Recent Advancements in Food Waste Management

[1]Tawheed Amin, [1]Poonam Chhabra, [2]Suman Vikas Bhat

[1]Amity Institute of Food Technology, Amity University, Sector-125, NOIDA, Uttar Pradesh 201303, India
[2]Department of Food Technology, Islamic University of Science & Technology, Awantipora,
Jammu & Kashmir, 1921 22, India
Email: tawheed.amin@gmail.com

ABSTRACT

In the past few years, there has been a tremendous increase in food waste generation due to rapid urbanization and industrialization. Population is also increasing and is expected to reach 9.5 billion by 2050. Both of these factors have put an emphasis to employ novel techniques for management of waste generated so that waste generation could be reduced to a minimum or these wastes could be converted into some valuable products. Therefore, in this view much technological advancement has occurred in the recent past which has proved to be useful for combating this problem. In this review, a brief introduction to status of waste generation and novel methods for its management has been discussed.

Keywords : Waste generation, plasma incineration, bioremediation, plasco, europlasma

1 Introduction

Waste generated from food industries is a source of an untapped energy which is mostly dumped in landfills whereby it releases greenhouse gases into an atmosphere [1]. It is very difficult to treat and recycle food waste due to its composition. Food waste consists of high levels of sodium and moisture and is usually mixed with other types of waste during its collection. Amount of waste generated is largely determined by two factors- population in a given area and its consumption patterns. These two factors are evolved by Gross Domestic Product Per Capita (GDC/c). It has been estimated by UN that by the end of 2025, the world population will increase by 20% to reach 8 billion inhabitants [2]. By 2050, the total population will be around 9.5 billion unless some specific control measures are adopted. It thus becomes a reality that a population of 8-8.5 billion by 2050 would be considered a successful stabilization of numbers. About 97% of this growth will happen in Asia and Africa. These areas include some of the poorest countries and have inadequate means of infrastructure to absorb it. It is believed that after 2025, Asia will hold more than two thirds of the world population which will trigger urbanization of population and will create extended zones of poverty in cities. Besides an increase in population, GDP/c is also increasing. Both of these factors i.e. an increase in population and GDP/c will lead to an increase in volume of waste production [1] [2]. The accurate estimation of waste production is not possible; however, a rough analysis has been done to estimate the production of waste. Using macroeconomic data from 30 Organization for Economic Cooperation and Development (OECD) countries it has been estimated that a 1% increase in national income creates a 0.69% increase in municipal solid waste amount [2].

In order to cope with this huge waste production, advanced and effective waste management systems are to be adopted that can overcome the gap between production and management of waste disposal. It is known that bigger is the GDP/c, the more advanced and the more effective waste management systems are adopted. Evidently this increase in GDP/c will drive for the use of modern landfills, efficient collection systems, MBT and WTE in almost every part of the world. A lot of technological advancements in the field of waste management are happening and is going to revolutionize the world in the coming years.

The modern technology and intensive agricultural practices have proved to be a great asset in combating famine throughout the world. Despite an increase in food production to meet the demands of growing population, food insecurity is still a problem in many parts of the world [3]. There are still millions of people all around the world who live without getting sufficient and adequate food [4].

Waste from food industries poses a significant risk on food safety and security which is rarely acknowledged because in developed countries, food is considered a disposable commodity [5]. The long term effects of food production are neglected. In the food industry, policies often favor economic growth rather than emphasizing on environmental protection and nutrition promotion [6]. In most of the developing countries, food is trashed before it reaches the final consumer. This is attributed to the lack of technology and infrastructure,

ISSN 2278-7763

microbial growth, insect infestation, high temperature and humidity [7].

NOVEL METHODS USED FOR TREATMENT OF WASTE

PLASMA INCINERATION/PLASMA ASSISTED GASIFICATION.

Plasma is the fourth state of matter and is an ionized gas that exists in nature [8] [9]. Plasma can be produced industrially on an industrial scale by the help of plasma torch (figure 1). Plasma creates a huge amount of energy which otherwise cannot be produced by nuclear fission/fusion.

