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Basic Design Of An Integrated Plasma Gasification Combined Cycle System For Electricity Generation From RDF

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Abstract

The waste management in Greece is a very important issue by virtue of the increasing of waste material. The study is concerned with the energy design of a plasma gasification plant in Athens for electricity production from RDF(refuse derived fuel) which is provided from the recycling and composting plant Ano Liossion which belongs to the Association of Communities and Municipalities of Attica Region located in central Greece. That region has a population of approximately 5,000,000 inhabitants.

In this study, a basic energy design of a plasma gasification combined cycle has been investigated. Initially the RDF is dried in the installation and after is led in a gasification system. The drying is done using the heat of the exhausts. The gasification results in high value gas production and the combustion of the produced gas takes part in a steam turbine combined cycle ignoring the high cost of investment and the high standards of cleaning gas. Although that process is not a common solution, the results show that it is particularly interesting because it yields significantly net power 24,4 MW.

1. Introduction

A common topic of all developed countries is the excessive amounts of waste material per capita. The amount of waste material generated has increased to a level that is becoming unmanageable. That, together with the increasing awareness of general public for the damage caused to the environment, explains the need to plan for and implement sustainable and integrated strategies for handling and treating wastes. The main strategies for the waste management are the increase of material recovery which can reduce the landfill disposal, the improvement of energy recovery from waste and the minimization of the environmental impact. Recent studies have focused on an innovative technology, the plasma gasification that has been demonstrated as one of the most effective and environmentally friendly methods for solid waste treatment and energy utilization.

Plasma gasification uses an external heat source to gasify the waste, resulting in very little combustion. Almost all of the carbon is converted to fuel gas. Plasma gasification is the closest technology available to pure gasification. Because of the temperature involved, all the tars, char and dioxins are broken down. The exit gas from the reactor is cleaner, and there is no ash at the bottom of the reactor. At the most basic level, a plasma waste converter is a plasma torch applied to garbage. A plasma torch uses gas and powerful electrodes to create plasma, sometimes called the fourth state of matter. Plasma is an ionized gas; in other words, it’s a gas with free-roaming electrons that carries a current and generates a magnetic field.

The plasma is created by applying energy to a gas in order to reorganize the electronic structure of the species (atoms, molecules) and to produce excited species and ions. This energy can be thermal or carried by either an electric current or electromagnetic radiations. Depending on the type of energy supply and the amounts of energy transferred to the plasma, the properties of the plasma change, in terms of electronic density or temperature. Among all the plasmas processes, the thermal plasmas is the most suitable for waste materials treatment, because the organic compounds, under high temperature conditions, are decomposed into their constituent elements and the inorganic materials (glass, metals, heavy metals) are melted and converted into a dense, inert, non-leachable vitrified slag.

The syngas produced by the plasma gasification process contains the plasma gas components, usually oxygen and/or nitrogen if air or nitrogen is used as plasma gases, respectively. The use of other inert gases, such as argon, as plasma gas medium, can allow the improvement of the gasification process performance, even if the costs of the whole system increase.

Plasma gasification is a technologically advanced and environmentally friendly process of disposing of waste and converting them to usable by-products. It is a non-incineration thermal process that uses extremely high temperatures in an oxygen starved environments to decompose completely the input waste material into very simple molecules. The products of the process are a combustible gas, known as synthesis gas, and an inert vitreous material, known as slag. Furthermore, it consistently exhibits much lower environmental levels for both air emissions and slag toxicity than competing technologies, e.g. incineration.

In this work the analysis focuses on plasma gasification of the RDF (refuse derived fuel) and specifically the objective of this work is the basic design of an energy installation.

2. Materials

The physical and chemical features of RDF are directly dependent from the respective features of his components. Moreover, both the qualitative and quantitative features of gas and solids waste of gasification depend on the composition of RDF. Finally, the creation of RDF depends on the heat capacity. The features of RDF waste from mechanical and composting plant of Ano Liossion is :

- Produced quantity RDF: 470 tn / day
- Moisture of RDF: 27,1% (pessimistic case)
- Elemental analysis of RDF: The elemental analysis is shown in table below.

Table 1. Elemental analysis of RDF

Materials	Paper	Plastic	Miscellaneous	RDF composition
RDF %	78,45	11,30	10,25	100
C%	27,44	63,57	24,92	31,26
H%	3,76	8,78	3,14	4,26
O%	25,60	9,02	15,06	22,71
S%	0,16	0,34	0,18	0,37
N%	0,16	0,90	0,73	0,43
Cl%	0,27	3,38	0,41	1,05
W%	36,80	4,20	33,40	32,75
A%*	5,81	9,81	22,16	7,94

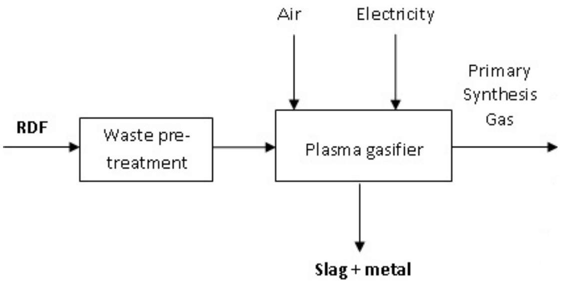
*A%: The percentage of aggregate materials in each component of the RDF.

