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Short Communication

A Comparative Study on Plasma Gasification of Lignite Coal

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Abstract

In addition to the great advantages brought by the industrial revolution, the inevitably emerging global pollution is an important criterion in determining the methods used in energy production, especially the selection of raw materials used for energy production. It has become a necessity to use environmentally friendly technologies instead of traditional methods in order to prevent the environmentally harmful emissions of flue gases that are expelled by burning coal in thermal power plants. The flue gas that is discharged from thermal power plants can be converted into syngas, and it is possible to discharge it as both additional energy and a cleaner gas only thanks to plasma technologies and this constitutes the main theme of this study.

The carbon dioxide content in the syngas is significantly lower and the combustible component is higher than conventional gasification processes, which has a beneficial effect on the environment and are important to meet the requirements of the Kyoto Protocol, when coal is gasified using plasma technologies.

Keywords: Arc plasma; Microwave plasma; Syngas; Flue gas

Introduction

Today, coal is mainly used as fuel in boilers and thermal power plants to generate heat and electricity, but these combustion technologies are associated with problems such as incomplete combustion of coal, nitrogen oxide, carbon and ash emissions. There is also a danger of soil contamination where slags are exposed. The firing of the pulverized coal boiler and the stabilization of the burning of the torch inside are made with fuel oil. 1-2 thousand tons of fuel oil is consumed annually for a boiler with an average steam capacity, depending on the number of start-ups [1]. Fuel consumption is 3-5 times higher due to the constantly decreasing quality of the coal supplied to thermal power plants. In addition, the completeness of coal combustion is decreased, and harmful emissions (nitrogen oxides, sulfur and carcinogenic vanadium pentoxide) are increased.

Syngas, which can be used for the combustion of solid fuel in plasma technology boilers, the accompanying gasification of coal and sorbent production, and also to obtain Synthetic Liquid Fuel (SLF) during coal gasification, is obtained in the energy sector [2,3].

According to our current knowledge, there are four states of matter in the universe. These are solid, liquid, gas and plasma phases. Plasma can be defined as a collection of charged and uncharged particles that are constantly interacting. Plasmas can be divided into two categories as cold and hot plasmas.

Plasma is formed when a substance in the gas phase is heated, exposed to a strong electromagnetic field applied by a DC, RF, laser or microwave generator. Depending on the strength of the applied electrical field, positive or negatively charged particles called free electrons and ions are formed, and if the gas used is a compound, the dissociation of molecular bonds is also observed [4]. Plasma in general remains neutral, while the presence of these charged particles make the plasma electrically conductive. Plasma does not have a certain shape or volume unless it is placed in a container [5].

Plasma is the most common form of ordinary matter in the universe. Nebulae which are the cradle of new star formations in most low-density regions in space, all stars, including the Sun are also plasma. In the world, lightning and Aurora are examples of naturally occurring plasma. In addition to naturally formed plasma, there are also man-made plasmas, and these plasmas are used in all areas of our lives.

Industrial use of plasma is increasing rapidly and its usage areas are expanding. Today, plasma-based technologies are widely used in agriculture, energy, health, aviation and many other fields. The high temperature process of plasma gasification of coal by syngas generation is a complex heterogeneous physicochemical process in which a series of chemical interactions of carbon and its compounds with gasifying reagents (oxygen, water vapor, etc.) take place.

Plasma gasification is characterized by the formation of radicals and ions during the decomposition of the gas forming the plasma, which leads to a high rate of physical and chemical processes at high energy concentration per unit volume [6]. Chemical transformations in two-phase systems of a plasma-forming gas with solid fuel particles are extremely complex and involve several types of reactions: destruction of solid fuel with the release of volatile products, gas phase reactions of released products, gas-solid reactions [7].

The coal particles and air are heated simultaneously when the flow of the "cold" air mixture (Ta=350-400 K) comes into contact with the plasma flow. In this case at a heating rate of 104-105 degrees/second, coal particles up to 250 microns particle size is crushed. They are subjected to thermal shock due to thermal stresses arising in their volume, as a result, coal particles are crushed into 5-30μm pieces in a period of 0.01-0.05 seconds [8].

This phenomenon leads to a sharp increase in the interfacial area between the gas and solid phases and, consequently, to a corresponding increase in the re-activity of the fuel. Volatile coal substances (CO, CO_2, CH_4, C_6H_6, N_2 and H_2O) and nitrogen-containing components - pyridine (C_5H_5N) and pyrrole (C_4H_5N) are released. Subsequently, in the gas phase, atomic forms (O, H, N, C and S) are formed from the mineral part of coal (Si, Al, Ca) and radicals (NH, CH, CN, OH, etc.). Gas phase contains positive (C^+, H^+, N^+, CO^{++}, Si^+, K^+, etc.) and negative (O^-, H^-, N_2^-) ions [9].