Plasma can be generated either by DC electric discharges, radiofrequency (RF) and microwave discharges. For treating waste, plasma is preferentially generated by DC electric discharge. By passing a DC current between cathode and anode of the plasma arc torch and simultaneously passing air in an annular space of the torch, an extremely high-temperature environment is created ranging in temperature from 5000°C to 10,000°C. A simplified circuit of the plasma torch is shown in Fig. 2. Two types of devices are mostly used: non-transferred and transferred arc.

- **Non-transferred arc:** This is the most commonly used waste treatment process. In this system, thermal energy is produced from electricity by the help of electric discharges from cathode to anode within a water cooled torch that heats the plasma jet issued from the torch. It provides a plasma flow which is used for an effective waste treatment as a result of its better mixing with it. [9].
- **Transferred arc:** In this, heat is produced from electricity within a gas column issuing from a torch. A counter electrode is incorporated into the torch and plasma jet projects beyond it. This counter electrode is concentric with the jet axis and arc is transferred to external electrode [9].

Plasma process has been widely used for destruction of hazardous wastes [8] [9]. But now it is being also used as a treatment method for municipal solid wastes (MSW). However, the high consumption of electricity limits its use for low value materials. Plasma-assisted gasification processes are being developed and may offer environmental benefits. Advantages of this process is high energy output and low capital cost.

Process. It involves the volatization of solid waste materials under anaerobic conditions. Under such conditions, waste materials get decomposed and oxidized partially to carbon monoxide (CO), hydrogen (H_2) and water (H_2O). Here in the organic matter of waste is converted into synthetic gas called S*ynGas* while as inorganic fraction is converted into an inert vitrified glass and thus no ash is left to be landfilled [9].

There are several plasma-assisted gasification technologies which include:

- **Syngas polishers**. It heats or polishes the syngas immediately after it is produced by a conventional gasification process.
- **Waste zappers**. It involves the passage of waste directly through transferred arc for destruction.
- **Plasma assisted gasification**. In this process, plasma torches are used to speed up the process of gasification, to decompose volatile gases into CO and H_2, and to vitrify the inorganic fraction of waste.

Thermal plasma is used in combination with traditional gasification on which basis; there are two types of processes:

1. **Europlasma.** A plasma technology developed by Europlasma, a French company, as applied to waste treatment uses non-transferred arc torches in plasma reactors. Here the heat is provided by plasma jets directly into the reactor. A special plasma torch called "TurboPlasma" developed by Europlasma is used to crack the syngas produced by gasification [9].
2. **Plasco.** This is a private waste conversion and energy generation company of Canada. This company converts municipal solid waste (MSW) to energy by using a process called Plasco Conversion process. Before sending it to the process, MSW is pretreated for the removal of materials with high reclamation value to be recycled after which the waste is shredded. In the first step, MSW is converted to crude syngas which flows to the refinement chamber where plasma torches crack it to produce a product called Plasco-Syngas. After this, sulphur, acid gases and heavy metals are removed by air pollution control system. This syngas is then used as a fuel to generate electricity.

ADVANTAGES OF PLASMA ASSISTED WASTE TREATMENT PROCESS OVER CONVENTIONAL TREATMENT METHODS [8] [9]

- Reduces the production of exhaust gas and lowers its flow rate resulting in lesser air pollution.
- Equipment is compact so takes a minimum space for large disposal wastes.
- From the techno-economic point of view, oxides of nitrogen and sulphur are not emitted as this process occurs in the absence of oxygen.
- Toxic materials produced become entrapped and encapsulated thereby making them easier and safer to handle.
- Low capital investment.
- Faster start-up.
- Faster shut-down times.