3. Process description

The first step of plasma gasification is presented in Fig.1. The waste feed sub-system is used for treatment of each type of waste in order to meet the inlet requirements of the plasma furnace. For example, for a waste material with high moisture content, a drier will be required. The plasma furnace is the central component of the system where gasification are taking place. Two graphite electrodes, as a part of two transferred arc torches, extend into the plasma furnace. An electric current is passed through the electrodes, and am electric arc is generated between the tip of the electrodes and the conducting receiver, i.e. the slag in the furnace bottom. The gas introduced between the electrode and the slag that becomes plasma can be oxygen, helium or some other, but the use of air is very common due to its low cost.

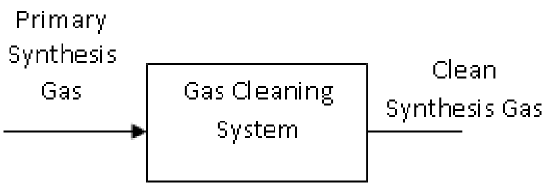
In the installation, the RDF is dried and the moisture content will be lowered by 32.75 wt% to 13 wt%. The RDF, after drying, will be led in gasification unit, which will produce a gas mixture and a small percentage of sludge and metal (oils and tar). In the process of drying the RDF, before cracking, will include a multi-cyclone for the retention of suspended particles RDF, which will be then driven gasification reactor. The fluidized bed will be supplied with lime (CaO) from silo to capture mainly emitted sulfur dioxide (SO2) during gasification, and urea from the tank, to capture the various oxides of nitrogen (NOx).

Figure 1. First steps of plasma gasification process



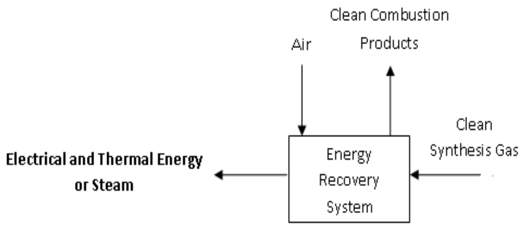
The second step is the gas cleaning system sub-system (Fig.2) has to achieve the elimination of acid (HCl,SOx), suspended particulates, heavy metals and moisture from the synthesis gas prior to entering the energy recovery system. The syngas from the PG reactor must be cooled down and cleaned before it can be used as fuel in a gas turbine combined cycle. Immediately after leaving the unit, the gas will pass through deducting unit consisting of multi-cyclone and remove the bulk of the produced dust and ash. Dry scrubbing is followed by semi-dry cleaning, through semi-dry scrubber , arranged in confluent. The gasification installation of RDF in Athens, will include all the necessary anti-pollution systems, in order to comply with the relevant national legislation and the relevant directives of the European Union.

Figure 2. Second step of plasma gasification process



The energy recovery system can be based on a combined cycle system, gas turbine and steam turbine. The sludge is collected from the bottom of the reactor while the gas is led into a combined cycle gas turbine unit, which will produce superheated steam. The steam turbine will be driven at two levels (high and low pressure). The strength of the power plant, according to the calculations that follow, it will be 1,71 MW if the drying of RDF used the exhaust gases after the gasification reactor to heat the air stream will dry out the RDF.

Figure 3. Final step of plasma gasification process (power generation)



The studied plasma gasification installation of RDF uses fluidized bed technology and the daily capacity is approximately 300 tn / d dried RDF with moisture 13% (or 70,41 tn / day with moisture content 32.75%). The choice of fluidized bed technology is due to the high quantity of gas produced by this technology (about 86%). The RDF will come from a mechanical sorting which will be located in a short distance from the plasma gasification installation, so that the transfer of RDF is to be direct, quick, easy and will not be incurred significantly from the costs of the RDF transport. That case study uses the exhaust gases for heating of the air stream that will dry the RDF, from the initial moisture 32.75% to the moisture 13%, used the exhaust after the gasification reactor.

4. Results

The analysis of energy quantities is a complicated process for the plasma gasification since the energy outputs should also be reproducible in real scale. The lack of real data makes the problem more difficult because the information such as the adequacy of energy recovery systems of the gas, heating capacity or the combustion efficiency for gaseous mixtures are limited without having proved even in practice.

It is decided to study the case of electricity generation from a combined cycle system. The gas engines are considered to have 40% electrical efficiency and thermal efficiency of 50%.

