Development and research of possible usage of plasma equipment for syngas production

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Abstract. The paper considers a number of issues related to the development and research of the plasma equipment usage for syngas production. Its applicability in power engineering necessitates the description of the perspective plasma equipment designs along with the main characteristics and optional versions of its application.

1. Introduction
Syngas is not only a valuable chemical feedstock; it can be used as an alternative fuel. At the same time, its production may employ organic raw materials: coal, wood, and municipal solid waste. Over the past decades, a wide range of equipment, including turbines have been developed and two power plants operating on coal gas synthesis using Plasma Enhanced Melter (PEM) technology have been built in the world.

The plasma systems used to produce syngas serve to significantly increase the efficiency and economic attractiveness of this technology, since the distinctive feature of plasma pyrolysis compared to the traditional autothermal are:

- temperature range in the reactor from 1000 to 10000 K;
- deep destruction of raw materials with simultaneous reduction of flue gases;
- higher rate of chemical processes in reactor due to high thermal and chemical activity of low-temperature plasma;
- high environmental safety of the process, achieved due to the physical parameters and the usage of special technical measures, such as afterburning and quenching chambers.

2. Brief review of existing problems in the field of renewable energy
Nowadays the rate of waste generation and per capita energy consumption are steadily increasing. The approximate amount of municipal solid waste (MSW) per capita is ~ 0.85 kg/day. Accordingly, the problem of waste disposal is becoming more urgent and requires close attention and immediate action.
Recently, an increasing interest has been observed in the development of environmentally friendly technologies for waste treatment on the basis of plasma torches [1-5]. The advantages of using plasma torches are:

- the organic part of the waste is almost completely decomposed to form mineral substances;
- the inorganic part is completely disinfected, which allows not only neutralizing, but also reducing the waste volume for disposal 50-400 times.

It is well known that ionized plasma particles are reactive and capable of generating reactive particles (radicals) at collision with neutral molecules. Significant intensification of chemical processes can be expected, when the time of the plasma supply to the reaction zone is less than the radical’s life time. A higher mass average temperature in the plasma chemical reactor also leads to an increase in the wall temperature. As a result, the amount of unreacted substance or the amount of by-products is reduced due to the disappearance of colder zones near the walls. The supply of hot rather than cold air to the reactor reduces the cold zones space inside the reactor.

Therefore, the extensive application of plasma torches as an energy supplement in the pyrolysis of raw materials for obtaining fuel for the needs of clean renewable energy can lead to the creation of a highly efficient economic industry aimed to improve the conditions and quality of life of the population.

It should be noted that the plasma system design can be both with an abridgement of a high current arc on the melt in the plasma chemical reactor, and with plasma torches application as a part of the reactor. It is reasonable to transfer the maximum energy to the plasma chemical reactor, when using free-burning arcs in plasma chemical reactors for processing various raw materials. It is possible to obtain temperature in afterburning chambers of 1200-1400°C using plasma heating. It is sufficient for toxic products sterilization of high efficiency (\(\text{Cl}_2\), \(\text{C}_2\text{F}_4\), \(\text{CF}_4\), \(\text{C}_2\text{F}_6\), \(\text{SO}_2\), \(\text{H}_2\text{S}\), etc.).

3. Alternating current plasma torches

A number of three-phase arc plasma torches were created in the IEE RAS [6-8]. They were designed to work as part of a plasma chemical reactor for the destruction of solid wastes and a plasma chemical reactor for the destruction of liquid and gaseous wastes.

3.1. Rod electrode

Figure 1 shows the three-phase arc plasma torch with rod water-cooled electrodes for operation on inert, oxidizing and reducing media with power up to 50 kW [6].

![Figure 1](image_url)

**Figure 1.** High-voltage three-phase arc plasma torch: 1 - case, 2 - bushing insulator, 3 - electrode tip.

The high-voltage three-phase arc plasma torch consists of the following components: case, bushing insulators, replaceable tips - electrodes. The case is made of stainless steel and has water cooling.
The case accommodates three cylindrical channels extending to the nozzle. Each channel has tangential gas injection from a common chamber made in a ring-like form on the external surface of the case. The bushing is made of stainless steel and has water cooling. Replaceable tips-electrodes are made of iron and copper alloy. This plasma torch is designed for operation in oxidative and inert media (air, argon, and carbon dioxide), and gas flow rate ranges from 1 g/s to 30 g/s.

