RF and Arc Plasma for Environmental and Agriculture Applications

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Abstract: Over the past decades RF plasma technology has been used in many areas. Most thermal plasma processes are based on inductively coupled plasma (ICP) and arc plasma. Non-equilibrium plasma is mostly used in the semiconductor industry and for some special applications, such as plasma synthesis of fine powder and bio-material surface treatment. We will focus on the present situation in this field by discussing the commercial and R&D efforts related to RF plasma technology for environmental and agriculture applications.

Keywords: RF plasma, arc plasma, waste, tires, medical, seeds, sterilization.

1. Plasma sterilization of dispersed material

Current methods of decontamination must weigh the level of microbial reduction with the amount of acceptable product degradation. Some current methods affect detriment upon the substrate. For instance, substances with heat-labile active ingredients are prone to degradation when exposed to high heat; the active element in dry and steam is heat treatments. Oxidizing agents, such as, ethylene oxide or sodium hypochlorite can either be reactive toward or be absorbed into the processed material. Cold, low pressure RF plasma (CLPP) was modeled for decontamination of powdered botanicals, such as: hydrilla, stinging nettle leaf, organic wheat grass powder and saw palmetto. Chia seeds were tested as a coarse-material out-group.

2. Seeds Treatment

The primary change which can be made to the surface of the target material is its ability to absorb or reject liquids. We have experimented with using the RF plasma to improve the hydrophilic properties of seeds prior to planting. Plasma treatment of seeds results in: Speeds and increases germination; Speeds the process of separation during sprouting; Increase the speed of water absorption by sprouts; Enhancement of plant respiration; Increased development of axil leaf-buds; Initiates plant cell division mechanisms; Increases both the bio-mass of the plants and number of fruit; Fungicide's effect or ability to kill or inhibit fungi or fungal spores w/out using any chemicals. The effects of plasma on the seeds are carried throughout the life cycle of the plant without changing their genetic make-up. Plasma technology is an environmentally friendly process requiring only electricity and process gases. The plasma system includes; computerized process controls, material handling systems, and controlled environment (temperature & humidity) storage facilities for the treated seeds. The following types of the seeds were studied: corn, wheat, barley, alfalfa, tomato, carrots, and beans. The plasma process improves germination and young seedling vigor, which shows benefit throughout the life of the plant. Not only do forage plants produce 20% more biomass, but fruiting plants, such as tomatoes, increase fruit production up to 50% and barley yield increase about 70%.

3. Plasma systems for medical waste treatment

This work is focused on the studies of RF plasma discharge with respect to use on bio-hazardous medical waste. The system includes: liquid nitrogen crushing unit, plasma reactor, high temperature oxidizer and emission control system. The medical waste is processed in the plasma reactor under nitrogen at atmosphere and reduces to carbon residue. The off gas is directed to the oxidizer and scrubbed before being discharged. The system works as a continuous batch. Processing rate is 1 ton/day. Total power required – 160 kW. Use of arc plasma solves the same problem. Productivity the system based on arc plasma is 1 ton/day and total power required – 100 kW.

4. Plasma system for bio-waste treatment

High temperature plasma ensures an almost complete conversion of waste carbon into carbon monoxide (CO) and neutralization of all the toxic substances. The synthesis gas formed in the gasification process consists mainly of hydrogen (35–45 %) and CO (35–55 %). The calorific value of the resultant gas typically reaches 30–35 % of the calorific value of natural gas and, occasionally, even exceeds the above values. This enables the use of synthesis gas for powering gas turbines and gas generator units as well as for generation of electric power with low-calorific gas steams. A typical composition of carbonaceous wastes is presented below: 47 % — paper and paper board, 21 % - food wastes, 12 % - glass, 3 % - iron and ferric oxides, 5 % - plastics, 5 % - wood, 3 % - rubber and leather, 2 % - textile, 2 % - calcium carbonate. The thermodynamic calculation for the plasma gasification of carbonaceous wastes was carried out using the TERRA program. The calculations covered a temperature range from 300 to 3000 K at pressure of 0.1 MPa. The air and steam gasification of carbonaceous wastes, respectively, for the following compositions of the initial technological mixture was calculated: 1) 10 kg CWs + 4 kg air; 2) 10 kg CWs + 1 kg steam. The thermodynamic calculations have shown that the maximum syngas yield for the plasma gasification process of carbonaceous wastes in an air and steam environment was achieved at a temperature of 1600 K. In air-plasma and steam-plasma gasification of carbonaceous wastes, a high-calorific syngas, respectively, with concentrations 82.4 % (CO = 31.7 %, H2 = 50.7 %) and 94.5 % (CO = 33.6 %, H2 = 60.9 %) can be obtained. The specific heat of the syngas obtained in the air gasification process amounts to 3410 kcal/kg, and that of the syngas obtained in the steam gasification process, to 4640 kcal/kg. At the optimal temperature, 1600 K, the power input into the air and steam gasification process of carbonaceous waste amounts, respectively, to 1.92 and 2.44 kWHr/kg. The obtained characteristics and revealed regularities of the plasma gasification process of carbonaceous wastes in various gasifying agents were used in developing and constructing an experimental plasma facility. According to the results of a thermodynamic analysis and an experimental study of plasma gasification of carbonaceous waste, no detrimental impurities were detected in the gaseous and condensed products of the process. From the organic and mineral mass of carbonaceous waste, respectively, high-calorific syngas and a neutral slag, predominantly consisting of ferric carbide, calcium mono-silicate, silica and iron, were obtained. A comparison between the experiment and the calculations showed a good consistency between the data.

5. Plasma processing of used tires

This system is used to study the process of recycling waste tires. Defined regimes where typical products are distinguished during the tire recycling process, such as: Synthesis Gas, Liquid Fraction and Carbon. In some experiments we observed only Synthesis Gas and Carbon Black (without Liquid Fraction). Particle size of carbon black is within nano-size range. Process parameters vary considerably and are dependent of the process temperature and energy used. The module is equipped with RF ICP torch and RF generator (2 MHz Frequency at power level of 100 kW). Additional to the plasma part, the reactor contents low-frequency (LF) induction heater. LF frequency heating generators are in 20 - 40 kHz frequency range at 15 kW power level. Modular construction of the installation allows different connection combinations of process equipment and the establishment of technological regimes depending on tasks. For example, the process system could use RF plasma torch or LF induction heater only or combined treatment (HF + LF). This principle provides the flexibility of the equipment by transforming internal and external structure of a plant depending on its purpose. Temperature processes can be adjusted from 500 °C to 5000 °C.

CONCLUSION

The following conclusion is related only to the areas, which have been described in this overview. For the last decade a big progress was made by introducing RF and arc plasma to some of bio-medical, water treatment and waste-to-energy applications. Efficiency of plasma processes is one of the critical factors for existing and new plasma systems. A few issues still exist and require future investigation and development, such as ignition of RF plasma discharge at atmospheric pressure, precise control of the plasma parameters and efficiency of RF power supplies. Solid state RF generators, having efficiency of 90% and higher, are successfully used for low pressure and low power plasma torches. High power (>25 kW) solid state RF generators are in the development stage. The combination of RF and DC arc plasma with other heat sources is one of the ways to optimize the treatment systems.