Thermal explosion of coal dust particles repeatedly accelerates the release of volatile substances due to a more developed reaction surface and the emergence of very small particles that are heated to the evaporation temperature much faster than large (100-250μm) particles. Heterogeneous thermochemical transformations of the fuel (release of volatile substances, gasification of coke residue) begin with the participation of electrically neutral, but chemically active components (radicals and decomposition products of molecules) with an increase in the temperature of gas and particles.

The transition of volatile coal (CO, H_2, C_6H_6, CH_4, CO_2, H_2O, etc.) to the gas phase begins their chemical interaction with air. The condensing effect of the thermoelectric component of the low-temperature plasma is in the gas phase reactions, manifested in the acceleration of chemical transformations due to the transition to reactions with chemically active centers and lower values of activation energy. The aforementioned characteristics of the interaction of plasma with pulverized coal fuel increase the energy efficiency of plasma gasification of fuel 3-4 times compared to conventional processes.

Plasma gasification process is environmentally friendly. Gaseous products do not contain resins, phenols and hydrocarbons that contaminate conventional coal gasification products, due to the high temperatures in the reactor zone. Gaseous products contain more than 95% CO and H_2 and the volumetric hydrogen content is higher than the carbon monoxide content, when solid fuels are processed in a water vapor plasma. Small amount of carbon dioxide (3%), trace amounts of methane, hydrogen sulfur are also present. The CO_2 content in products of plasma-chemical gasification of coal is significantly lower than in conventional gasification processes products.

It should be noted that the economic efficiency of plasma gasification can be significantly increased if not only the gaseous products of coal processing, but also solid residues are used rationally. For example, it has the possibility to be used as a filler for industrial rubber products, as an adsorbent to purify drinking water, or mainly to obtain valuable materials such as ferrosilicon, carbosilicon, technical silicon [10]. In this study, the gasification studies of lignite coal, in order to make maximum use of lignite coal, within Anadolu Plasma Technology Center AŞ.by plasma method are explained. The arc and microwave plasma systems are compared and more useful application areas of these methods are explained in terms of the experimental findings.

Experimental Studies

The experimental setup was designed by using the arc and microwave plasma system (Figure 1) [11]. It was possible to use arc and microwave plasma systems for gasification of coal, due to the specific features of the experimental setup.

1kg domestic (Tunçbilek) coal was gasified in both experimental setups. The purpose of the application of two different plasma systems (Figure 2 & 3) is to compare the efficiency of the systems in the gasification of lignite coal. Water vapor is required for the gasification of lignite coal. The arc method transforms the water filled into the plasma directly into high temperature steam and discharges it out of the nozzle under 0.5 atm pressure, and thus the gasification in the reactor chamber takes place.

On the other hand, the coal in the reactor chamber was gasified by mixing around 5% coal dust from outside to the steam at 200 ºC under 0.5 atm pressure to the microwave plasma system.

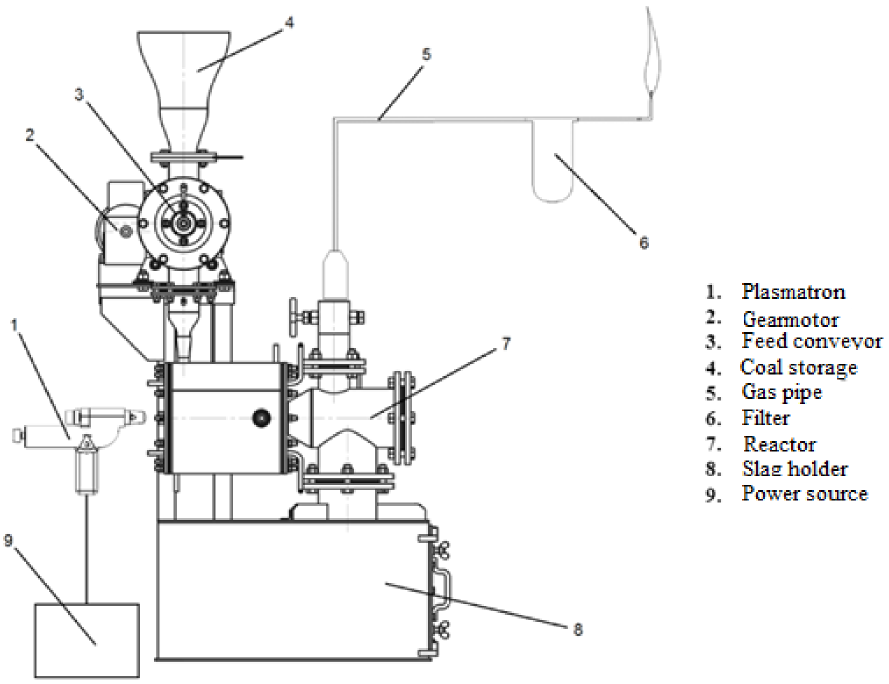

Figure 1: Experimental set-up.

