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(54) Title: LIQUID OR LIQUID/GAS STABILIZED PLASMA PYROLYSIS, GASIFICATION AND VITRIFICATION OF WASTE MATERIAL

(57) Abstract: A reactor for plasma pyrolysis, gasification and vitrification of waste material comprising a vessel having a gas exhaust port, said vessel being constructed to receive said waste material; said reactor further being characterized in that a liquid and/or liquid/gas stabilized plasma torch is mounted in said vessel to convert said waste material.



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**LIQUID and LIQUID/GAS STABILIZED PLASMA PYROLYSIS,
GASIFICATION AND VITRIFICATION OF WASTE MATERIAL**

5 **FIELD OF THE INVENTION**

This invention relates to a method for an ecologically and economically acceptable reduction in volume of waste material and more particularly to a method for the pyrolysis and vitrification of such waste by means of plasma arc
10 heating technology.

The present invention also relates to methods for disposal of wastes in general, and in particular to a method for gasification of waste material by means of a plasma arc torch in an enclosed, reactor vessel.

15

The present invention relates to a technique for converting waste material to a liquid fuel and more particularly to an efficient method for gasifying said material to produce a feedstock gas for use in the production of fuels. The present invention also relates to the utilization, as a gaseous fuel, of useful gas produced
20 by the gasification of said material by carrying out the gasification method.

BACKGROUND ART

At present, the development of techniques alternative energy production and the
25 widespread use of these techniques are urgently needed for preventing global warming and for avoiding the depletion of limited fossil fuel resources. Among various types of alternative energy sources, waste material is often regarded as the most promising natural energy from the viewpoint of its abundance and storability.

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Direct combustion of waste material such as woody biomass, which has hitherto been adopted, however, suffers from limited amount of resource and low

efficiency. For example, gasification of carbonaceous materials to produce reaction products comprising carbon monoxide and hydrogen has been carried out in the past by injecting finely-divided solid or liquid carbonaceous material suspended in oxygen containing gas into the cylinder of an internal combustion
5 chamber, and thereafter igniting or exploding the suspension therein. The temperature within the cylinder tends to decrease as a result of the work carried out by these product gases in moving the piston away from the cylinder head. This temperature decrease is of course very undesirable inasmuch as the gasification of carbonaceous material such as coal requires high temperatures to achieve a rapid
10 reaction between carbon and an endothermically reacting gas such as steam.

Recently, it has been well recognized in that if waste is transported to a central location, pyrolysis and vitrification can be accomplished, using plasma arc heating technology, in an efficient and safe manner and useful gaseous and vitrified
15 products produced so as to avoid placing the waste residue into a landfill.

Plasma arc heated processes are receiving considerable attention for waste treatment over fuel combustion heated processes because of several distinct advantages of plasma heat which are well suited for the pyrolysis and vitrification
20 of waste materials. A plasma arc torch operates by supporting a high power electric arc on a flow of gas to generate an extremely hot plasma jet. The quantity of plasma gas flowing through the plasma torch is significantly less than the quantity of gas required to release the equivalent heat energy by the combustion of hydrocarbon fuels. A further difference and advantage of a plasma torch heat
25 source over a combustion heat source is that the plasma torch can be used to produce useful by-product gases of higher caloric content referred to here as the gasification. In addition, by virtue of the fact that a plasma arc torch uses only a small quantity of gas to support the arc and generate the heat, combustion is unlikely to occur spontaneously in the materials, which are being heated. A major
30 advantage of the plasma torch is that it is capable of unusually high rates of heat transfer, adding to its inherent efficiency. Also, the temperature of above 2500 °K generated by a plasma torch is much hotter than that generated by a combustion

source and is hot enough to melt any known material simultaneously with the pyrolysis process.

