is a promising alternative to the conventional system as regards efficiency and environmental and economic considerations [4, 7-10]. Since plasma technology is used in the energy sector to produce energy from waste, biomass and even coal one can conclude that it is promoted in developed countries, e.g. European countries and the USA, and preferred in eastern countries, such as China, Kazakhstan and Russia (for coal gasification and coal combustion assistance in electric power plants [1, 2, 3, 5, 6].

It seems that the qualities of plasma technology argue for its increasingly common use in the commercial power industry. Plasma, being a more or less ionized gas, by many researchers is considered to be the fourth state of matter, despite the fact that macroscopically, regardless of its type, plasma is electrically neutral. In plasma technologies, plasma can be divided into three main types: high-temperature (equilibrium) plasma, occurring in, e.g., thermonuclear reactions, low-temperature (quasi-equilibrium, thermal) plasma, occurring, e.g. during a disruptive electrical discharge (electric arc), and nonthermal (non-equilibrium, cold) plasma characteristic of a partial electrical discharge (a corona, a discharge in a rarefied gas, a dielectric barrier discharge (DBD)) [11, 12]. Low-temperature plasma is used in most energy applications while nonthermal plasma is used in some atmosphere protection and chemical technologies [1-6. 13].

Thermal plasma is a strongly ionized high-temperature medium in which fast thermal decomposition of organic matter occurs. After the degassing products are cooled down, gaseous components (e.g. CO, CO2, CH4, C2H6, N2), liquid (condensing) components (e.g. water, alcohols, acids, aldehydes, tar) and solid components (carbon residue) are liberated. Plasma makes the mixture being converted more reactive as a result of the thermal dissociation of many gaseous products, yielding radicals (C, S, CN, OH, NH, CH, CH3...). Moreover, the decomposition products are ionized, whereby positive ions (C+, H+, N+, CO+, O+, Si+, K+ and other) and negative ions (O-, H-, N- and other) are produced, which facilitates the gassing/pyrolysis process [13, 14].

Intensive research on the use of thermal plasma in the combustion and gasification of municipal wastes (biomass and plastics), including hospital wastes, industrial wastes, especially hazardous organic chemical compounds (phenols, chlorinated biphenyls and dioxins – PCBs, PCDDs) has been conducted in recent years [14-19]. The aim of the current research in this field is to improve the effectiveness and quality of the thermal processing of wastes and consequently, to reduce the emission of dangerous gases, including greenhouse gases. The results of pilot studies indicate that the application of the plasma technique to the acquisition of liquid fuels from biomass and municipal wastes can be effective and safe for the environment [4, 16-19]. Also the rational and economical energy management aspects, stemming from the increase in the amount of generated wastes and from the increased energy demand, argue for the use of the plasma technique. Particularly worthwhile seems to be the use of the plasma techniques of gassing and pyrolysis instead of conventional combustion in the utilization of hazardous wastes. The synthesis gas generated in the process is a potential energy source, which considerably reduces the utilization costs. The high hydrogen content in the syngas is a further argument for the plasma gasification of refuse-derived fuels [4, 18].

2. SOURCES OF PLASMA FOR ENERGY APPLICATIONS

As mentioned above, thermal plasma is particularly widely used in technology. The so-called plasma jets based on the arc discharge are commonly used as the source of plasma in conventional plasma reactors/burners. The electric arc arising between electrodes is generated in a direct (DC) or alternating (AC) electric field whose frequency is usually that of the mains (rarer elevated to a few kilohertz) [12, 13, 20, 24]. Figure 1 shows an arc plasmatron of PW type (a property of the Faculty of Mechanical and Power Engineering at Wrocław University of Science and Technology) with a special cylindrical design of its electrodes.

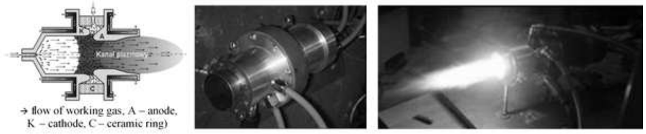

Fig. 1 .Model and actual cavity plasmatron of PW type on test stand (operating power 12-28 KW) [4]

The power of the arc plasmatrons described in [4, 9, 30-34] is in a range of 10-100 kW. Plasmatrons with a higher power of 100-500 kW are commercially available and their special versions can have power as high as 1 MW (trade offers of PlasmaAir AG and PyroGenesis Canada Inc.).

