NOVEL PROJECT ON TOTAL PLASMA BASED TREATMENT OF WASTE

G. Van Oost[1], M. Hrabovsky[2], J. Pieters[3], M. Tendler[4], J. Verstraeten[5]

[1]Department of Applied Physics, Ghent University,Rozier 44, B-9000 Gent, Belgium;
[2]Institute of Plasma Physics AS CR, Za Slovankou 3, Prague 18211, Czech Republic;
[3]Biosystems Engineering, Ghent University, Coupure Links 653, B-9000 Gent, Belgium;
[4]Alfvün Laboratory, Royal Institute of Technology, Stockholm, Sweden;
[5]Envitech S.A. Belgium

An experimental plasmachemical reactor has been started at IPP Prague for the innovative and environmerntally friendly total plasma treatment of waste streams, biomass and low grade fuels, with a view to their sustainable energetic and chemical valorisation and to a reduction of the emission of greenhouse gases. Existing incineration and biological waste elimination processes cannot always fulfil the objectives of sustainable development, i.e. maximum recovery of energy and materials from the waste streams in an environmentally friendly manner. Moreover, these processes often generate residues which are concentrates of hazardous material and need to be landfilled.
Plasmas offer an alternative and superior solution for the treatment of waste streams. Plasma torches have the unique capability of increasing the energy of the process gas compared with conventional combustion equipment. They therefore offer several distinct advantages over traditional methods where the energy content of the waste is used as the heat source. Since the process energy is provided by direct heat transfer from an electric arc, gases of widely varying chemical composition may be used; use of electrical energy also reduces the gas flow needs and on-site off-gas production, and offers control over the chemistry. The very high heat conditions in a plasma reactor trigger a dual, simultaneous reaction process: organic materials are converted into synthesis gas (syngas) without formation of toxic products such as dioxins and furans, while inorganic materials are converted into a non-leaching, vitrified, inert slag which has industrial applications. The quality of the syngas can be controlled by non-thermal plasmas, using new generations of gas cleaning corona plasma technologies.
A plasmachemical experimental reactor has been commissioned in Prague in August-September 2004, using the novel IPP-CAS hybrid gas-water stabilized torch (160 kW).
PACS: 52.77.-j; 52.75.Hn; 81.20.Ka

1. INTRODUCTION

A new research and development project has been started at IPP-AS Prague, together with the academic partner Ghent University and the private partner Envitech S.A. (both from Belgium). The increasingly stringent legislation on treatment of waste streams and the limitations of conventional technologies such as thermal incineration, catalytic oxidation and adsorption render plasma technologies more and more attractive. The driving force behind the project is to give priority to environmental quality at affordable cost, and to contribute to sustainable development in general and to solving the ever increasing world energy problem in particular [1]. Thus, the investigation of ways to increase the efficiency of the plasma based treatment processes is very important. The paper presents the concept of a fully plasma based system for the investigation of the feasibility of the treatment of a wide range of possible feedstocks: in the first phase waste from mainly industrial and consumer activities; in a second phase fossil fuels like high-sulfur brown coal, bituminous coal and oil shale presently considered to be of insufficient quality for conventional combustion processes [1].

In most industrialised countries, integrated solid waste management is mainly governed by the so-called Ladder of Lansink. This ladder specifies a generally accepted hierarchy of preferred methods for dealing with waste. The highest rung is occupied by waste prevention, followed (in that order) by re-use (of the object as it is), recycling (material re-use without loss of quality) and down-cycling (material re-use with loss of quality). A still lower rung is the energy recuperation from waste (by incineration, gasification or pyrolysis), followed by incineration and / or destruction of waste without energy recuperation, while the least preferred option is landfilling. Although re-use and recycling are still preferred, energy recuperation and landfilling are still key aspects with respect to waste management, since health aspects and the precautionary principle often overrule the technical possibilities