5 An example of apparatus and method utilizing plasma arc heating for processing household and industrial waste in a plasma heated reactor is disclosed in U.S. Pat. No. 3,779,182 to the present inventor. The '182 patent is also noted for teaching the introduction of oxygen or air to the reactor. Entrapped air, if permitted to enter the reactor with the solid waste, will allow combustion in an uncontrolled process and cause the resultant gases to be both different in nature and non-useful as
10 compared to those resulting from pyrolysis of the organic waste materials alone in a substantially air-free environment. Through pyrolysis of organic waste, the by-product gases are principally valuable fuels such as hydrogen and carbon monoxide. The inclusion of a large quantity of air will add a significant quantity of nitrogen that will dilute the energy content of the gas.

15

From the above, it is clear that continuous effort is needed to optimize and investigate plasma arc heating to render plasma arc heating into an industrial feasible application for waste treatment.

20 Given the above, it is therefore an overall objective of this invention to provide an industrial feasible process for plasma pyrolysis and vitrification, which reduces the volume of input mixed waste materials, and results in by-product gases which have high energy content that can be used.

25 It is therefore a particular objective of the present invention to provide an improved process, particularly from an economic standpoint, for the gasification of waste material especially carbonaceous materials such as, for example, wood, coal, natural gas, ethane, propane, petroleum oil, gas oil, residual oil, etc, to produce gases comprising primarily carbon monoxide and hydrogen.

30

According to the present invention the water liquid and liquid/gas stabilized plasma process, in its broader aspect, comprises reacting waste material especially

carbonaceous materials with a free oxygen-containing gas to produce gases containing primarily carbon monoxide and hydrogen.

- It is an additional objective of the present invention to provide a reactor to
- 5 enhance the process control of the gasification of the waste material, allow the gasification process to occur in the reactor, ensure optimum performance, ensure complete breakdown of all waste material fed into the system and decrease torch power consumption and optimize energy performance of the entire process.
- 10 It is also a further objective of the present invention to disclose the plasma pyrolysis, gasification and vitrification process as an efficient method of producing a fuel such as methanol.

- Finally, it is an objective of the present invention to disclose the utilization of the
- 15 process of the present invention to produce H₂, CO gas as a fuel source.

- It has now been surprisingly found that liquid and liquid/gas stabilized plasma arc heating is especially useful for providing the above-mentioned objectives. In particular, water/Argon stabilized plasma arc heating is a preferred embodiment of
- 20 the present invention (hybrid torch).

- The liquid stabilization and 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
- 25 water stabilized torches to lower enthalpy, higher density plasmas generated in gas stabilized torches. The high temperature, the absence of air and the composition of the plasma generated in especially 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
- 30 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 liquid and liquid/gas 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.

5

Especially suitable type of plasma for the process of the present invention is that produced by plasma torches with electric arc stabilized by water vortex in combination with gas flow, especially Argon, as has been described by M Hrabovsky, Pure & Appl. Chem, Vol 70, No 6, pp 1157-1162, 1998. This type of
10 plasma torch generates an oxygen-hydrogen-argon plasma jet.

The process of the present invention has cost, size, operability and environmental advantages over current disposal methods. These benefits are not found in current disposal processes, and make plasma gasification particularly advantageous for
15 the disposal of the waste material, in particular carbonaceous material:

By the application of the process and reactor according to the present invention to a wide range of possible feedstocks, which are CO₂ neutral, a clean syngas of high
20 caloric value is produced from the organic substances simultaneously with a non-leachable vitrified lava from the inorganic substances. The results will provide the advanced technology for the environmentally friendly treatment of waste material.

The problem solved by the present invention includes both the recuperation of
25 clean energy from waste and renewables without pollution at affordable costs.

Furthermore, the present reactor and the process of the present invention offers possibility of decomposition of waste material by pure pyrolysis in the absence of oxygen. The main advantage is better control of composition of produced gas,
30 higher heat capacity of the gas and reduction of unwanted contaminants like tar, CO₂ and higher hydrocarbons.

Other objectives and advantages will be more fully apparent from the following disclosure and appended claims.

DETAILED DESCRIPTION OF THE PRESENT INVENTION

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The present invention is directed to a reactor for plasma pyrolysis, gasification and vitrification of waste material comprising a vessel having a gas exhaust port and said vessel being constructed to receive said material; said reactor further being characterized in that a liquid and/or a liquid/gas stabilized plasma torch is mounted in said vessel to heat said waste material.