Assumptions

1. The gas composition, since is cleaned from unwanted substances, is burned in an internal combustion engine to produce electricity.

2. Modern gas engines can use fuel gas of low haeting value. However, there is a low limit and for this study will be set equal to 1,25 KWh/Nm3. This value is not arbitrary but based on operating data pilot plant operating in the Czech Republic by the company Pyroforce.

3. As mentioned, the synthesis gas produced in the reactor, passes through a cyclone for the cleaning of solid particles and then through a heat exchanger it gives an appreciable part of the heat to produce steam which is used to dry the feed.

4. The plasma torch, i.e. the device which provides energy in the form of electric current in the reactor is deemed to have 85% yield. The reason it din not be supposed a price equal to 100% is the flares cooling requirements for safe operation. Companies like Westinghouse and Geoplasma, give for torch performance a range from 70 to 90%.

4.1. RDF flow

The E. Kapetanios and D. Malamis reported lower calorific capacity 14200 Kj / Kg for RDF, initial moisture 27.1%, which is produced in the mechanical and biological pre-treatment plant (MBT) of the Attica Region, while the European Union of 15 members reported [4] that the average lower calorific capacity for RDF from mixed MSW, 24.4% initial moisture is 13300 Kj / Kg. The lower calorific capacity of dried RDF, with humidity 13%, is Hu = 17918,422 Kj / Kg. The lower calorific capacity of RDF is expected to be increased in the near future for the reasons cited above for the expected reduction of the moisture content and was calculated by the eequation:

$$Hu=38834c+93868h+101325s-5945n-10802o-2449*w$$

with c,h,s,n,o,w the quantities IN carbon(C), hydrogen(H_2), sulphur(S), nitrogen (N_2), oxygen (O_2) and moisture.

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The RDF flow before his drying, with initial moisture of 27.1%, is 12500 Kg / h. The RDF flow after drying at 13% humidity, after calculations, that is 10413,75 Kg / h.

4.2. Overall quantity of prodiced exhausts

The theoretical combustion air was calculated to be μ_{LO} = 5,31025 Kg / Kg. The combustion is done with 40% excess of air and from the calculations is estimated that the actual combustion air is μ_L = 7,4427 Kg / Kg. With an efficiency of the boiler 96% and 86% of the RDF, which is converted into syngas by the gasification and then is burned, the calculations show that the total amount of produced exhaust gases is m_G = 71.211,2753 kg / h

4.3. Exhausts used for process

With exhaust gases temperature at the outlet from the stove T_{G1} = 1100 ^oC and after leaving the gasification reactor T_{G2} = 600 ^oC and with the calculations the final amount of exhausts which will be used for the gasification is m_{G1} = 12297,6294 Kg / h

4.4. Energy required for drying the RDF

The energy required for drying the RDF is calculated by the equation:

$$q=1,05*[N*(r+C_{pd}*(\Theta_2-20))+(w-N)(\Theta_2-20)*C_{pw}+(1-w)*(\Theta_2-20)*C_\kappa]$$

and
C_{pd} : heat capacity of vapor: 1,996 KJ/Kg ^oC
Cpw : heat capacity of water: 4,186 KJ/Kg ^oC
Cκ : heat capacity of fuel (RDF): 0,8337 KJ/Kg ^oC
r : the latent heat vaporization: 2454 KJ/Kg (The amount of heat required to transform a given mass of saturated water in saturated steam of the same pressure)
Θ_2 : fuel temperature leaving the drying systems: 120 ^oC

The energy required for drying the RDF for studied are Q_{drying} = 11031912.7KJ/Kg = 4,05 MW (2773594,4 Kj/h). This will enable the RDF to a stream of hot air which will be heated by the exhaust gases of the combustion of RDF produced gasification reactor.

4.5. Energy required for gasification

The fluidization of the bed, as already mentioned, will be done by using the exhaust of combustion in the boiler. The gas production is maximized (86%) around 1200 ^oC, so it is selected as the temperature at which the gasification reactor operates. The reactions occurring during the gasification are endothermic and requires energy about E_{gas} = 1944 Kj / Kg dried RDF, humidity 13%. From calculations is showed that the total energy required is Q_{gas} = 7,85 MW. This heat will be provided by the exhaust gases, therefore should be calculated the total amount of exhaust gases as well as the amount of exhaust gases which will be used for gasification.

4.6. Produced energy from installation

The combined cycle is the most efficient energy method since the energy of the exhaust is used to produce steam and then electricity.