3.2. Rail electrode

Figure 2 presents the high-voltage three-phase arc plasma torch with rail electrodes [8]. The operation of the plasma torch with rail electrodes is based on the principle of electrodynamic movement of arcs in the field of its own current, the so-called railgun effect. Heat load along the electrode length is distributed due to the rapid movement of arc attachment along the electrode under the action of electrodynamic and gas-dynamic forces. It allows using water-cooled electrodes made of a relatively low-melting material with high thermal conductivity.

![Figure 2. High-voltage three-phase arc plasma torch](image)

The plasma torch consists of two modules: injector (back) and main case (front). The case of both modules is made of stainless steel and is water cooled. Each module has two circuits of tangential gas supply. The main case has a flattened cone shape; and high voltage plasma torch injector is installed in its rear part. The injector outlet nozzle is directed to the zone of the minimum gap between main electrodes.

Electrodes have a curved shape and are made of copper rod. Each electrode has two hole fittings that serve to fix the electrode position in the discharge chamber of the plasma torch. The electrode is inserted by these hole fittings into two electrically insulating bushings installed in parallel into the chamber case. Thus, the installed electrode has the degree of freedom only for radial motion limited by an adjustment bolt between the nozzles outside the case. This allows changing the electrode gap at the user's request in the operating mode without re-adjustment and removal of power supply from the plasma torch.

The plasma torch can operate with neutral (nitrogen or inert gases) and oxidizing (air) media; the air flow rate ranges from 15 to 70 g/s; and its power is up to 500 kW.

4. Plasma torch characteristics

4.1. Rod electrode

Figures 3 and 4 show the dependences of the current-voltage characteristics and the effective voltage drop on the gas flow rate of the arc plasma torch with rod electrodes, respectively.
4.2. Rail electrode

Figures 5 and 6 show the dependences of the current-voltage characteristics and the effective voltage drop on the gas flow rate of the arc plasma torch with rail electrodes, respectively.

5. Plasma torch usage in energy units

The laboratory-scale plasma reactor was built on the basis of these plasma torches [9]. It is designed to work as part of a plasma chemical plant for waste processing. The plasma reactor was operated with a down draft, i.e., the raw material and the air plasma stream was fed to the reactor from above, and the produced gas was removed from the bottom of the reactor.

First, the treated material enters the oxidation zone, where it is subjected to cracking and partially burns out. Then, vapor and CO₂ are restored to CO and H₂ in the lower reduction zone, later the produced gas is supplied to the afterburner through the gas duct.

One or two high voltage plasma torches were positioned at the top of the reactor. Experimental parameters were: plasma torch power from 10 kW to 50 kW, mass average gas temperature of 1700 °C, and gas flow rate of 2.3-2.9 g/s. The maximum plant capacity was 50 kg/h.

Table 1 shows the comparison of the main parameters of the plant during waste wood gasification [10].
6. Conclusion

Experiments have shown the promising results of the use of arc plasma torches in energy applications with rather high efficiency. The conversion levels for C gained 76.5% and for H – about 86.3% that confirms the possibility of arc plasma torch use to create high-efficiency plasma chemical systems and technologies in the field of renewable energy.

Acknowledgments
The authors acknowledge the support of Presidium RAS Program No. 7: «New developments in promising areas of energy, mechanics and robotics».

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Table 1. Main parameters of the experimental plant obtained during waste wood gasification.

| Comparison parameter       | Unit of measurement | Experiment 1 | Experiment 2 |
|----------------------------|---------------------|--------------|--------------|
| Conversion level           | %                   | 76.5         | 71.5         |
| H                          | %                   | 84.2         | 86.3         |
| Product gas combustion heat| MJ/m³               | 5.84         | 5.96         |
|                            | MJ/kg               | 6.23         | 6.24         |
| Specific energy consumption| for 1 kg raw material | kWh/kg     | 0.84         | 0.55         |
|                            | for 1 m³ gas        | kWh/m³      | 0.28         | 0.18         |