10

The reactor comprises a vessel having a plurality of intake ports and further comprises a material delivery system to provide said material to said reactor through said plurality of intake ports, said delivery system comprising: a receptacle to receive said material, and/or a shredding and/or a compacting unit disposed to accept said material from said receptacle and to shred and compact said material, and a transfer unit to deliver said shredded and compacted material to said vessel. Preferably the torch generates an oxygen-hydrogen-argon plasma jet. The reactor vessel may have one or more tap holes at a bottom thereof and may further comprise a water cooling unit and a combustion burner.

20

The present invention is also directed to a method for the conversion of waste material comprising waste, biomass or other carbonaceous material by plasma pyrolysis, gasification and vitrification, said method comprising: providing a liquid and/or a liquid/gas stabilized plasma torch in a vessel; providing one or more successive quantities of said material into the vessel, said vessel having an gas exhaust port, heating said material using said liquid and/or liquid/gas stabilized plasma arc torch.

25

The present invention also includes the use of a liquid and/or a liquid/gas stabilized plasma arch torch for the pyrolysis, gasification and vitrification of waste material in particular wood. Preferred arch torches are water stabilized. Highly preferred hybrid arch torches are those which generate oxygen-hydrogen-

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argon plasma jet. The present invention is also directed to the use of the product gas as produced by the method of the present invention as starting compounds for production of methanol.

5

Waste material

Waste material which the method of the present invention can be applied is not particularly limited and includes all useful organic materials from which useful liquid fuel components such as methanol can be produced. Specific examples of waste material usable herein include: carbonaceous materials such as wood- or forest-derived woody materials; plant/algae resources derived from marshes, rivers, grasslands, and seas; forestry and agricultural product wastes; and waste plastics.

The fine grinding (powdering) or size reduction of these waste material feedstocks is preferred for increasing the contact area (specific surface area) at the time of the gasification reaction to effectively and efficiently carry out the reaction. In this case, the feedstocks are typically finely ground or size reduced to a suitable size.

20

Preferred carbonaceous solid fuels, which can be utilized herein, are bituminous coal, anthracite, brown coal (lignite), peat, coke, charcoal, wood, etc.

Liquid fuels which can be utilized according to the present invention herein are mineral oils, petroleum oil, gas oil, distillate or residual fuel oil and similar petroleum fractions, coal tar oil, brown-coal tar oil, shale oil, tar oils from low temperature carbonization, etc. Gaseous fuels which can be employed in this invention are gases comprising methane, ethane, propane, butane or mixtures thereof such as natural gas, and other hydrocarbon gases. The foregoing liquid and gaseous fuels are in the liquid and gaseous state respectively at ordinary temperatures.

30

Reactor

The walls of the vessel of the present invention are advantageously constructed of a material which exhibits excellent strength and durability so as to enable this
5 material to withstand the relatively high and alternating pressure and the attack of reactants and reaction products produced within the chamber during the rapid and sometimes violent gasification reaction. Steel such as stainless steel, and other suitable metals are eminently adapted and can be employed, if desired.

10 The reactor may be designed such as to optimize the process conditions of the present process. A typical vessel used in this apparatus and method may be sized to process up to high volumes of mixed sources of waste material, although vessel sized larger or smaller may be used; the exact throughput will depend on the composition of the feed material and the desired overall throughput of the
15 generating plant.

The vessel is constructed preferably of high-grade steel. Depending upon design criteria, the entire vessel may be water-cooled. Alternatively, water-cooling may be used for only the top of the vessel while the lower part of the reactor is air-
20 cooled. The vessel may have refractory configurations using typical commercial refractory products, which are known to those in the reactor industry.

Although not limited to specific design and configuration, the vessel may be shaped like a funnel and divided into sections. The top section of the vessel is
25 referred to as pyrolysis/thermal zone. Typically, gas exits the vessel through an outlet which may be situated in the centre of the top section. Alternatively, a plurality of exit gas outlets may be provided in the vessel. The vessel also contains feed waste inputs which may be situated at the top section of the vessel. The middle section of the vessel is defined to as the gasification
30 zone. The bottom of the vessel is vitrification zone. The vitrification zone also houses one or more tap holes where molten slag liquid is tapped continuously into a moving granulating water bath, where it is cooled and vitrified into an inert slag

material suitable for re-use as construction material. Construction materials with which this slag may be used include tile, roofing granules, and brick.