ISSN 2278-7763

NOVEL PYROLYSIS TECHNOLOGY

This technology was developed by Energystics Technologies, Ltd. In this technology, concentrated and direct electromagnetic waves are allowed to fall on solid, liquid or gaseous waste [10]. This technology directly couples electromagnetic energy with a target material to produce heat. When EM waves fall on the target, it absorbs energy producing temperature which is above the melting or vaporization temperature of target waste material [11]. Such a high temperature causes the disassociation of strong molecular bonds in waste materials.

This technology requires only a relatively small energy input because the technology does not utilize conductive medium. In order to demonstrate the effect of this technology on animal tissues, pyrolysis of beef carcass was done which resulted in complete dematerialization of the tissue leaving no residues or smoke (Figure 3).

ADVANTAGES OF NOVEL PYROLYSIS TECHNOLOGY

- Instantaneous heating.
- Controllable heating.
- Lack of hydrocarbon pollutants.
- No harmful emissions.
- Reduced energy requirements.

BIOREMEDIATION

Bioremediation is the naturally occurring process in which microorganisms either immobilize or transform environmental contaminants to innocuous end products [12].

Advantages of bioremediation

- It conserves financial resources by the virtue of reduced cleanup times. Capital expenditure is also less as compared to other remediation technologies [13].
- This technology is widely accepted by industry as it maintains nature's harmony.
- It destroys contaminants rather than transferring them from one medium into another [12].

CONDITIONING

The process of conditioning enhances the characteristics of biosolids preparing for their further processing [14]. There are many novel technologies which are applied for the purpose of conditioning which include ultrasonic degradation, chemical degradation, enzyme addition, electro-coagulation and biological cell destruction. These processes modify the inorganic and organic characteristics of waste which is critical to other processes.

ULTRASONIC DEGRADATION

Before sending it for digestion process, solid waste material is subjected to acoustic waves to attain extremely high temperatures and pressures within biosolids. This helps in the destruction of microbial cells due to shear stresses produced as a result of explosion of gas bubbles. This process is adjustable to high frequency and low frequency waves. Advantages of this technique include an increase in rate of cell disruption, decrease in anaerobic digestion time, reduce sludge quantity and increase in biogas production [14].

CHEMICAL CELL DESTRUCTION

The basic purpose of this process is to disrupt the cell membrane of microorganisms in waste activated sludge process for the improved efficiency of anaerobic digestion and amount of biogas [14]. In this process, waste material is treated with caustic soda (NaOH) for about one hour. The cell membrane of microorganisms gets weakened and viscosity of solution also decreases. Microsludge™ (Biocell) has been specifically designed for this purpose. It involves the use of industrial-scale high pressure homogenizer which causes a sudden and enormous pressure drop responsible for causing lysis of microbial cell in the sludge. This sludge is then liquefied, mixed with primary sludge followed by anaerobic digestion to produce biosolids and biogas.

ENZYME CONDITIONING

This technique is intended to increase the dewaterability of biosolids and reduce odors during digestion process. It involves the addition of a mixture of enzymes, specialized nutrients (humic acids, amino acids) and anaerobic and aerobic bacterial cultures into digestion systems. These microbes produce enzymes which degrade organic materials converting them into carbon dioxide and water.

ELECTROCOAGULATION

Electrocoagulation increases the rate of anaerobic digestion of waste material. This technique involves an electric current which dissolves an anode (sacrificial anode) and releases chemically reactive aluminum into the wastewater stream. The positively charged aluminum ions attract very fine negatively charged ions and particles towards them resulting in agglomeration. As a result, the agglomerated particles increase in size and settle down due to their increased weight [14].

BIOLOGICAL CELL DESTRUCTION

In this process, activated sludge is diverted from the settling tank into a vessel and chemical agent is added. The chemical agent has strong oxidation properties and weakens the cell wall of bacteria. These processed bacteria are then returned back to the activated sludge process where they decompose into carbon dioxide and water.

