System for generating Brown Gas and uses thereof

Field of the invention

The present invention relates to a system for generating Brown gas and uses thereof for different applications.

Background of the invention

Natural gas is commonly used for domestic and industrial purposes. However, there is growing concern on the use of natural gas as a source of fuel to meet the increasing needs, such as heating, of households and factories. Greenhouse emissions from the combustion of natural gas include carbon dioxide, sulphur dioxide, nitrous oxide and water vapour. In fact, the combustion of natural gas is deemed to be one of the main environmental factors contributing to global warming. Another problem with natural gas is its long-term economic viability and availability due to increased global demand compared to the global shortage of supply of natural gas. A further problem is that not all countries have their own source of natural gas and, accordingly, rely heavily on other countries to obtain natural gas. It is also essential that there be an extensive infrastructure network to support the supply, storage and distribution of natural gas to the end users. A network of exposed pipelines and terminals over a vast area is not only costly to build and maintain, but also highly vulnerable to external influence such as natural disaster or terrorist threats.

Several alternative fuel sources have been proposed instead of natural gas. One example is using solar power and transforming it into a viable source of energy. Another example is Brown gas, as described in US 4,081,656, the contents of which are incorporated herein by reference. Brown gas was described as being a suitable source of energy for pure industrial welding and cutting applications. In particular, US 4,081,656 describes a process of generating a mixture of oxygen and hydrogen gases from the electrolysis of

water. The product, Brown gas, has remarkable characteristics such as high calorific value and is capable of reactive combustion with selected metal and low pollutant emissions.

Several patents describe the uses of Brown gas. For example, US 6,761,558 describes a heating apparatus using thermal reaction of Brown gas, the contents of which are incorporated herein by reference. It further describes a method of trapping heat from the reactive burning of Brown Gas after it has passed through hexane liquid. US 6,443,725 describes a method to burn Brown gas cyclically in a burner to heat up a heat generating unit, the contents of which are incorporated herein by reference.

In view of the above, it can be seen that there is a need in the state of the art for a reliable and safe system to supply energy for domestic and industrial use, which can cater to an increase in the demand of energy, and with minimum impact on the environment. Further, this shows for a range of new technologies capitalising on these advantages.

For instance, incineration is the most common process to destroy pathogens, viruses, and toxic organics found in most domestic and industry waste. However, conventional incinerator is increasingly faced with several problems. For example, an incineration plant consumes large amounts of fuel to burn waste. The fuel may include natural gas, propane or light fuel oil. Due to the increased global demand for natural gas and the global shortage of supply of natural gas, traditional thermal incineration is a very expensive means for waste management. To mitigate the impact, new incineration plants are sited further away from populous areas, resulting in high transportation cost of waste, fuel and other supplies which are required for the operation of the incineration plant over the extended distance.

A further problem is that the discharge of dioxins and furans to the atmosphere as a result of incomplete combustion during incineration of domestic and

industry waste poses a serious health threat to the community. This has led to increasing pressure from environmentalists to impose stringent control and regulations over the disposal of dioxin- and furan-producing waste. High combustion temperatures of more than 1200°, with high turbulent mixing (using force draft air) of waste and high dwelling time of flue gas for at least 2 seconds can effectively destroy dioxins and furans in the combustion chamber during the incineration process. Therefore, one way of ensuring the complete combustion of waste and minimising the formation of dioxins and furans during combustion is to modify the existing incineration process to substantially raise the temperature of the furnace in order to enhance the combustion efficiency. However, this will lead to an increase in operation costs as fuel consumption will increase.

Several alternative approaches have been proposed to attain high combustion temperature. One example is to switch to a fluidized bed propane incinerator. Another example is using the thermal plasma incinerator that uses high energy, high intensity plasma jet for waste destruction. These approaches, however, cannot be directly incorporated into existing incineration facilities. Another approach is to use alternative fuel sources that are inexpensive, high in calorific value and have minimal environmental impact.

