Design of heat recovery system for radioactive waste treatment and vitrification system with plasma torches

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Abstract

Energy and environment are currently one of the most important world's preoccupation. Plasma gasification, has been demonstrated as one of the most effective and environmentally friendly methods for waste treatment and energy utilization. The purpose of this project is to design, simulate and analyze a plasma gasification system for low and intermediate level radioactive waste and its integration into a system of electricity production from the point of view of energy savings. This device consists of a downdraft gasifier coupled with three plasma torches. The characteristics of each plasma torch are: (Torch power: 30kw, Plasma current: 300-500A, Plasma voltage: 60-100v) .The goal is to formulate a simple mathematical model able to make a prediction of the performance of the plasma incineration system. In this research, the effect of fuel moisture content on the electric generation system efficiency, the overall exergetic and the efficiency of the overall system has been studied.

Keywords: Plasma gasification system, **Radioactive waste, Plasma torch, EES Software**

Introduction

Large amounts of radioactive waste, with varying characteristics, are generated from the operation and maintenance of nuclear power plants, the nuclear fuel cycle, research laboratories, pharmaceutical and medical facilities. It is in the interest of the waste producers and future generations that a high volume reduction factor (VRF) of the waste is achieved in order to minimise the volume and overall costs of storage and waste disposal.
The waste to be treated has a certain specific activity for alpha, beta and gamma emitters. A maximum contact dose rate of 2 mSv/h, which can be correlated to a certain permissible radioactivity content in the waste, is often applied as an acceptance criterion for thermal treatment of low-level waste. Incineration is a mature and well-proven technology and the most commonly used thermal treatment process for radioactive waste coming from the nuclear industry.[1] The first plasma system, the ZWILAG facility in Switzerland, was taken into nuclear operation at the beginning of 2004. The maximum capacity of the facility is 200 kg/h burnable waste and 300 kg/h fusible waste. [2] Another plasma facility has been ordered for the Kozloduy Nuclear Power Plant site in Bulgaria. Advantage of plasma treatment is The process fulfils without doubt ALARA principles. There is no need for pretreatment of the waste and entire waste drums are fed unopened, virtually eliminating direct radiation exposure and contamination risks to personnel.[1]

Description of the Process

Plasma gasification refers to a range of techniques that use plasma torches or plasma arcs to generate extreme temperatures that are particularly effective for highly efficient gasification. A plasma torch is a tubular device which possesses two electrodes that can produce that arc. When electricity is fed, an arc is created and the electricity is converted into heat through resistance of the plasma. This torch can reach very high temperatures and has the advantage of being an independent heat source not affected by the characteristics of the feedstock. Gasification is a thermochemical process that generates a gaseous, fuel rich product. It is a two stage process. First, pyrolysis occurs and releases the volatile components of the fuel at temperature below 600°C. Not all the waste is vaporized in this stage, the remaining components are mainly ash and fixed carbon. In the second stage of the process, the remaining carbon is combusted with air or pure oxygen. Converting waste to a gas to generate electricity directly in gas engines, gas turbines or fuel cells dramatically improves energy conversion efficiency and maximises electrical output. The gas is also capable of being converted to liquid fuels, hydrogen or to substitute natural gas for distribution to homes and businesses in existing gas grids. The concept of thermodynamic equilibrium model is based on the second law of thermodynamics as applied to chemical reacting systems.In the model, it is assumed that fuel is dry and ash free, and contains C, H, O and N; the element of sulfur was not considered to simplify the global reaction. The chemical formula of the fuel is represented as ($CH_hO_oN_n$). The model, wihch was also developed by the Equation Engineering Solver

(EES) software. Due to the high temperatures of the gasification vessel, it is acknowledged that a chemical equilibrium model is suitable for the description of the plasma gasification process and the study of the most important parameters[3].The model follows a previously developed integrated gasification combined cycle (IGCC) model by Shelton and Lyons [4]. To evaluate the potential of plasma gasification for electricity production, an Integrated Plasma Gasification Combined Cycle System (IPGCC) power plant model is developed. The IPGCC model is illustrated in Fig.1. The model consists of five different interconnected sections: Plasma gasifier, Cooling compression and Clean-up, Gas turbine, Heat Recovery Steam Generator (HRSG), and Steam cycle.