Since plasma treatment of waste gives rise to some vitrified product on the one hand and releases energy on the other hand, this technology has potential in waste recycling (incl. down-cycling), energy recuperation and also as a pre-treatment to landfilling. Since the inert fraction is vitrified and since harmful substances can hardly leach from the lava, this product can be used for road construction, or even better as a building material (e.g., as bricks made from the ashes from a classic incinerator). The leaching characteristics make this technology especially suitable as a pre-treatment when landfilling hazardous substances. In some national or regional regulations (like for instance in Flanders - Belgium) hazardous waste may only be landfilled after solidification and provided leachability of e.g. heavy metals is below strict thresholds.
The organic fraction on the other hand can be used as an energy source. Using a gasification or a pyrolysis process,

the organic fraction of waste can be converted into a fuel gas, which can substitute fossil fuels.

The concept of the present project concerns thermal plasma gasification and vitrification, i.e. a dual simultaneous disintegration and fusion process. The feedstock is treated by plasma torches in a reactor chamber, whereby organic components are converted into a synthetic gas of high caloric value, and inorganic components are converted into a non-leachable vitrified lava. The quality of the syngas will be controlled by non-thermal plasmas using new generations of gas cleaning plasma technologies, which can of course also be used in other industrial processes generating large volumes of polluted waste gases. Optimization of the treatment of feedstocks, i.e. optimization of the quality of the synthetis gas (or *syngas*) according to criteria determined by the end use, will be investigated. These criteria can be: the maximum energy content of the syngas for electricity or heat production (*thermal conversion*), or the production or recovery of a valuable by-product from the syngas such as methanol, respectively hydrogen for fuel cells (*chemical conversion*).

The major steps in the project are: the realization of an efficient system for clean and efficient plasma based waste treatment using thermal and non-thermal plasmas and the testing of an integrated system for various feedstocks.

2. GASIFICATION AND VITRIFICATION BY PLASMA TORCHES

Since the 1980s applications of thermal plasmas experienced an important increase. In the 1990s fundamental research led to great progress in the understanding of the basic phenomena involved, and to a renewed interest in applying thermal plasmas to material processing and waste treatment [2]. *The application of plasma torches for environmental purposes is a relatively new process.*

Plasma torches operate simultaneously as a plasmachemical and a thermal apparatus. The electrical energy of the torches goes into the plasma which transfers its energy to the substances to be treated, thereby triggering a dual simultaneous reaction process in the plasmachemical reactor: the organic compounds are thermally decomposed into their constituent elements (syngas with more complete conversion of C into gas than in incinerators), and the inorganic materials are melted and converted into a dense, inert, non-leachable vitrified slag, that does not require controlled disposal. Therefore, it can be viewed as a totally closed treatment system.

The use of thermal plasmas for gasification allows:

- Far higher temperatures than can be reached by conventional heat generators.
- Highly reactive and reducing environment.
- High energy density and high heat transfer efficiency, allowing shorter residence times and large throughputs.
- Low thermal inertia and easy feedback control .
- Lower plasma gas input per unit heating power than the gas flow of a classical burner and thus lower energy loss corresponding to the energy necessary for heating of gas to reaction temperature; also lower amount of off-gases to be treated.
- Absence of combustion gases generated by conventional incinerators.
- Smaller plants than for incinerators due to high energy densities, lower gas flows, volume reduction.
- Heat source is electricity and thus independent of the treated substances, providing flexibility and fast process control.
- Optimal control of the composition of reaction gases.

The heat source is electrical energy rather than energy liberated from combustion, and is therefore independent of the treated material, providing more options in process chemistry, including the possibility of generating valuable co-products. The process temperature can be readily maintained or instantly varied to select optimal conditions.