In another example airborne particulate matter emissions and flue gas emissions are still a prevalent problem. It is also widely known that such emissions pose a significant environmental and health risk. Such emissions may be produced by industrial processes, coal firing and incineration plants from the burning of waste, just to name a few. As a result of the processes, the constituents of the emissions may be harmful to the environment if discharged into the atmosphere without further treatment.

Existing measures to control and treat the emissions and flue gas include the use of cyclones, electrostatic precipitators (ESPs), settling chambers, wet

scrubbers and fabric filter systems. However, to a large extent, these only aid in reducing particulate matter within the emissions and flue gas and partially treat the constituents of the flue gas and emissions. Therefore, when the "treated" emissions and flue gas is discharged into the atmosphere, the emissions and flue gas may still contain harmful constituents which may be hazardous to the environment.

For example, cyclones have a low overall particulate collection efficiency, especially for particulate sizes below 10 mm. In the case of ESPs, though effective in treating the emissions and flue gas, these are very expensive to install and maintain. They also require a large space for installation. Also, ozone may be produced by the negatively charged electrodes of the ESPs during gas ionization, which adds to the environmental problems. Highly trained personnel may also be required to operate the ESPs. Fabric filter systems are also expensive in that costly refractory mineral or metallic fabric is required when operated at temperatures in excess of about 290°C. There also exists an explosion and fire hazard of certain dusts at certain concentrations in the presence of accidental sparks or flames.

With this in mind, an environmentally sound and energy efficient means to address those issues would be advantageous.

Summary of the invention

According to a first aspect, the present invention provides a system for the generation, storage and use of Brown gas comprising:

- at least one Brown gas generator, in communication with an electricity supply and water supply;

- at least one first storage chamber, in fluid communication with the generator, for storing the Brown gas generated from said generator; and

- Brown gas application means in communication with said at least one first storage chamber,

wherein said generator and first storage chamber are located proximate the Brown gas application means.

It will be appreciated that "proximate" makes reference to the intended application of the invention. For example, an application for use within a building would necessarily require a definition of "proximate" to fall within the building premises, such as a plant room as with a conventional boiler, roof mounting similar to industrial air conditioning or adjacent an external housing of the building as with an electrical distribution box.

In a different application, such as for a residential development, "proximate" may include a central location within the residential development. This is compared to, and differentiated from, conventional energy supply, such as mains electricity, whereby generation may occur several kilometres away from the development. Thus, in this case, "proximate" will be defined as within a usable location, not requiring substantial infrastructure before the final distribution for use, as compared to conventional energy supply which is "remote" in terms of generation and/or storage and so requiring substantial infrastructure for distribution. Accordingly, in the present invention, one advantage of having the generator and first storage chamber located proximate the Brown gas application means is to increase the efficiency of the system. Such an arrangement would also reduce the costs for providing less infrastructure when compared to relying on external sources for energy.

Brown gas has been shown to have high calorific value and negligible pollution emission when compared to other forms of natural gas. Accordingly, it would be advantageous to use Brown gas for domestic and industrial purposes. For example, the Brown gas generated may be used for the provision of piped gas for cooking and space heating or for industry heat treatment in production

processes, for producing hot water for use in laundry, sanitary and washing, for producing chilled water for use in space cooling and for providing fuel for an incineration unit to decompose garbage, refuse and other domestic or industrial waste.

In a second aspect, the invention provides a boiler and burner unit for producing hot water, the boiler and burner unit comprising:

- a first inlet for receiving feed water;
- a second inlet for receiving Brown gas from a Brown gas generator; and
- an outlet for discharging hot water produced,

According to a further embodiment, the application means may comprise at least one first chamber for producing hot water, wherein heat for heating said hot water is derived from combustion of Brown gas, with the Brown gas obtained from the at least one first storage chamber. In particular, the at least one first chamber may be a boiler and burner unit. The at least one first chamber may comprise:

- a first inlet for receiving Brown gas from the at least one first storage chamber;
- a second inlet for receiving water;
- a gas burner; and
- an outlet for discharging the hot water produced,

wherein the Brown gas from the first inlet may be burnt by the gas burner, thereby heating the water from the second inlet and wherein the heated water may be discharged from the outlet.

