Conversion of industrial liquid construction waste with plasma on hydrogen

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Abstract. This paper presents a modern system for conversion with plasma with hydrogen of industrial liquid waste which has implemented a control system through thermoregulatory with PID control laws. Modeling and simulation of thermochemical plasma process performed using specialized software Matlab & Simulink, Ansys allows the optimum control of the temperatures and chemical reactions of the plasma reactor on hydrogen, allowing the conversion of hazardous industrial liquid waste into electrical and thermal energy and useful raw materials that can be reused in the production process.

1. Introduction
The main objective is to design a plasma eco-innovative technology to optimize syngas by controlling the plasma conversion of liquid waste according to the results obtained from modeling and simulation of thermochemical plasma processing. The management of plasma hydrogen reactor is controlling the temperature of the reactor so that it can evolve as a profile imposed by technology, designed based on the information on the type, chemical composition, viscosity, quantity and density of dangerous industrial liquids.

The general principles of waste management are [1-4]:
- waste prevention targets to reduce emissions,
- reduction of hazardous substances in material streams and increase resource efficiency,
- preparation for reuse involves checking, cleaning or recovery by which products or components of products that have become waste are prepared for reuse,
- energy recovery from waste and other recovery activities.

2. The principal technologies for treating of dangerous industrial liquids.

2.1. Comparative analysis of the technologies used for the treatment of industrial liquid waste
The following figure presents a comparative analysis of the main methods used for the treatment of industrial liquid waste with the highlighting of technical and economic particularities [1-8].
Figure 1. The increase in the efficiency of the technological process

a) Incineration [1, 2]:
- an auxiliary fuel is used to start the process, the combustion temperature is reduced;
- gases with a low calorific value, a different chemical composition and a low degree of purity are produced;
- the process has a negative impact on the environment;
- the amount of inert waste is high;
- the area occupied by the installation is large.

b) Classic pyrolysis [3-5]:
- the process temperature is high;
- gases with a low calorific value, a different chemical composition and a low degree of purity are produced;
- the process has a negative impact on the environment;
- the amount of inert waste is high.

c) Plasma pyrolysis [3-5]:
- the temperature in the reactor is high above 2000°C;
- a small amount of syngas used in cogeneration equipment is produced;
- the amount of inert waste is more than 15%.

d) Air plasma gasification [8-10]:
- the temperature in the reactor is high over 4000°C;
- high-purity, high-calorie syngas is produced and used for cogeneration equipment for energy production;
- the gases emitted into the atmosphere have a minimal impact on the environment;
- the amount of waste is reduced approx. 5 - 10%;
- the installations are large, require expensive consumables, the carbon footprint of the equipment is reduced.

e) Hydrogen plasma gasification [10-14]:
- the temperature in the reactor is very high above 10000°C;
- high-purity, high-calorie syngas is produced and used for cogeneration equipment for energy production;
- by controlling the chemical reactions in the reactor, raw materials can be obtained, the gases emitted into the atmosphere have a minimal impact on the environment;
- the amount of waste is reduced approx. 5%;
the installations are compact, small in size, fully automated, the carbon footprint of the equipment is reduced.

The following figure shows the system for conversion with hydrogen plasma for hazardous recyclable liquid waste, the authors have redesigned plasma torches on hydrogen and system for controlling the variable power sources.

![System for conversion with plasma with hydrogen of industrial hazardous recyclable liquid waste](image)

**Figure 2.** The system for conversion with plasma with hydrogen of industrial hazardous recyclable liquid waste

Designing a system for automatic control of a reactor temperatures involves the following steps:

- mathematical modeling for the prediction of the technological parameters of the plasma – chemical gasification unit;
- mathematical characterization of the behavior of the controlled plasma hydrogen reactor and acting on operating mode, setting goals adjustment determined by the type of reactor process management, external signals and nature awareness of the mathematical model of the reactor, establishing the adjustment of the objectives determined by the management of the process in the reactor and the external disturbing signals;
- establishing the influence of certain technological factors specific to the plasma conversion technology of municipal waste;
- modeling the ordering process of the installation, establishing the agreement parameters for thermoregulators (classical regulation, based on fuzzy neural networks);
- choice of method design involves optimizing parameter values agree, establish criteria for the selection and award regulators and determining optimal control algorithms, identification experimental model driven process, identification is performed online in safe working condition without raw material inside the reactor, as input data becomes available through measurement;
- simulating the control structure of the plasma hydrogen reactor using the Matlab & Simulink package;
- test design and analysis of algorithms, possibility of achieving implementation, the optimal choice of equipment that ensures a precise implementation of the algorithm of management;
- finite element analysis of the evolution in time of the temperature and heat flow of the raw material subjected to heat conducted in the reactor with thermo-regulator controlled PID algorithm;
- experimental identification of the driven process model, the identification is performed online in the normal working conditions of the installation, as the input data become available by measurement;
• implementation on the plasma-chemical gasification unit of the simulated control structures and following the evolution in time of the monitored parameters.