The plasma arc torch is generally supplied with electric power, deionised water
5 and secondary plasma gas through supply conduits from appropriate sources.
The numbers of torches, the power rating of each torch, the capacity of the waste feeding system, the size of the reactor, etc. are all variable to be determined according to the type and volume of waste to be processed by the system.
Especially suitable types of plasma for the process of the present invention are
10 liquid and/or liquid/gas stabilized plasma torches. Preferred liquid/gas plasma torches with electric arc are those stabilized by water vortex in combination with gas flow as has been described by M Hrabovsky, Pure & Appl. Chem, Vol 70, No 6, pp 1157-1162, 1998. The teachings of the Hrabovsky reference are herewith incorporated by reference. Preferred stabilizing gas in accordance with the present
15 invention is inert gas. Highly preferred stabilizing gas is Argon. This type of plasma torch generates an oxygen-hydrogen-argon plasma jet.
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
20 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

The vessel will additionally contain sensors to detect the pressure and temperature
25 inside the reactor, as well as gas sampling ports and appropriate gas analysis equipment at strategic positions in the reactor to monitor the gasification process. The use of such sensors and gas analysis equipment is well understood in the art.

The preferred embodiment of the present invention is plasma gasification reactor
30 configured for the gasification of solid waste materials. It consists of an 80-180 KW plasma heating system, a reactor vessel, a material feeding subsystem and a process control subsystem. The maximum throughput of the experimental reactor

of the present invention is 80 kg per hour of wood.

The plasma heating consists of a power supply, which converts three phase AC into DC to feed a single 160 kW non-transferred plasma arc torch. The normal
5 operating range of the plasma arc torch is 300 VDC at 300-600 amps. The power supply consists of a transformer, a rectifier, a low energy plasma starter. The plasma starter, commonly referred to as the Low-Energy Plasma (LEP) igniter, is used to provide a very high step voltage to ignite the plasma and start the torch. The plasma gas is stabilized by evaporating the liquid, preferably water, vortex
10 surrounding the arc. In another embodiment, an inert gas, preferably Argon is additionally supplied as plasma stabilized gas. Torch power, plasma gas flow and torch cooling are controlled through interlocks on the process control console to turn off the torch when parameters are not maintained within certain prescribed limits. A liquid and liquid/gas stabilized torch is used wherein the liquid vortex,
15 preferably water vortex, is created in cylindrical chamber with tangential injection. Other liquids for the plasma stabilization may be suitable, preferred liquid is water or a combination thereof with water. The anode is positioned outside the arc chamber.

20 The heat supplied by the plasma pyrolyzes the input material, as opposed to incinerating it, since air is excluded from the process. Pyrolysis provides for virtual complete gasification of all volatiles in the source material, while non-combustible material is reduced to a virtually inert slag. The free carbon produced through the gasification of the volatiles reacts with the water in the input material
25 forming additional combustible gases.

In a typical gasification application, the source material is fed into the reactor vessel with no pre-processing except possibly for the drying and the shredding of very large and bulky objects to enable trouble free feeding into the vessel. The
30 reactor vessel is lined with refractory to permit the high temperatures required for processing to be achieved and for the retention of the heat within the vessel. The source material is gasified at a temperature of approximately 1100 °C. (dependent

on the source material). The resultant products are a product gas and a virtually inert slag. The product gas can be fed directly to other equipment and/or processes for combustion, or if immediate use is not required, it can be stored or flared directly. This product gas has a high hydrogen content; therefore, it burns very
5 cleanly and efficiently. The product gas from the gasification can be recycled for the gasification process. The obtained gas can be readily used or further purified and used in the synthesis of methanol.