The second inlet for receiving water may be connected to an outlet of at least one heat exchanger contained within the at least one Brown gas generator.

The second inlet for receiving water may also be connected to an outlet of at least one solar thermal collector.

There may be provided at least one flash arrestor before the first inlet. The flash arrestor may include devices commonly used on the supply line of volatile gases such as hydrogen, acetylene and other fuel gases to prevent a flame from propagating to the source of the supply such as a pressurized gas storage tank or gas generator. For the purposes of the present invention, a flash arrestor may be installed at various junctions of Brown gas supply to prevent flash back from torching the Brown gas storage tank that is partially filled with the liquefied hydrocarbon as a flame coolant.

The at least one first chamber may further comprise a reactive metal element. For example, the reactive metal element which may be used in the at least one first chamber may include, but is not limited to, any of the following: platinum, steel, nickel-chromium alloy or other high temperature nickel alloys. The reactive metal element may be in the form of a singly curved or doubly curved shell with perforation on the shell surface to maximise the contact area between the metal element and the Brown gas flame. The nickel-chromium alloy may be in the form of a nichrome wire. The reactive metal element may be placed in the path of the Brown gas flame to effect reactive combustion to further elevate the flame temperature in the first chamber.

The system of the present invention may further comprise at least one second storage chamber for storing the hot water produced from the at least one first chamber. Accordingly, the at least one second storage chamber may be connected to the outlet of the at least one first chamber. The hot water produced may be stored in a storage chamber for future space heating, use in laundry, sanitary and washing.

According to a further embodiment, the application means may further comprise at least one second chamber for producing chilled water. In particular, the at least one second chamber may be an absorptive chiller unit.

The at least one second chamber may comprise:

- a first inlet for receiving an absorbent;
- a second inlet for receiving a refrigerant;
- a third inlet for receiving cool water;
- a fourth inlet for receiving warm water;
- a first heat exchanger;
- a second heat exchanger;
- a first outlet for discharging warm water; and
- a second outlet for discharging chilled water produced,

wherein the third inlet and first outlet may be connected to the first heat exchanger, and the fourth inlet and second outlet may be connected to the second heat exchanger.

The absorbent may be lithium bromide (LiBr), ammonia (NH_3), or other suitable absorbents such as desiccants or dehumidifiers as would be clear to the skilled addressee. The refrigerant may be water. Other suitable refrigerants may also be used for the purposes of the present invention.

The at least one second chamber may utilise the heat produced from a heat exchanger running hot water from the at least second storage chamber or produced directly from the at least one first chamber from the combustion of Brown gas to vapourise the refrigerant and the absorber to effect a cooling

cycle. As a result of the cooling cycle, water from the at least one second chamber is chilled. The chilled water produced may be stored in at least one third storage chamber. The chilled water may be used for various applications. For example, for space cooling applications. In particular, the chilled water from the at least one third storage chamber may flow into an air handling unit, which comprises a heat exchanger with a blower, to provide space cooling.

According to a further embodiment, the application means of the present invention may further comprise at least one third chamber for burning waste. In particular, the at least one third chamber is an incinerator unit. The at least one third chamber may comprise:

- a combustion unit for burning waste by combusting Brown gas;
- a first inlet connected to the combustion unit for receiving waste;
- a second inlet connected to the combustion unit for receiving Brown gas from the at least one first storage chamber; and
- an outlet connected to the combustion unit for discharging flue gas produced from the combustion unit.

The waste may be separated into solid and liquid waste. The waste may be treated prior to being fed into the combustion unit to reduce the moisture content in the waste.