A special novel type of plasma torch with electric arc stabilized by water vortex in combination with gas flow has been developed at the IPP Prague [3,4, 5]. This torch generates an oxygen-hydrogen-argon plasma jet with extremely high plasma enthalpy and temperature. The hybrid gas/water stabilization provides the possibility of controlling the parameters of the plasma jet and the plasma composition in a wide range from high enthalpy, low density plasmas typical for water stabilized torches to lower enthalpy, higher density plasmas generated in gas stabilized torches. Both the high temperature and the composition of the plasma generated in argon/water torches are highly advantageous for waste treatment process. The other characteristic feature of this hybrid torch is very low mass flow rate of plasma. As a low amount of plasma carries high energy, the power needed for heating of plasma to reaction temperature is very low and the efficiency of utilizing plasma power for waste destruction is extremely high. The torches with water stabilization have been utilized at industrial scale for plasma spraying. Due to the physical characteristics of the generated plasma the spraying rates and powder throughputs achieved with these torches are several times higher than with classical gas stabilized torches.

The experimental plasmachemical reactor with closed water cooling system is designed to operate at 1700 C and to treat about 50 kg/h. The waste container with a content of 30 kg (first phase) is hermetically closed and equipped with a continous waste supply system. Measuring equipment for the reactor vessel and gas analysis are provided.

3. SYNGAS CLEANING

An important drawback of conventional gas cleaning techniques is that separate processes are needed for each type of contaminant. Most difficult to control are mercury vapor and dioxins. *Non-thermal(cold) plasma techniques represent a new generation of gas cleaning technology that will treat a number of different pollutants simultaneously* [6]. During the last decade or so, worldwide investigations and industrial trials have demonstrated the effectiveness against a wide range of compounds, such as: dioxins, mercury vapor, HCl, H_2S, NO_x, SO_x, VOC's, tars, heavy hydrocarbons, CFC's and odours. Plasma systems combine removal mechanisms that vary from oxidation, reduction/decomposition, scrubbing/adsorption (wet systems), to aerosol formation followed by particle removal [7].

Since most of the electrical energy input in a non-thermal plasma goes into the production of energetic electrons rather than into gas heating, the energy cost for cleaning diluted VOC (Volatile Organic Components) laden gas streams is drastically lower than in thermal incineration. The decomposition mechanism in non-thermal plasmas is based on radical production through electron-molecule collisions and is therefore non-selective, allowing for treatment of mixed gas streams.

In spite of the apparent advantages, non-thermal plasma technology has not yet been deployed on an industrial scale. The generation and stable operation of non-thermal plasmas at atmospheric pressure on an industrial scale indeed remains a challenging problem. Furthermore, our knowledge of the plasmachemical kinetics that govern VOC decomposition and by-product formation has to be improved. With the present status of technology, another problem for industrial implementation is the difficulty to avoid the formation of by-products. The combination of a cold plasma with catalysts is considered to be a promising approach to achieve complete oxidation at reduced energy cost [8].

The syngas generated from a torch operated gasifier leaves the plasmachemical reactor at a temperature of 800 to 1000° C. It has been demonstrated that pulsed corona is well fitted for gas conditioning at these temperatures in biogas-like mixtures[10]. Depending on the further development and upgrading of pulse power sources for industrial applications, a corona operated cylcone is planned to be installed directly behind the reactor to charge/cluster and remove aerosols and to perform temperature enhanced cracking of heavy hydrocarbons. As a second process, behind the heat exchanger/quench, a non-thermal plasma (scrubber) cleaning system will be used.

The proposed high-temperature pulsed corona plasma cyclone offers a unique solution to combine removal of gaseous and particulate pollutants:

- The high gas velocity and turbulent conditions in a cyclone greatly improve the mixing of the plasma-induced radicals. Modeling shows that by good mixing, the energy efficiency of plasma processing can be improved substantially.
- Combined centrifugal and electrostatic forces can drastically enhance particle collection. Pulse energization of the plasma leads to a very high ion density. We therefore expect that up to 10 nm particles can be collected. Moreover, the energy consumption for pulsed energization is low, typically less than 1 J/L.
- High temperature plasma processing leads to a large reduction of the energy consumption. For example: a reduction with a factor 8 is possible for the removal of heavy hydrocarbons in producer gas (typically 400 J/L at low temperature of 200 ºC).
- Collected products are recycled back into the vitrification/gasification process.