Considering the development of power engineering, highly promising sources of thermal plasma for industrial uses are radio frequency (RF) plasma generators and microwave plasma generators [4, 25-28]. The advantage of high-frequency plasma generators is the absence of discharge electrodes. The generated plasma has the character of a volumetric discharge, whereby the pulverized material can be thermally treated in the whole volume of the reaction zone.

Hybrid reactors, combining the advantages of microwave plasma and induction plasma, deserve special attention. Such a reactor generates stable volumetric high-temperature plasma owing to the cascade connection between the microwave part and the induction part. The idea of producing thermal gas plasma under atmospheric pressure is based on the generation of local microcharges (high-temperature charges) within the volume of the gas by means of a concentrated microwave beam (with a frequency of, e.g., 2.45 GHz). Then from the microwave part the plasma channel (ionized gas) is directed into the zone of action of a high-frequency (≥ 100 kHz) field where it is stabilized and maintained thanks to electromagnetic induction (the induction part of the reactor). In the induction part the stabilized plasma assumes the character of an electrodeless ring discharge.

Figure 2 shows the principle of operation of the electrodeless high-frequency plasma reactor (consisting of a microwave part and an induction part) [4].

Figure 3 shows an electrodeless high-frequency plasma reactor (with indicated main components) with a plasma channel power of about 8 kW, generating volumetric thermal plasma (under atmospheric pressure) in its microwave part, which is then stabilized in the inductor action zone, installed in the Department of Boilers, Combustion and Energy Processes at the WUS&T Faculty of Mechanical and Power Engineering.

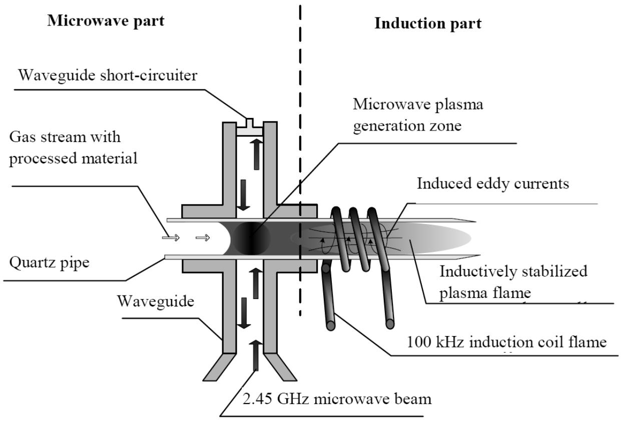

Fig. 2. Idea of electrodeless high-frequency plasma reactor

An electrodeless high-frequency plasma reactor of this design generates volumetric thermal plasma under atmospheric pressure. The material to be converted introduced into the reaction space partly constitutes a plasma-generating agent. Consequently, the fuel conversion proceeds dynamically.

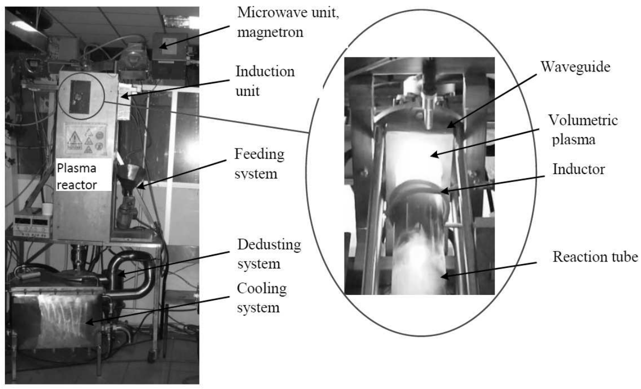

Fig. 3. Electrodeless plasma reactor and burning high-frequency plasma [4]

In the authors' opinion, the microwave plasma technology can prove very attractive in the future, considering that microwave radiation sources with a power of up to 100 kW are already commercially available and the results of tests show this technology to be suitable for the combustion of coal dust-air mixtures and the thermal utilization of wastes [1-5, 24-27].