The system according to the present invention may also comprise a heat exchanger connected to the outlet for discharging flue gas with a lower temperature. Alternatively, the system according to the present invention may comprise a wet scrubber connected to the outlet connected to the combustion unit to quench the temperature of the flue gas discharging from the outlet and/or to remove particulates and fly ash in the flue gas. A wet scrubber is a device for treating gas streams to remove sub-micron or larger fly ash. A wet scrubber

may have a series of high volume, water spraying nozzles to provide rapid quenching of the flue gas discharging from the outlet. For example, the flue gas may be quenched to 200°C to 300°C. This may prohibit the reformation of dioxins and furans in the atmosphere. The outlet may also be connected to an air filter system. Having an incinerator within the system is advantageous so that harmful waste may be treated without delay and accordingly, harmful emissions to the environment are avoided. The incinerator may also be configured as a waste-to-energy incinerator whereby the heat of combustion of waste is recovered for steam or power generation.

According to a second aspect, the present invention provides a boiler and burner unit for producing hot water, the boiler and burner unit comprising:

- a first inlet for receiving feed water;
- a second inlet for receiving Brown gas from a Brown gas generator; and
- an outlet for discharging hot water produced,

wherein the Brown gas is burnt to produce heat which heats the feed water to produce hot water.

The outlet for discharging hot water produced may be connected to a storage tank for storing the hot water produced. The first inlet of the boiler and burner unit may be connected to: the outlet of a first heat exchanger of the Brown gas generator; the outlet of at least one solar thermal collector, and/or the storage tank for storing the hot water produced.

In a third aspect the invention provides a system for recovering heat generated by burning of combustion material comprising:

- at least one Brown gas generator, in communication with an electricity supply and water supply;

- at least one first storage chamber, in fluid communication with the generator, for storing the Brown gas generated from the generator;

- at least one combustion chamber, in communication with the at least one first storage chamber, for burning the combustion material; and

- at least one heat-extracting chamber adapted to receive heat produced by the combustion chamber from the burning of the combustion material,

wherein the generator and the first storage chamber are located proximate the combustion chamber and the heat-extracting chamber.

In a fourth aspect the invention provides a method of recovering heat generated by the burning of combustion material, the method comprising the steps of:

- burning combustion material in at least one combustion chamber by combusting Brown gas; and

- receiving flue gas produced by the combustion chamber for recovering heat therein.

The at least one Brown gas generator takes in electricity to dissociate water into oxygen and hydrogen gases in an electrolysis process. The at least one Brown gas generator may include an electrolysis chamber. The mixture of oxygen and hydrogen gases is piped to the at least one first storage chamber. The at least one first storage chamber may contain a pre-determined quantity of a liquefied hydrocarbon that may act as a flame coolant. For example, the liquefied hydrocarbon may be selected from the group consisting of: hexane, heptane, methanol, ethanol and a combination thereof. The liquefied hydrocarbon may be maintained at a low temperature, for example at a temperature below the

boiling point of the hydrocarbon. The skilled addressee will appreciate suitable storage temperatures for the applicable hydrocarbon, as these are a matter of common general knowledge. For example, the temperature may be between 20°C to 100°C. In particular, the temperature may be between 10°C to 20°C. In particular, the temperature may be 20°C when the hydrocarbon used is hexane. The liquefied hydrocarbon serves as a catalyst to moderate the flame temperature of the Brown gas. In particular, the liquefied hydrocarbon may be hexane.

According to a further embodiment, the waste is burnt in the at least one combustion chamber. The at least one combustion chamber uses Brown gas as fuel. The Brown gas may be obtained from the at least one first storage chamber. In particular, the combustion chamber may be an incineration unit. The combustion chamber may be of a single-stage or a multiple-stage configuration. The at least one combustion chamber may comprise:

- a combustion unit for burning combustion material by combusting Brown gas;
- a first inlet connected to the combustion unit for receiving combustion material;
- a second inlet connected to the combustion unit for receiving Brown gas from the at least one storage chamber; and
- an outlet connected to the combustion unit for discharging flue gas produced by the combustion unit.