The slag must be cooled and then it can be disposed of very easily. Depending on
10 the type and composition of input material the slag can also have commercial application. The slag from the gasification of municipal solid waste, for example, can be used in applications similar to crushed stone or it can be moulded into building type blocks directly from its liquor state.

15 The high process temperatures achievable by liquid and liquid/gas stabilized plasma processing of the present invention ensure rapid and complete breakdown of chemical bonds and avoid the particulates and partially combusted hydrocarbons normally associated with combustion processes. Total gasification can be achieved very efficiently. The general absence of oxygen results in
20 significantly less air pollution from contaminants such as nitrogen oxides (NOX) and sulphur dioxide (SO₂) than is associated with conventional gasification processes.

The size of the plasma arc torch utilized is normally selected on the basis of the
25 type and quantity of input material, which must be processed in a specific period of time. This in turn dictates the size of the reactor vessel required and the capacity of the electrical power source.

The basic conversion process proceeds as follows:

Waste material is fed into the reactor vessel. The reactor vessel typically has been
30 preheated. The volatile content of the input material begins to decompose and is expelled from the input solid mass as gases as soon as the material enters the vessel because its temperature rises sharply due to heat radiation from the plasma.

When these gases encounter the higher temperatures their temperature rises very rapidly due to heat acquired from the hot plasma and they are completely dissociated. The non-decomposed material is forced to move around the vessel as the gases suddenly acquire the high temperatures encountered around the plasma arc and expand very rapidly. Motion is also due to the geometry of the inside of the reactor vessel, which forces the material to flow through the plasma flame to a different level as it becomes molten. As the solids pass under the plasma jet, which is through the highest temperature profile, the volatile content is completely expelled, the free carbon is converted to mostly Carbon Monoxide with small amounts of Carbon Dioxide. The vessel floor temperature is also at a temperature of 1100 °C., the same as the vessel inside wall and ceiling temperature, but as the glass, metals and dirt become molten and chemically combine, they remain in a molten pool over the floor of the vessel and are subjected to the higher temperature profile directly radiated from the plasma arc flame. This temperature can be upwards of 1300 °C. and even higher where the torch plasma flame is concentrated.

The solid residue is permitted to remain in the vessel until it reaches a preset volume, at which time it is tapped and permitted to flow from the vessel into a catch container.

Preferred carbonaceous waste material, which can be efficiently particularly gasified and vitrified in this manner, include coal, peat, wood and municipal solid waste (city refuse), as well as incinerator ash.

The system may be operated by a single operator monitoring critical parameters of the process through meter readouts on the control console. All critical parameters are interlocked to automatically shutdown the operation should any of these parameters exceed predetermined tolerances. The operator also has instantaneous control of the operation and can shutdown the process and bring it back up virtually at will. These operator functions are quite straightforward and no more demanding than those found in most industrial control systems.

Input materials handling will normally require a materials handler. The input process and design complexity will be dictated by the quantity and type of input material to be processed. Mostly manual operation may be possible with a very
5 low quantity input volume.

Output slag handling will normally require a slag handler. Again, the output process and the design complexity will be dictated by the volume and physical composition of the slag to be handled.

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The system heat input process can be turned on and off virtually at the will of the operator. Vernier controls on torch input power also permits a varying input load to be readily catered to up to the maximum capacity of the system while maintaining the optimal heat transfer rate to the process. Conversion of a system
15 to one of a larger size can also be accommodated very easily; a larger size torch can be used, a second torch can be added to the reactor vessel. The cost of either of these options would normally be small compared to the initial cost outlay.

Example :

20

The experiments were performed in a system for pyrolysis of biomass and waste materials with hybrid water/argon dc arc plasma torch operated at power up to 160 kW. The torch generates an oxygen-hydrogen-argon plasma jet with extremely high plasma enthalpy and temperature. The other characteristic feature
25 of the hybrid torch is very low mass flow rate of plasma. As 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 torch has an external rotating anode that was positioned in an anode chamber downstream of the exit nozzle of the torch. This
30 chamber was separated from the reactor and the plasma enters into the reactor through the entrance nozzle of diameter 40 mm.