4. DISCUSSION

In evaluating the opportunities of plasma treatment in waste management, comparison should be made with classical chemical-thermal conversion technologies, such as (grate) incinerators, gasification and pyrolysis units. Whereas the latter two are still relatively new and mainly suitable for small-scale applications, the incinerator can presently be considered to be a BAT (best available technology) for common waste streams, such as municipal solid waste. Incinerator ashes can be easily upgraded to a road construction material, while energy recuperation via steam and power production is commonly applied. Consequently, it is clear that for these waste streams, plasma treatment will not be a viable option in the near future. However, the increasingly stringent legislation on treatment of waste streams and the limitations of conventional technologies render plasma technologies more and more attractive. Hence, opportunities are presently to be found for those waste streams where the performance of grate incinerators is insufficient, while the superior performance of plasma reactors compensates for the higher costs (capital and operational expenses). Apart from relatively easy process control and the small footprint required, the major advantage of plasma treatment is certainly the good hygienisation of the end products, as a result of the very high temperatures in the process and the vitrification. As a result, opportunities for plasma treatment of waste are most likely situated in the destruction or size reduction of difficult, hazardous waste streams (medical and toxic waste, etc.), combined not only with energy recuperation but also with recycling of materials, that are otherwise to be landfilled after solidification. Because of the volume reduction of the inert fraction, other applications could be situated in handling radio-active waste, which needs to be stored for hundreds of years or more.

A procedure of CO2 dissociation in a plasmachemical reactor has been patented and will be tested soon in Prague in view of the Kyoto protocol.

It can therefore be concluded that further research into waste treatment using plasmas is justified and required.

Apart from the energy and mass balances, the characterisation of side streams needs to be addressed. In particular, the required (flue) gas cleaning needs to be investigated, since this is by far the highest cost factor for actual incinerators.

REFERENCES

1. J.Ongena and G.Van Oost.// *Trans. of Fusion Technology (45).* 2004, pp. 3-14P.

2. Fauchais and A. Vardelle.// *Plasma Phys. Control. Fusion (42).* 2000 , p.3

3. V.Brezina, M.Hrabovsky, M.Konrad, V.Kopecky, V.Sember.// *Proc. 15th Int.Symp.on Plasma Chemistry, Orleans, 9-13 July 2001* Vol.III, p. 1021-1026

4. M. Hrabovsky.// *Int.Conf. on Low temperature plasmas* /Ed. Zhovtyuansky V.A., Kiev, NASU 2003, pp. 20-23

5. M. Hrabovsky, V.Kopecky, V. Sember, T.Kavka, O.Chumak// *IEEE Trans. on Plasma Science*, TPS0333 (to be published)

6. E.M. van Veldhuizen, *« Electrical Discharges for Environmental purposes »*. Nova Sci. Publishers Inc., N.Y., USA, 2000

7. H.W.M. Smulders, E.J.M. van Heesch, S.V.B. van Paasen// *Trans. on Plasma Science* (*26).* 1998, pp. 1476-1484

8. R. Morent, J.Dewulf, N. Steenhaut, C. Leys, H. Van Langenhove// *Proc. XV Int. Conf. On Gas Discharges and their Applications, Toulouse, 5-10 September 2004* (to be published)

9. E.J.M. van Heesch, A.J.M. Pemen, K. Yan, S.V.B. van Paasen, K.J.Ptasinski, P.A.H.J. Huijbrechts// *IEEE Trans. on Plasma Science (28).* 2000, pp. 1571-1575