The combustion material may be waste, refuse garbage and other domestic or industrial waste. The combustion chamber may further comprise a pre-treatment unit for pre-treating combustion material prior to being fed into the combustion unit. The combustion material may be separated into solid and liquid combustion material. The combustion material may be sorted to remove

recyclable, non-combustible material and hazardous combustion material. The combustion material may be compacted and/or dried to reduce the moisture content in the combustion material.

Combustion material is burnt in the combustion unit. Combustion material is fed into the combustion unit by any suitable method. For example, the combustion material may be fed into the combustion unit by gravitational or mechanical means. The combustion unit may comprise a Brown gas burner to project a high temperature flame into the combustion unit to burn the combustion material. The combustion unit may also comprise a further inlet to allow fresh air to be supplied to the combustion unit to achieve more complete burning of the combustion material. The combustion unit may be lined with a refractory material to maintain a high temperature within the combustion unit. The burnt combustion material and charred non-combustible material may be collected within the combustion unit and removed from the combustion unit for disposal. The burnt combustion material and charred non-combustible material may undergo further treatment before being disposed.

The combustion chamber may also comprise a re-oxidation chamber in addition to the combustion unit. The re-oxidation chamber may be a means for thermal scrubbing of flue gas produced in the combustion unit before the flue gas is discharged into the atmosphere. For example, the flue gas produced from the burning of combustion material in the combustion unit may be oxidised in the re-oxidation chamber to further decompose or oxidise the flue gas into a form which is less harmful to the environment. The re-oxidation chamber may also use Brown gas for its operation. The re-oxidation chamber may therefore comprise a Brown gas burner to heat the flue gas to a suitable temperature. For example, the temperature to which the flue gas is heated may be the reduction reaction temperature of the flue gas constituents. The temperature may be between 1000°C and 2000°C. In particular, the temperature may be between about 1000°C and 1500°C.

To further reduce the emission of nitrous oxide, the Brown gas burner in the re-oxidation chamber may use a mixture of pure oxygen and Brown gas for burning instead of fresh air. The high nitrogen content in fresh air may react to form nitrous oxides under high temperature, which may be harmful to the environment.

The re-oxidation chamber may comprise a mesh-grid block. The mesh-grid block may be positioned such that it is in direct contact with the Brown gas flame in the re-oxidation chamber to attain a high temperature. The mesh-grid block may be supported on metal frames. The mesh-grid block may be of any suitable material. For example, the mesh-grid block may be made of platinum, stainless steel, nickel-chromium alloy or aluminium-chromium alloy. Incoming flue gas from the combustion unit may be made to pass through the heated glowing mesh-grid block to effect thermo-chemical reaction that completely oxidises the flue gas constituents such as carbon monoxide, nitrous oxides and other particulates in the flue gas. The treated flue gas may be used for other applications in the system of the invention, or be further treated before being discharged into the atmosphere.

In a multiple-stage configuration of the combustion chamber, for example a two-stage combustion chamber, the combustion material may be burnt in the combustion unit with insufficient air conditions to produce flue gas comprising carbon dioxide gas, water vapour, carbon monoxide gas, hydrogen gas and gases of hydrocarbon compounds. The flue gas may then be ducted to a re-oxidation chamber. The re-oxidation chamber may be supplied with sufficient air and oxygen-enriched conditions to further oxidise the components of the flue gas.

To ensure that the flue gas produced is ducted out of the combustion unit, the combustion unit and re-oxidation chamber are maintained at a suitable negative pressure. For example, the pressure may be -50 Pa. The negative pressure

may be maintained by installing a suction fan at the outlet of the combustion unit.

As mentioned above, the burning of the combustion material in the combustion chamber produces flue gas. The heat from the flue gas is used in other applications within the system. For example, the flue gas produced may be ducted to the at least one heat-extracting chamber. In particular, the at least one heat-extracting chamber may be a boiler unit or a dryer.