3. PROPOSED APPLICATIONS OF THERMAL PLASMA IN DOMESTIC ENERGY SECTORE

Coal is still considered to be one of the main energy resources in Poland in the 21st century [29]. However, because of the EU's current environmental policy the domestic energy sector must reduce the use of coal in the total energy production. Also the coal quality and energy efficiency indices and the requirements for reducing hazardous pollutants emission into the environment are constantly raised [29].

In some countries in order to improve coal combustion efficiency, plasma technology has begun to be used in thermal power stations. The plasma-assisted coal dust combustion technology has been successfully tested on 27 pulverized-fuel boilers in 16 combined heat and power plants located in Turkey, Russia, Kazakhstan, South Korea, the Ukraine, Slovakia, Mongolia and China. The data contained in the literature show the merits of the plasma system, such as: quick light-up, easy and safe flame stabilization, high efficiency and reduced emission [1, 2, 3, 25, 27, 28]. The plasma gasification of coal, as efficient and environmentally friendly, is also mentioned as one of the most important and effective ways of converting coal into high-energy gases (syngases) and useful chemicals [1, 7, 12]. Many authors propose to use the plasma technique to process the stream of carbon-rich wastes as an alternative to the conventional coal technologies [5, 6, 8, 10, 14, 18].

A study of the literature on the subject indicates that considering the trend towards the minimization of the negative effect on the environment, the plasma technique should be regarded as one of the major techniques which should be applied to assist the conventional coal combustion and gasification technologies used to produce electricity for the domestic power supply system. As mentioned above, technologies based on thermal plasma ensure a high-temperature atmosphere with a large number of active radicals, which improves coal combustion efficiency while reducing or totally eliminating the demand for additional fuels (heating oils and/or gases) [1, 2, 3].

3.1. Use of thermal plasma for boiler start-up

The Polish power industry is mainly based on steam power units with steam boilers. In order to start-up such a boiler from its cold state a start-up procedure aimed at warming up the combustion chamber and ensuring stable operating conditions for the upper burners needs to be carried out. Typically, the start-up is conducted with the use of auxiliary mazout burners. This way of starting up the boiler is arduous to the environment due to the high emission of heavy hydrocarbons and soot into the atmosphere. The use of mazout is also quite expensive [3, 9]. As the environmental protection standards become more rigorous, it seems very reasonable to look for a method alternative to the mazout start-up. Currently, in some of the power plants the mazout start-up and support installations are being replaced with gas installations.

From the economic, energy and environmental points of view, it would be most advantageous to start-up boilers, using exclusively coal dust. But this is difficult when the boiler is cold since coal dust needs to be fed (e.g. from the boiler bunker), the ignition must be reliable and the operation of the pulverized-fuel burner must be stable. Therefore it is necessary to use an additional high-power ignition source sufficient to cover the loss of energy to the environment and to ensure the reliable ignition of the coal dust-air mixture. Plasma generators (plasmatrons) mounted directly on coal dust burners can be used as such an ignition source. Analyses indicate that this solution can bring about a reduction in both the investment and operational costs and can reduce the boiler start-up environmental nuisance [1-5].

A literature survey shows that that currently variously advanced (laboratory, pilot and full industrial scale) plasma start-up installations are in operation in the world [1, 2, 3, 9, 12, 25, 27, 28].

Also in Poland research (in which one of the co-authors took part) on the application of the plasma technique in the direct start-up of coal-dust power boilers has been carried out [9, 30-33]. It was conducted on the laboratory scale and the pilot scale on coal-dust boiler OP 130 in the Czechnica heat and power plant [9, 30-33]. Figure 4 shows the results of the operation of the plasma coal dust burner during experiments conducted on the OP 130 boiler.

Fig. 4. Plasma pulverized-fuel burner during combustion of coal dust-air mixture [34]

The focus of the experiments was on the design and implementation of a boiler plasma start-up installation based on the air-fed cavity plasmatron. The operation of the plasma coal dust burner consisted in introducing a thermal plasma stream into the conduit in which a coal dust-air mixture flowed. Under the physicochemical action of the plasma on the coal dust the volatiles would be rapidly liberated, the particles would disintegrate and ignition would follow. As a result, a stable dusty flame was obtained. An important task was to ensure coal dust supply. The existing coal dust lighting-up burner (after a slight modification) was used as the plasma pulverized-fuel burner.