THERMOPHILLIC FERMENTATION

This technology converts sewage sludge and residuals into fertilizer grade product. Thermotech™ is a digestion technology based on the use of microbes as an agent to step up the digestion process. It was originally developed to produce an animal feed supplement from relatively high-solids content food wastes. Another technology called ThermoMaster™ process has been developed in which autoheated aerobic digestion is operated at a relatively short residence time (30 hours) to maximize the production of single-cell protein using an influent waste material as a substrate [14]. The solids thus obtained are dried and pelletized.

THREE PHASE ANAEROBIC DIGESTION

In this process, anaerobic digestion occurs in three phases.

Phase I: First phase is a volatile fatty acid digester which is operating at a temperature of 35^{o}C.

Phase II: It is an anaerobic thermophillic gas digester operating at a temperature of 50^{o}C to 56^{o}C.

Phase III: This phase is not heated but remains above 35^{o}C.

ANAEROBIC DIGESTION WITH OZONE TREATMENT

Biolsolids are digested anaerobically and are passed into a reaction tank where they are exposed to low levels of ozone. According to [15], only 0.06g of ozone per gram of dissolved solids is sufficient to destroy the biological activity of the digested biosoilds. The ozone treated waste material is then sent to thickening tank followed and back to digester in which both ozone treated and non-ozone treated waste materials are mixed. After this, waste material is either sent for dewatering or for ozone treatment.

DEWATERING OF WASTE MATERIAL

ELECTRO-DEWATERING

Waste material is subjected to direct current (DC) which, in the initial stage, causes particles to migrate to the oppositely charged electrode and the process is called electrophoresis. After the cake is formed, electroosmosis occurs because ions migrate to their appropriate electrode to compensate for particle charge. This technology can be used in combination with conventional filtration.

ELECTROACOUSTIC DEWATERING

It uses the combination of electric fields and ultrasound waves and increases the efficiency of dewatering. Electric field is responsible for electrophoresis and electroosmosis while as acoustic waves (sound waves) help in maintain electrical continuity throughout the waste material. Aslo it is believed that acoustic waves decrease specific energy consumption, increase filtration rate and helps to keep cathode clean [14].

MECHANICAL FREEZE-THAW

In this process, the sludge is frozen followed by crushing and is allowed to thaw naturally under ambient conditions. Chemical bonds in the sludge are altered due to freezing thus making removal of water easier. This step increases the amount of water that can be removed from sludge. The treated sludge is then treated by conventional sludge dewatering equipment.

SUPERCRITICAL WATER OXIDATION

This technology is also called "hydrothermal oxidation". It uses the physical properties of water and reduces the volume of waste materials. The water is heated and pressurized above the critical point i.e. 374°C and 3,191 pounds per square inch (psi). As a result of this process, the solubility of organic substances and oxygen into water is significantly increased. This technology has an advantage that it decomposes organic matter completely and produces a high-quality effluent.

DRYING OF WASTE MATERIAL

The main objective of drying process is to remove water from waste material producing solids with high solid percentage and reduce weight and volume of waste materials. Drying is usually accomplished by direct or indirect heating. The various types of drying technologies include the following:

- **Belt drying.** It involves two or more slow moving belts arranged in series and air is supplied or around belts. Sludge which is dewatered is spread in the form of a thin layer on a belt to increase the surface area.
- **Direct microwave heating.** Burch BioWave® is a dryer which is patented and involves a continuous flow process. It removes water and pathogens from dewatered sludge. This process involves the use of high-efficiency multi-mode microwave system which is specifically designed to remove moisture. This process is highly automated and can dry waste materials having an initial moisture content of 85% to a final moisture content of 10%. This technology has an added advantage that it has the capacity of about 100% pathogen without any change in its nutrient content.
- **Flash drying.** It can dry waste material to about 90% or more solids. Sludge containing water is fed into centrifuge where dewatering takes by conventional means and its solid content reach a concentration of 25%. This material is then discharged into thermal stage as a fine-grained spray. Once the particles of solid waste enter thermal cyclone chamber, they get dried up instantly. These dried particles are then taken out of the chamber in a fraction of second, by the help of sweep gas. The sweep gas, drawn through ventilator fan is reheated in hot gas generator before re-entering into dryer loop.
- **Fluidized bed dryer.** The wet cake which has been already dewatered is passed into fluidized bed dryer where it comes into contact with already dry granules. Here, indirect heating is applied by means of tubular heat exchangers immersed in fluidized layer of solids. Advantages of this process includes the flowing:
  - It is more reliable.
  - It is safer to use and operate.
  - It is a more flexible technology.
  - It can dry the material to solids content greater than 90%.