The boiler unit may be for producing steam, such that the heat for producing the steam is derived from the flue gas ducted to the boiler unit from the combustion chamber. Any suitable boiler unit may be used. The boiler unit may be designed so as to take in flue gas not exceeding a pre-determined temperature and to admit in flue gas at a pre-determined minimum volumetric flow rate. In this case, a blower may be installed at the inlet of the boiler unit to reduce the temperature of the incoming flue gas and to increase the volumetric flow rate of the incoming flue gas. For example, the boiler unit may be in the form of a metallic-tube counter flow heat exchanger boiler unit. The at least one heat-extracting chamber may comprise:

- a water inlet;
- a flue gas inlet for receiving flue gas produced from the combustion unit;
- a first outlet for discharging the steam produced, and
- a second outlet for discharging flue gas,

such that water from the water inlet is heated by flue gas from the flue gas inlet, thereby producing steam and wherein the steam is discharged from the first outlet and flue gas is discharged from the second outlet. Accordingly, the flue gas inlet of the at least one heat-extracting chamber may be connected to the outlet of the at least one combustion chamber.

The feed water into the heat-extracting chamber may be obtained from a water supply within the system. The feed water in the heat-extracting chamber absorbs the heat from the flue gas produced by the combustion chamber to form steam. The steam may rise to a steam drum for further heating at elevated pressure to produce superheated steam.

The feed water to the at least one heat-extracting chamber may be pre-heated at the combustion chamber. For example, tubes of feed water may run at the roof and along the walls of the combustion chamber, such that the tubes are exposed to the heat from the flue gas produced by the combustion chamber or the heat within the combustion chamber. The feed water within the tubes may be heated by convection and radiation heat. The volumetric flow rate of the feed water in the tubes may be controlled such that the water is heated to approximately 90°C or less. The heated feed water may then be pumped into the at least one heat-extracting chamber for steam production.

According to a further embodiment, the system of the present invention may further comprise a means for generating electricity in communication with the at least one first chamber. The means for generating electricity may comprise:

- at least one steam turbine adapted to receive steam produced by the at least one first chamber;
- at least one generator, in communication with the at least one steam turbine, for generating electricity; and
- means for discharging the electricity generated from the generator.

The steam from the at least one heat-extracting chamber, for example boiler unit, turns the turbine producing mechanical energy which is converted into electrical energy in the at least one generator, thereby generating electricity and wherein the generated electricity is discharged. Any suitable steam turbine may be used. For example, the steam turbine may be a single-stage or multiple-

stage steam turbine. The supply of steam or superheated steam to the steam turbine may be regulated by a control system. For example, the supply of steam to the steam turbine may be regulated by varying the flow rate of feed water into the boiler unit.

The electricity generated may be supplied to the at least one Brown gas generator for generating Brown gas and/or to an electricity grid. Therefore, one of the advantages of the system of the present invention is that by generating electricity from steam, reliance on an external source of electrical power may be reduced.

The system may further comprise a heat exchanger in communication with the at least one steam turbine. In particular, the heat exchanger may be a cooling unit. The heat exchanger may comprise:

- a steam inlet for receiving steam from the steam turbine; and
- a water outlet,

wherein the heat exchanger cools the steam received from the steam inlet, thereby condensing the steam to produce water and wherein the water is discharged from the water outlet. The water discharged from the heat exchanger may be recycled within the system. For example, the water discharged from the heat exchanger may be used as feed water into the boiler unit.

The heat exchanger may also be in communication with the at least one heat-extracting chamber. In particular, when the steam turbine has reached maximum capacity, the steam produced in the boiler unit may be ducted to the heat exchanger to be cooled into water. Accordingly, the heat exchanger may comprise a second inlet adapted for receiving steam produced by the at least one heat-extracting chamber when the steam turbine has reached its maximum capacity.