The advanced temperature control of the hydrogen plasma reactor has been achieved with the help of thermoregulators that have implemented algorithms of regulation based on fuzzy neural networks that allow the acquisition of data and real-time decisions in conditions of risk and uncertainty that characterize the conversion with plasma of municipal waste.

2.2. Design of multivariable control system from plasma hydrogen reactor
Simulation of the control process with the Simulink software package (PID and one-step predictive) and optimization of parameters for process management. Automatic control algorithms for temperature control in the plasma-chemical gasification unit, the main problem of the management of the plasma-chemical gasification unit is the temperature control so that it evolves according to the profile imposed by the technologist [15-18].

For the implementation of one-step predictive control, the non-interactive open circuit decoupling structure of figure 3.

Figure 3. Non interactive multivariable adjustment of a reactor with two temperature zones

The control of the plasma-chemical gasification unit must take into account the following aspects:
• the regulated temperature profile of plasma hydrogen reactor are machines with very long delay times, errors due to adjustment must be 0;
• the quality of the thermal process is given by the accuracy of the control system.

Thermal processes can be accurately modeled with transfer functions for first-order elements with dead time. PID algorithms are sometimes successfully implemented in the control of such reactors but
downtime has unfavorable effects in regulation, the best regulation can be achieved using a one-step predictive algorithm [17-19].

Implementing the plasma hydrogen reactor control structures and tracking simulated time evolution of track parameters, validation solution by analyzing the performance of the entire control system implemented allows the reactor if necessary, redesign or adjustment parameters for the operating agreement.

Modeling and simulation of the industrial operation of the hydrogen plasma reactor controlled by thermoregulators with PID algorithm one step ahead was realized with the help of the Matlab & Simulink.

The experimental tests were performed on the plasma-chemical gasification unit shown in figure 3 modified in the sense that the two heating zones are supplied separately with electricity through a system based on thermoregulators controlled with classical, PID and one-step predictive algorithms.

The sampling of the data from the reactor (temperature measured by optical pyrometers located in the jacket) is performed with a data acquisition plate mounted in the computer that controls the plasma-chemical gasification unit, this information is processed by the mathematical model to determine the agreement parameters of thermoregulators, which adjusts the plasma supply voltage separately for each area of the reactor.

The sampling period used by the control system algorithms is 5 sec equal to the thermal inertia of the optical pyrometers used to measure the temperature in the installation. The actual results from the installation obtained from the plasma control were plotted with a sampling period of 10 sec.

Real-time implementation of the temperature regulation structure with one-step predictive algorithm.

To improve the performance of the dead time control system used to control the heat treatment reactor, we used in the following experiment thermoregulators controlled with one-step predictive type control algorithm.

2. 3. Design of main components of the plasma reactor

Plasma torches on hydrogen have been redesigned so that fluid flow is swirling to uniformly blend spray liquids and compressed air resulting a homogeneous flame with high temperature and very high dispersion, figure 4 is a part of the modeling and simulation performed in Ansys software (figure 4, 5, 6) that have been validated experimentally on the existing plant in the research laboratory.

![3D drawing of plasma on hydrogen](image1)

![Fluid flow simulation](image2)

**Figure 4.** Plasma torches on hydrogen, nozzle diameter 2,5 mm

The temperature generated by the plasma on hydrogen varies over 4000 - 5000 °C for this reason the cooling is very important, the agents used for cooling the plasma are air or water, the main component of the cooling equipment is the air or water turbine [20, 21].
3. Conclusions

The main objective is the design of an eco-innovative plasma-based technology for the recovery of waste as a renewable energy source, improvement of the technical and economic performance of the plasma installation for the waste processing by upgrading some components of the plant (plasmas, adaptive thermal conduction processes from the plasma reactor enclosure, plasma gas purification system) and optimization of the syngas production technology by controlling the plasma conversion of waste depending on the results obtained from the modeling and simulation of thermo-chemical processes of plasma waste processing with the help of specialized software.

This paper presents a modern system for conversion with plasma with hydrogen of industrial liquid waste which has implemented a control system through thermoregulatory with PID control laws. Modeling and simulation of thermochemical plasma process performed using specialized software Solidworks, Matlab & Simulink, Ansys allows the optimum control of the temperatures and chemical reactions of the plasma reactor on hydrogen, allowing the conversion of hazardous industrial liquid waste into electrical and thermal energy and useful raw materials that can be reused in the production process.
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