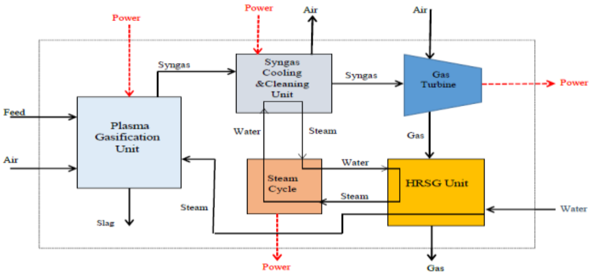

Figure 1. The IPGCC power plant[4].

The Physical structure of the analyzed plant is shown in Fig 2. The syngas produced exit from the plasma gasifier unit . Heat is transferred from the hot syngas to water, through a HRSG, producing steam, which fuel a Rankin cycle. The superheated steam undergoes an expansion in a steam turbine providing electrical energy. Then the syngas goes throw a compressor until before entering in the combustion chamber. In the combustion chamber, the syngas reacts with air, producing exhaust gas. The exhaust gas, expanded up in the gas turbine, producing electricity. The exhaust gas flows through a second HRSG heating the fluid and The cooled gas exit.

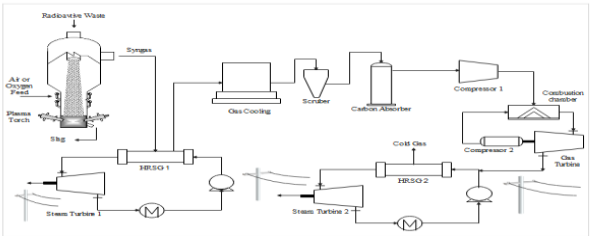

Figure 2. Physical structure of IPGCC plant

Energetic analysis Results

The fuel chosen for this study is low and intermediate level radioactive waste which ultimate analysis is shown in Table1. The plant performance depends on the main characteristic parameters of the cycle: the maximum cycle temperature, the machine efficiencies, the air mass flow and the operating conditions of the gasifier. If the waste moisture content varies from 0% to 70%, the percentage of H_2,CO, N_2,CO_2, and H_2O in the syngas changes according to the table1. The percentage of CH_4 in the gas can be neglected. It is shown that an increase of moisture content contributes to gradually increase the concentration in H_2 in the syngas, where as it can be observed that it leads to a decrease of the CO content.

Table 1. The Ultimate and Proximate analysis

Composition Weight (%)		Wast moisture (0% to 70 %,)		
C	52	H_2	26/57	24/58
H	6/7	CO	32/19	11/98
O	40/3	N_2	39/81	23/72
N	0/9	CO_2	0/7	10/78
H_2O	------	H_2O	0/73	28/94
Ash	0/1			
HHV(MJ/Kg)	24/673			
GasificationTemperature	800 °c			
Gasification Pressure	0/93 bar			
LHV (CH_4)	253969 KJ/Kmol			
LHV (CO)	232781 (KJ/Kmol)			
LHV (H_2)	762523 (KJ/Kmol)			

Conclusions

In this work a stoichiometric chemical equilibrium model was simulated with EES software. The model was integrated in a Combined-Cycle for electricity generation. The syngas high temperature produced by plasma energy can be seen as a great advantage for electricity production. Results show that the moisture content has a serious negative effect on gasification efficiency, due to the high consumption of plasma energy. But an increase of moisture content also allowed an increase in the electric power generation.

Acknowledgments

I wish to express my sincere thanks to the director of the Plasma and Nuclear Fusion Research Institute, Dr. Darestani, and her colleagues at the New Technologies Laboratory, for their unwavering supports.

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