НОВЫЙ ПРОЕКТ ПОЛНОЙ ПЛАЗМЕННОЙ ОБРАБОТКИ ОТХОДОВ

Г. Ван Оост, М. Храбовский, Дж. Питерс, М. Тэндлер, Дж. Верстретен

В ИФП в Праге запущен экспериментальный плазмохимический реактор с использованием новейших экологически чистых технологий для полной плазменной обработки отходов, биомассы и низкосортного топлива с учётом сохранения их энергетической и химической ценности и снижения выбросов парниковых газов. Существующие процессы уничтожения отходов путём сжигания и биологической обработки не всегда обеспечивают максимальное восстановление энергии и материалов из отходов без ущерба для окружающей среды. Кроме того, эти процессы часто приводят к образованию остатков, содержащих опасные вещества и подлежащих захоронению.

Плазменные технологии предлагают альтернативное и лучшее решение задачи переработки отходов. По сравнению с обычным оборудованием для сжигания плазменные факелы обладают уникальной способностью повышать энергию газа, выделяющегося при переработке. Поэтому они дают некоторые явные преимущества над традиционными методами, в которых энергия, содержащаяся в отходах, используется как источник тепла. Так как процесс выделения энергии обеспечивается прямой передачей тепла от электрической дуги, можно использовать газы разнообразного химического состава. Использование электрической энергии позволяет уменьшить потребление газа и его сопутствующее выделение и осуществить химический контроль. Сильный нагрев в плазменном реакторе запускает два одновременных процесса - превращение органических веществ в синтетический газ (сингаз) без образования токсических продуктов, таких как диоксины и фураны, а неорганических веществ – в невыщелоченный стекловидный инертный шлак, имеющий промышленное применение. Качество сингаза можно контролировать с помощью нетепловой плазмы по новым плазменным технологиям очистки газов с использованием плазменной короны.

Плазмохимический экспериментальный реактор с использованием нового гибридного газоводяного стабилизированного факела IPP-CAS (160 кВт) принят в эксплуатацию в Праге в августе-сентябре 2004 г.

НОВИЙ ПРОЕКТ ПОВНОЇ ПЛАЗМОВОЇ ОБРОБКИ ВІДХОДІВ

М. Ван Оост, М. Храбовський, Дж. Пітерс, М. Тендлер, Дж. Верстретен

В ІФП в Празі був запущений експериментальний плазмохімічний реактор з використанням найновіших екологічно чистих технологій для повної плазмової обробки відходів, біомаси та низькосортного палива з урахуванням збереження їх енергетичної і хімічної цінності і зниження викидів парникових газів. Існуючі процеси знищення відходів засобом спалювання та біологічної обробки не завжди забезпечують максимальне відновлення енергії і матеріалів з відходів без завдання шкоди навколишньому середовищу. Крім того, ці процеси часто призводять до створення залишків, що містять небезпечні речовини і підлягають похованню.

Плазмові технології пропонують альтернативне и краще рішення задачі переробки рідких відходів. Порівняно зі звичайним обладнанням для спалювання, плазмові факели мають унікальну здібність підвищувати енергію газу, що виділяється під час переробки. Тому вони дають деякі явні переваги над традиційними методами, де енергозміст відходів використовується як джерело тепла. Оскільки процес виділення енергії забезпечується прямим передаванням тепла від електричної дуги, можливе використання газів різноманітного хімічного складу. Використання електричної енергії дозволяє зменшити витрати газу та його супровідне виділення і здійснити хімічний контроль. Сильний нагрів в плазмовому реакторі ініціює два одночасних процеса - перетворення органічних речовин у синтетичний газ (сингаз) без створення токсичних продуктів,

таких як діоксини та фурани, а неорганічних речовин – у невилужений склоподібний інертний шлак, що має промислове застосування. Якість сингазу можна контролювати за допомогою нетеплової плазмы за новими плазмовими технологіями очищення газів з вживанням плазмової корони.
Плазмохімічний експериментальний реактор з використанням нового гібридного газоводяного стабілізованого факела IPP-CAS (160 квт) прийнятий в експлуатацію в Празі в серпні-вересні 2004 р.