  - It is dust free.
  - It is mechanically stable.
- **Chemical drying.** In this process, solids are dried through chemical reaction. Dewatered waste material is mixed with ammonium salts or anhydrous ammonia and concentrated organic acids (sulphuric acid, phosphoric acid). Ammonia reacts with organic acids and produces heat (exothermic reaction). During this reaction, sulphates and phosphates are produced. The heat produced from the reaction is utilized for drying of waste materials. In this process, hard granular materials are produced which can be mixed with plant nutrients to raise their nutritive value.

VERMICULTURE

Vermiculture is defined as the science of cultivating earthworms feeding on waste material and soil. This technology is used to augment or replace conventional composting process [16]. This technology releases digested food material back into the soil which increases the nutrients in soil [17].

WASTE MANAGEMENT IN PARTICULAR FOOD SECTORS

HIGH VALUE CO-PRODUCTS FROM PLANT FOODS

Some studies have shown that plant food products such as vegetables and fruits are effective in protecting cancer and cardiovascular diseases [18] [19]. This is attributed to the presence of phytochemicals or phytonutrients in them. These constituents have relevant biological activities, particularly when they are consumed on a daily basis [20]. Many of these phytochemicals have antioxidant properties which prevent the oxidation of low density lipoprotein (LDL) [21] [22]. Extracts containing phytochemicals are used in the preparation of nutraceuticals and functional foods [20].

In fruit and vegetable industry, one of the main sources of waste generated is external tissues (peels) which are obtained during handling and processing. Leaves and fruit peels are a rich source of phytochemicals; therefore, wastes from plant food industry serve as an important source for the preparation of functional ingredients and nutraceuticals [23] [24] [25].

TECHNOLOGICAL PROCESSES FOR EXTRACTION OF PHYTOCHEMICALS FROM RESIDUES

In order to develop extraction techniques and technological processes for the preparation of high-value extracts, factors like phytochemical solubility, chemical and biochemical stability and tissue localization are to be taken into account [20]. Mostly, phytochemicals have less solubility in water and much better solubility in organic solvents. Mixtures of alcohol and water are the solvents used for more polar compounds [26] while as less polar solvents such as ethyl acetate, petrol or ether are used for most lipophilic phytochemicals. pH of a solution is very important for some kinds of compounds as solubility of these compounds can be increased by changing pH. Therefore, acidic compounds, such as polyphenols, can be extracted in water at an alkaline pH, at which phenolic hydroxyl are ionized [20].

REQUIREMENTS TO BE MET BY EXTRACTION PROCESSES

Depending on the nature of residues, the extraction processes for extraction of phytochemicals have to meet some requirements which are as follows:

a. Fresh raw material should be used as otherwise drying process increases production costs.
b. Food compatible solvents are to be used.
c. Thermal treatments should be given to waste to inactivate enzymes that could otherwise degrade phytochemicals during extraction processes [27].

Another feasible technology called supercritical fluid extraction (SFE) using CO_2 in supercritical state has been proposed. Enzymes such as pectinases or cellulases can also be used for increasing extraction yield of phytochemicals from residues [20].

Concentration of extracts obtained is done before use by either spray drying or freeze-drying method. The technology to be used depends on the market price of extract. Non-ionic polymeric resins can be used for purification of extracts [28].