4.6.1. Turbine unit

The airflow $\dot{m}_\alpha$ which penetrates the compressor is that determines quantitatively the energy produced. Thus the power output in these units , which always depends on the generator load (ie the demand), is regulated by valves that control the flow of air in the combustion chamber and hence the fuel flow to that in the ratio defined by the ratio of fuel / air.

$$Pg = \dot{m}_\alpha*[(C_{Pg}*(T_4-T_5)*\eta_m-C_{P\alpha}*(T_3-T_2)]$$
Pg=10794,5628KW = 10,80MW

4.6.2. Steam-turbine unit

The steam, which will be the cause of steam operation, is carried out by introducing the exhaust gases from the turbine in the heat exchanger

The output (power) from the steam turbine is calculated :
$$P_S= \eta_{th}* \eta_W*\dot{m}_g* C_{Pg}* T_5$$
PS=25598,93KW = 25,60MW

4.6.3. Vitrification energy

In the study so far have counted constraints that reduce the efficiency of the process, but they offer a safe estimation for the energy terms. The only parameter that is not included is the vitrification energy of the inorganic part of the feed. According to the recommendation given by John Frantzis for Greek junk, 16.2% of this mineral is not melted and gasified but vitrifies.

Because there are no data on the mineral composition of the Greek garbage attempted to calculate the vitrification energy. The above evaluation was made without causing problems of accuracy because the price of vitrification energy expected to be small compared with the energy required for gasification and thus obtain the value of 570 KJ / s corresponding to 0,57 MW. As expected, the price is negligible compared to the gasification energy required.

4.6.4. Overall energy of system

The total power output of the combined cycle plant is the sum of the powers of the steam turbine and gas turbine are:

$P = Pg + P_S = 36{,}3$ MW

Table 2. Net energy of the process

Quantity	Τιμή (MW)
Energy for drying	4,05
Energy for gasification	7,85
Total energy consume	11,9
Total energy production	36,3
Vitrification energy	0,57
Net energy production	24,4

5. Conclusions and general assessment

The application of plasma gasification in RDF with fluidized bed technology for power generation is interesting, especially the case studied. The international experience from the implementation of plasma gasification with fluidized bed technology is very small which increases the investment risk. Also for the plasma gasification fluidized bed technology is beyond technical implementation and the limitation of only small and medium sized facilities. But the above should not discourage investments for further development of the existing plasma gasification technology, so it can be increased the expertise and be resolved remaining technical problems because plasma gasification technology can be clearly demonstrated one state-of-the-art, environmental and techno-economic method and in the near future will be fully prepared to give very beneficial solutions to large-scale thermal recycling of solid waste.

The plasma gasification process is a future method for treating solid waste. The option of oxygen and the humidity rates is crucial issue and depends on the exploitation mode of synthesis gas.. The process is an effective and environmentally friendly option for treatment and energy recovery of RDF from E.M.A. of E.S.D.K.NA. Based on that energy evaluation from our study, the RDF can be used for energy recovery using a process that includes the milestones of plasma gasification, drying and electricity production. The effective implementation of the proposed process shows that plasma gasification process is not only energy independent but can lead to a net production of electricity.

The first conclusion drawn from the analysis is that the price of electricity and the waste disposal fee are what can make the investment more financially viable. The electricity can be subsidized if the energy production by exploiting waste is considered as a renewable form of energy. The disposal waste fee is important to integrate the unit revenue plasma gasification. From the side of a state disposal fee can replace council tax paid currently in landfills. A good combination of grant, refuse disposal fee and sales price of electricity can make the investment of plasma gasification very attractive, but should not be neglected the high cost of electricity production. This value is very high compared with both the more expensive renewable electricity (photovoltaic - wind) and conventional energy sources (oil - gas). If the system combined cycle is successfully integrated, the total pop-generated electricity can then plasma gasification to become more competitive as electricity generation technology.

The impacts study of major economic parameters (price electricity production, waste disposal fee subsidy) can be showed how much the investment of a power plant with integrated plasma gasification combined cycle system can be advantageous with appropriate policies promoted by the state. The various toxic substances are destroyed by high temperatures and this plasma gasification is particularly suitable for the treatment of hazardous waste such as medical waste and some industrial. The treatment of hazardous waste can justify the choice of the high waste disposal fee per tonne which as mentioned above it could contribute positively to the profitability of the investment.

In the process, harmful pollutants can be removed from the syngas before they reach the gas turbine; thus, back-end exhaust gas clean up is not necessary. The SOx, NOx, mercury, metals, and particle emissions from the plant are fractions of those of a conventional pulverized coal boiler power plant. Consequently, IPGCC plants require significantly less effort and time to meet air emissions regulations and to obtain local and state governmental environmental permits. The process is approximately 5% more efficient than other coal power technologies, thus, CO2 emissions per kW are also 5% lower.

Summarizing what we have been said above, we reach the undeniable fact that the gasification of RDF produced and the combustion of produced gas in a combined cycle plant will produce numerous environmental advantages at a time when such energy technologies are a powerful investment for man and nature.

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