The aim of the experiments was to verify the functioning of the plasma ignition installation and its components in real conditions, to check the coal dust ignition capability and to determine the characteristics of the plasma burner. Also the problem of electromagnetic compatibility was highly important for the correct and failure-free operation of the power unit's automatic control and protection system [32, 33]. The test results showed that the plasmatron functioned correctly and properly interacted with the muffle coal dust burner. All the components of the plasma start-up installation functioned correctly and consistently with the assumptions.

It should be noted that the trials were conducted on the working (hot) boiler. In order to more precisely examine the phenomena involved, to determine the stability of the boiler and to compare the start-up characteristics, trials must be carried out on the cold boiler. Only then it will be possible to verify whether the number of plasmatrons and their locations (depending mainly on the thermal output and type of the coal-dust boiler and the power of the plasmatrons) are proper.

3.2. Conception of the use of thermal plasma for boiler operation stabilization at lowered technical minimum

Power unit flexibility and operation at a lowered technical minimum is currently one of the key issues for operational power services. In the "Power Units 200+ Programme" announced by the National Centre for Research Development, the flexible operation and operation at a lowered minimum of power units are important targets to be achieved (https://www.ncbr.gov.pl/fileadmin/user_upload/akutalnosci/pl/5732/234_17_pu_regulamin_prowadzenia_postepowania.pdf).

Considering the technical constraints and the changing regulations concerning start-up times, power generating capacity increases and pollution emission, it seems that thanks to the use of thermal plasma these (often conflicting) requirements for power units of class 200 can be satisfied.

3.3. Cold start-up

A survey of the literature on the subject and an analysis of the results of the research presented in [9, 30-34 and in P. Kobel's PhD thesis] indicate that starting the boiler from cold through the use of thermal plasma and the primary fuel (coal dust) is possible. Therefore it can be concluded that it is also possible to stabilize boiler operation at a lowered technical minimum. In order to achieve this it is proposed first to install plasmatrons (thermal plasma sources) directly in the principal powdered fuel burners (after the latter have been slightly modified). Preliminary analyses show that in this case the plasmatron's power should amount to about 10% of the powdered fuel burner. This is advantageous considering that the electric power of plasmatrons can be relatively low (up to about 100 kW) and one can use arc plasmatrons of one's own design [4, 30-34].

3.4. Making up for unit's power shortage

An important issue raised in the "Power Units 200+ Programme" is the rate at which the power unit gains power while satisfying the combustion quality and emission requirements specified in directive IPPC and standard BAT. It seems that a good solution here is to use a plasma installation equipped with high-power (500-3000 kW) plasmatrons (trade negotiations in this regard were conducted with PlasmaAir AG and PyroGenesis Canada Inc).

3.5. Improving temperature distribution in boiler, especially in second boiler pass

When implementing operation plans for power units of class 200 at a lowered technical minimum (operation at ≤ 40% of the rated power), the temperature distribution in the boiler will be disturbed, especially in the second boiler pass. One of the ways of evening out the distribution of temperature in the boiler can be to use plasma burners to regulate the temperature of the primary and secondary steam (when underheated) by installing them in the primary and secondary steam superheating passes.

3.6. Using plasma burners to reduce emission of harmful gases

By properly locating plasma burners and using them in boiler operation one can effectively reduce the emission of such gases as: NOx, SOx, CO and CH4, and higher hydrocarbons, including dioxins. The synergic effect of the high temperature gradient, UV radiation emission and the production of active radicals (C, S, CN, OH, NH, CH, CH3...), positive ions (C+, H+, N+, CO+, O+, Si+, K+ and other) and negative ions (O-, H-, N- and other), produced by thermal plasma contributes to a reduction in the emission of harmful gases. Moreover, catalytic substances, which in plasma conditions enhance the decomposition of harmful gas compounds, can be added to the plasma generating gases. Also steam can be a plasma generating gas, which can have an advantageous effect on the thermal conversion of the fuel, whereby ultimately total and complete fuel combustion at possibly the lowest emissions will be achieved.