In non-ionic polymeric resin method, water extract is filtered through resin column during which the phytochemicals are retained in the stationary phase. After this, compounds are eluted with ethanol and the extract is concentrated which are subsequently used for the preparation of pills or other nutraceutical preparations or functional juices [29]. The extracts obtained are to be kept in nitrogen atmosphere or otherwise these compounds being highly anti-oxidative can get oxidized by oxygen.

CONCLUSION

Increase in the production of waste disposal has resulted in massive land degradation. This in turn has led to an increase in the demand for most promising techniques which will result in reducing the pollution level. Much of the technological advances occurred in the field of waste management many of which have proven to be a great asset for managing food waste. Despite several benefits which they offer, they have their downsides too which needs to be looked into or find some alternative technologies to overcome the problem of land degradation.

REFERENCES

[1] S. Zafar, 3 April 2012. [Online]. Available: http://www.bioenergyconsult.com/trends-in-food-waste-management/.

[2] A. Mavropoulos, "Waste mnagaement world," 2011. [Online]. Available: http://www.waste-management-world.com/index/display/article-display/8267238380/articles/waste-

management-world/volume-11/issue-2/features/waste-management_2030.html.

[3] K. Goulding, S. Jarvis and A. Whitmore, "Optimizing nutrient management for farm systems," *Philos Trans R Soc Lond B Biol Sci.* , pp. 363:667-80, 2008.

[4] S. Statistics., "Stockholm International Water Institute.," *Accessed 2009 August 13. Available from: http://www.siwi.org/sa/node.asp?node=159,* 2009.

[5] A. Y.-C. Lin, S. T.-Y. H. Hon and M. L. W. MD, "Waste management to improve food safety and security for health advancement," *Asia Pac J Clin Nutr,* pp. 18 (4):538-545, 2009.

[6] T. Stuart, "The scandal of food waste," *Financial Times Accessed 2009 July 13. Available from: http://www.ft.com/cms/s/2/87a89020-66a1-11de-a034-00144feabdc0.html,* 2009.

[7] A. Martin, "One Country's Table Scraps, Another Country's," *Available from: http://www.nytimes.com/2008/05/18/week,* 2008.

[8] G. C. (. K. Bhasin, "Plasma Arc Gasification For Waste Management," Technology Focus, 2009.

[9] C. Ducharme, "Technical and economic analysis ofPlasma-assisted Waste-to-Energy processes," Earth Engineering Center, Columbia University, Columbia, 2010.

[10] T. J. Shepera, "Personal communication to A.Nutsch regarding EnergyBeam™ technology:Thomas J. Sheperak (President & CEO,Energystics Technologies, Ltd.)," 2004.

[11] D. D. Jones, S. Hawkins and D. R. Ess, "Carcass Disposal: A Comprehensive Review," in *Non-Traditional & Novel Technologies*, 2004, pp. 1-38.

[12] P. Thassitou and I. Arvanitoyannis, "Bioremediation: a novel approach to food waste management," *Trends in Food Science & Technology,* p. 185–196, 2001.

[13] G. GeoEnvironmental, *www.gzea.com/bioremediation/bioremediation.asp,* 1998.

[14] M. Hetherington, M. Moore, R. Pepperman, T. G. Shea, L. Stone, R. Reimers and P. Rom, "Emerging Technologies for Biosolids Management," *Offi ce of Wastewater Management U.S. Environmental Protection Agency Washington, D.C.,* pp. 1-1 - 9-4, 2006.

[15] R. Vranitsky and J. Lahnsteiner, ""Sewage sludge disintegration using ozone – a method of enhancing the anaerobicstabilization of sewage sludge," *Proceedings of the European Biosolids and Organic Residuals Workshop, Conference and Exhibition,* 2002.

[16] P. Roupas, K. D. Silva, G. Smithers, A. Ferguson and Alamanda, "Waste managemeco-product recovery in red and white meat processingnt and," in *Handbook of waste management and co-product recovery in food processing* , New York, CRC Press, 2007, pp. 305-331.