Figure 2: Experiment setup with integrated arc plasma system.

Figure 3: Experiment setup with integrated microwave plasma system.

Results and Discussion

The most important problem in experimental work was the initiation of the gasification process by ionizing the coal. In the arc method, the plasma jet obtained as a result of the ionization of the water vapor gasifies the coal in the reactor. In the microwave system, the plasma jet formed by ionizing the water vapor with 5% coal dust which was given into the reactor, gasified 95% of the coal.

The syngas properties obtained with the application of both plasma systems exhibited differences. 1.62m^3 syngas was obtained by gasification of 1kg lignite coal by arc method. 1.91m^3 syngas was obtained as a result of gasification of 1kg lignite coal by microwave method. Although the coal source, reactor, pressure and temperatures of the experiments were the same, 0.29m^3 more syngas was obtained with microwave plasma. 1 ton of Tunçbilek lignite coal contains approximately 2300kws of energy. Since water vapor is required for the gasification of lignite coal, both plasma systems developed work with water vapor. In the gasification of 1 ton lignite coal, 1354kws of energy was used.

In arc gasification, 65%H_2+14%CO+5%CO_2+7%CH_4 and other gases are released. In microwave gasification, 65%H_2+12%CO+5CO_2+10CH_4) and other gases are present. It was observed that nitrogen oxide and sulfur oxides decreased 45-50% with the use of microwave, but the reduction rate was around 30-35% in the Arc method [12,13].

The advantages and disadvantages of plasma systems that are used in experimental studies can be summarized as follows:

A. Arc based plasma

Today, arc method plasma system which is possible to work with water vapor in industrial dimensions has not been developed. In this case, the ionized water vapor gasifies the coal. Plasma formed with electrode plasma has a thin (narrow) appearance, as a result, gasification in the gasification zone takes place in this narrow region exactly as burning in other regions. Therefore, sometimes undesirable components such as nitrogen oxides can be formed during gasification. In electrode plasma systems, ionization takes place between the electrodes, which causes material wear and electrodes to be changed frequently. At the same time, plasma becomes contaminated with the electrode material.

B. Microwave plasma

Today, industrial plasma systems are characterized by their parameter properties in the reaction zone. Microwave powered plasma system is the most efficient method of heating air flow or water vapor. The temperature efficiency of microwave plasma reaches 88%-95%. In experiments, around 5% of coal dust was mixed with water vapor and fed into the plasma. In this case, 95% of the coal in the reactor was gasified and a 3% increase in CH_4 was observed with a 2% reduction in CO.

The microwave plasma design is relatively simple in design, as the microwave energizer (magnetron) and coaxial resonator are combined without any elements. There is no electrode (anode) in the microwave plasma. This feature distinguishes the microwave plasma from others in principle. The magnetron is used in the plasma as the microwave power provider. The working time of these magnetrons is guaranteed in thousands of hours (~10,000 hours).

The convenience of use allows the microwave plasma to be used where other plasma systems cannot be used. For example, the burning of coal in power plants without natural gas and diesel oil or the replacement of coal with organic fuels.

Since the microwave plasma uses gas at atmospheric pressure, it is suitable for working with low- and high-pressure gases. Its dimensionally compact design has made it possible to use the microwave plasma in every possible area. Microwave plasma systems that are being used in incineration, gasification and other fields in all kinds of power plants, waste treatment and disposal facilities are ecologically clean and sought-after technology since they do not require the use of auxiliary fuel in these processes.

Conclusion

Today, various types of plasma systems are used in different fields (energy, metallurgy, automotive, space, medicine, etc.). Arc and microwave plasma systems are used in burning coal and gasification of different wastes in power plants for energy production. The results of the experiments carried out within the scope of this study showed that the microwave system is efficient in combustion and gasification applications in different areas, while the arc method will be a more accurate approach in metallurgy fields such as cutting materials, welding and coating.

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