3.7. Using plasma burners to consume energy surpluses produced by renewable energy sources

As a result of the introduction of renewable energy sources (RES), especially wind turbines, into the EU's and Poland's electric power systems, instantaneous (fast-changing and with a local reach) energy surpluses occur in certain (sometimes difficult to predict) periods. Managing such energy often poses difficulties. In the authors' opinion, the alternative here can be its consumption directly in plasma burners to ensure the flexible operation of power units, especially at a lowered technical minimum. This approach can also contribute to an improvement in the stability of the domestic electric power system. Moreover, this approach can be used in cross-border energy exchange clearing and settlement.

4. CONCLUSION

Summing up, the analysis of the research carried out by us and by other researchers [1-3, 27, 28, 30-34) has shown that the plasma technique used to start-up coal-dust boilers and stabilize their operation is relatively new and so there are no operational data on such solutions. There are many doubts and unknowns concerning, for instance, the operational reliability of plasma start-up/stabilizing burners and their lifetime. Nevertheless, the positive results of the experiments and the survey of the literature on the subject suggest that plasma technologies based on thermal plasma can be particularly useful in ensuring the flexible operation of power units, especially at a lowered technical minimum.

This analysis shows that in Poland there is a lack of wider experience relating to the use of thermal plasma in power plant operation conditions. However, the results of the preliminary studies are promising. The steps taken by the authors to implement the plasma technique in the domestic energy sector should result in its commercial implementation. It seems that if the R&D work receives proper support and appropriate regulations are introduced, the implementation of plasma technologies can turn out to be an undertaking profitable for the energy sector. It should be noted that this research team has the necessary resources to conduct trials on laboratory combustion process testing installations equipped with arc plasmatrons and microwave volumetric thermal plasma reactors. It can also carry out specialist tests and analyses of the zone downstream of the burners, including the chemical composition of the substrates and the products. Thus thanks to the available plasma installations and the advanced control and measurement apparatus one can carry out all kinds of simulations and analyses of the quality of plasma combustion/combustion assistance and to determine the energy balance of the process.

Considering the above, several R&D tasks, including simulations of the thermal/flow processes taking place in the boiler during thermal plasma generation (first, laboratory tests on designed and built stands and then, on-site trials), should be carried out in order to unequivocally determine the usefulness of plasma technologies for the domestic energy sector. Helpful in this regard will be the research programmes launched by the National Centre for Research Development and the willingness of the energy sector to make energy facilities available for conducting relevant on-site trials. Once the trials are carried out, a technical-economic analysis can be carried out to unequivocally determine the profitability of the use of the above technologies, including the replacement of the currently used mazout burners with plasma burners for boiler start-up, combustion process stabilization (especially at a technical minimum) and fast making up for the power unit's power shortages connected with the current demand.

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PERSPEKTYWY ZASTOSOWANIA TECHNIKI PLAZMOWEJ W KRAJOWYM SEKTORZE ENERGETYCZNYM

W niniejszym artykule przedstawiono, w oparciu o studia literaturowe, krótki przegląd technologii plazmowych stosowanych w energetyce zawodowej. Scharakteryzowano najczęściej stosowane źródła plazmy termicznej wykorzystywane w palnikach pyłowych i reaktorach stosowanych w procesach przetwarzania paliwa stałego. Krótko zaprezentowano doświadczenia własne z wykorzystania techniki plazmowej w zastosowaniach energetycznych. Przedstawiono propozycje wykorzystania plazmy termicznej w cyklu technologicznym przetwarzania paliwa w pyłowych kotłach energetycznych ze szczególnym uwzględnieniem ich pracy przy obniżonym minimum technicznym.

Z przeprowadzonej analizy wynika, że w kraju brak jest szerszych doświadczeń z wykorzystania plazmy termicznej w warunkach ruchu obiektu. Na podstawie analizy wstępnie wykonanych badań, można uznać takie zastosowanie plazmy za korzystne przede wszystkim ze względu na stabilność płomienia oraz regulacyjność palnika. Realizacja podjętych przez autorów działań na rzecz wdrożenia techniki plazmowej do krajowego sektora energetycznego powinny zaowocować jej komercyjnym wdrożeniem. Przy odpowiednim wsparciu prac badawczych i rozwojowych, w szerokim zakresie w tym legislacyjnym, wdrożenie technologii plazmowych może stać się inwestycjami rentownymi dla sektora energetycznego.

Keywords: plazma termiczna, reaktor/palnik plazmowy, rozruch plazmowy, minimum techniczne.