[17] K. Singh, B. Bhimawat and N. Punjabi, "Adoption of vermiculture technology by tribal farmers in Udaipur district of Rajasthan," *International Journal of Rural Studies (IJRS),* pp. 1-3, 2008.

[18] E. B. Rimm, M. B. Katan, A. Ascherio, M. J. Stampfer and W. C. Willett, "Relation between intake and risk of coronary heart disease in male health professionals," *Ann. Intern. Med.,* pp. 125, 384–389, 1996.

[19] R. Doll, "An overview of the epidemiological evidence linking diet and cancer," *Proc. Natl Acad. Sci. U.S.A.,* p. 49:119–131, 1990.

[20] F. A. T. Barberán, "High-value co-products from plant foods: nutraceuticals, micronutrients and functional ingredients," in *Handbook of waste management and co-product recovery in food processing* , New York, CRC Press, 2007, pp. 448-468.

[21] S. Rankin, D. C. Whaley, J. Hoult, W. Jessup, G. Wilkins, J. Gollard and D. Leake, "The modifi cation of low density lipoprotein by the fl avonoids myricetin and gossypetin," *Biochem. Pharmacol.,* pp. 45, 67–75, 1993.

[22] A. Scalbert, C. Morand, C. Manach and C. Rémésy, "Absorption and meta bolism of polyphenols in the gut and impact on health," *Biomed. Pharmacother.,* p. 56:276–282, 2002.

[23] R. Carle, P. Keller, A. Schieber, C. Rentschler, T. Katzschner, D. Rauch, G. F. Fox and H. U. Endress, "Method for obtaining useful materials from the by-products of fruit and vegetable processing," *Patent application WO01/78859 A1,* 2001.

[24] G. Laufenberg, B. Kunz and M. Nystroem, "Transformation of vegetable waste into value added products: (A) the upgrading concept; (B) practical implementation," *Bioresour. Technol.,* pp. 87, 167–198, 2003.

[25] R. Llorach, F. A. Tomás-Barberán and F. Ferreres, "Functionalisation of commercial chicken soup with enriched polyphenol extract from vegetableby-products," *Eur. Food Res. Technol.,* p. 220:31–36, 2005.

[26] J. B. Harborne, "Phytochemical Methods," *Chapman and Hall, London,* 1973.

[27] F. A. Tomás-Barberán and J. C. Espín, "Phenolic compounds and related enzymes as determinants of quality in fruit and vegetables," *J. Sci. Food Agric.,* p. 81:853–876, 2001.

[28] F. A. T.-B. M. A. Blázquez, C. García-Viguera, F. ferreresl and F. Tomás-Lorente, "A comparative study of different Amberlite XAD resins in fl avonoid analysis," *Phytochem. Anal.,* p. 3:178–181, 1992.

[29] M. Larrosa, R. Llorach, J. C. Espín and F. A. Tomás-Barberán, "Increase of antioxidant activity of tomato juice upon functionalisation with vegetable byproducts extracts," *Lebensm. Wiss. Technol.,* pp. 35, 532–542, 2002.

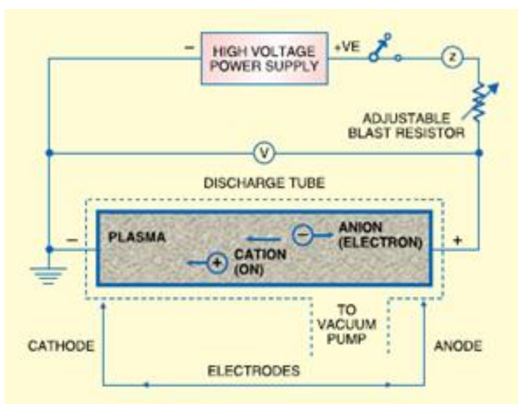

Fig. 1. Simplified circuit of a plasma torch

Fig. 2. A plasma torch in operation

[1]

Fig. 3. Pyrolysis of a 20- gram smaple of beef tissue using the ETL EnergyBeam™ (puple/white (Shepark, 2004)