The experimental plasmachemical reactor with closed water-cooling system was designed to operate at a wall temperature of 1700 C and to treat up to 50 kg/h of waste. The material container with a content of 20 kg is hermetically closed and equipped with a continuous material supply system with controlled flow rate.

- 5 Measuring equipment included monitoring of plasma torch operation, temperatures in several positions inside the reactor and calorimetry measurement on cooling water loop, measurement of exhaust gas flow rate and composition using a Pitot tube flow meter and quadruple mass spectrometer. The interaction of treated material with plasma flow was observed and photographed by a fast
10 shutter camera through the windows in the reactor wall. The temperature within the reactor was measured by a pyrometer.

- Crushed wood was injected into the plasma jet in the position about 30 cm downstream of the input plasma entrance nozzle at the reactor top. It was partially
15 gasified during its flight within the jet, the non-gasified part of the wood falls onto the bottom of the reactor where it was gasified in the plasma flow. The exit tube for exhaust gas was in the upper part of the reactor, so as the produced gases passed through the zone of high temperature within plasma jet or close to it. Natural turbulence of the generated plasma jet as well as disturbances of plasma
20 flow caused by the interaction with solid evaporating material ensure strongly turbulent conditions within the reactor and thus sufficiently homogeneous heating of all parts of the reactor volume.

- The sample was taken at arc power of 130 kW and arc current 450 A, input mass
25 flow rate of wood was 30 kg/h. The main components of the exhaust gas were hydrogen (40-45% vol.), CO (40-50%), CO₂ (4%), Ar (2%). No presence of complex hydrocarbons or tar was detected.

- The experiment shows that product gas of high caloric value with high content of
30 hydrogen and carbon monoxide was produced with low content of carbon dioxide. The concentration of hydrogen is higher than the maximum values reported for

classical treatment of waste material. H₂ and CO composition is ideal for heating processes that require reducing fuels.

CLAIMS

1. A reactor for plasma pyrolysis, gasification and vitrification of waste material comprising a vessel having a gas exhaust port , said vessel being
5 constructed to receive said waste material ; said reactor further being characterized in that a liquid and/or liquid/gas stabilized plasma torch is mounted in said vessel to convert said waste material.
2. A reactor according to claim 1 wherein said vessel has a plurality of intake
10 ports.
3. A reactor according to claims 1-2, further comprising:
a material delivery system to provide said material to said reactor through said plurality of intake ports, said delivery system comprising a receptacle to receive
15 said material, and/or a shredding and/or a compacting unit disposed to accept said material from said receptacle and to shred and/or compact said material, and a transfer unit to deliver said shredded and/or compacted material to said vessel.
4. A reactor according to claim 3 wherein said waste material is selected
20 from carbonaceous solid fuels, liquid fuels or gaseous fuels.
5. A reactor according to claim 4 wherein said carbonaceous solid fuel comprises wood.
- 25 6. A reactor according to claims 1-5 wherein said liquid is water.
7. A reactor according to claims 1-6 said liquid/gas stabilized torch generates an oxygen-hydrogen-argon plasma jet
- 30 8. A reactor according to claim 1-7 further comprising a water cooling unit and/or a combustion burner.

9. A method for the conversion of waste material by plasma pyrolysis, gasification and vitrification, said method comprising i) providing a liquid and/or a liquid/gas stabilized plasma torch in a vessel; ii) providing one or more successive quantities of said waste material into the vessel, said vessel having a gas exhaust port iii) heating said waste material is by using said liquid and liquid/gas stabilized plasma arc torch.
10. A method according to claim 9 further characterized in that said liquid is water.
11. A method according to claim 10 further characterized in that said torch generates oxygen-hydrogen-argon plasma jet.
12. Use of a liquid and/or a liquid/gas stabilized plasma arch torch for the pyrolysis, gasification and vitrification of waste material.
13. Use according to claim 12 further characterized in that said liquid is water.
14. Use according to claims 12 – 13 whereby said torch generates oxygen-hydrogen-argon plasma jet.
15. Use of the product gas as produced by the method claims as defined in claims 9-11 as starting compounds for production of methanol.