According to a further embodiment, the at least one heat-extracting chamber may comprise a dryer for drying combustion material before it is burnt in the combustion chamber. For example, the at least one heat-extracting chamber may be part of the pre-treatment unit of the combustion chamber as described above. In particular, the dryer reduces the moisture content of the combustion material before the combustion material is burnt in the combustion unit. Heat for drying the combustion material in the at least one heat-extracting chamber may be derived from flue gas discharged from the combustion chamber. Accordingly, flue gas from the combustion chamber may be ducted to the dryer. Flue gas from the boiler unit may also be ducted to the dryer for drying the combustion material. The dried combustion material is fed into the combustion chamber for burning in the combustion chamber.

The system of the present invention may also comprise a post-treatment unit for treating flue gas before it is discharged into the atmosphere. Accordingly, flue gas from the combustion chamber, dryer and/or boiler unit may be ducted into the post-treatment unit. The post-treatment unit may comprise at least one re-oxidation chamber, a wet scrubber and/or a quencher. A re-oxidation chamber, such as that described above, thermally scrubs flue gas by combusting Brown gas. A wet scrubber is a device for treating gas streams to remove sub-micron or larger fly ash. A wet scrubber may have a series of high volume, water spraying nozzles to provide rapid quenching of the flue gas discharging from the outlet. For example, the flue gas may be quenched to 200°C to 300°C. This may prohibit the reformation of dioxins and furans in the atmosphere. The outlet may also be connected to an air filter system. The quencher reduces the temperature of the flue gas discharging from the outlet and/or to remove particulates and fly ash in the flue gas.

According to a second aspect, the present invention provides a method of recovering heat generated by the burning of combustion material, the method comprising the steps of:

- burning combustion material in at least one combustion chamber by combusting Brown gas; and

- receiving flue gas produced by the combustion chamber for recovering heat therein.

The method may further comprise the step of producing steam in a boiler, wherein the heat for producing the steam is derived from the flue gas produced by the combustion chamber. The steam may be fed into a steam turbine, in communication with a generator for generating electricity.

The method may further comprise the step of drying combustion material before burning in the at least one combustion chamber such that the heat for drying the combustion material is derived from the flue gas produced by the combustion chamber.

In a fifth aspect the invention provides an assembly for treating flue gas before discharging into the atmosphere comprising:

- at least one processing chamber for receiving and heating flue gas;

- means for combusting Brown gas to supply heat for heating flue gas; and

- a portion for discharging heated flue gas.

In a sixth aspect the invention provides a method for treating flue gas before being discharged into the atmosphere comprising the steps of:

- providing flue gas to the at least one processing chamber;

- providing Brown gas to a means for combusting Brown gas; and

- heating the flue gas to a pre-determined temperature by combusting the Brown gas.

The means for combusting Brown gas may be a Brown gas burner. Any suitable Brown gas burner may be used for the purposes of the present invention. The Brown gas burner may project a high temperature flame into the processing chamber to heat the flue gas. The processing chamber may also comprise a further inlet to allow fresh air to be supplied to the processing chamber. The processing chamber may be supplied with sufficient air and oxygen-enriched conditions to further oxidise the flue gas constituents. The processing chamber may be lined with a refractory material to maintain a high temperature within the processing chamber. When the flue gas is heated, the flue gas may be oxidised in the processing chamber to further decompose or oxidise into a form which may be less harmful to the environment. For example, the flue gas may be heated to a suitable temperature. The flue gas may be heated to the ignition temperature. The temperature to which the flue gas is heated may be greater than 700°C. In particular, the flue gas may be heated to a temperature from 800°C to 1600°C.

The assembly may further comprise at least one member within the at least one processing chamber, wherein heating the flue gas in proximity to the at least one member achieves a greater heating efficiency of the flue gas. For example, the at least one member may comprise a mesh, steel wool, rods, metal plates or a combination thereof. The member may be made of any suitable material. In particular, the member comprises a mesh-grid block, wherein the mesh-grid block is housed within the at least one processing chamber. The mesh-grid block may be made of platinum, steel, nickel-chromium alloy, aluminium-chromium alloy or a combination thereof. The member may be positioned such that it is in direct contact with the Brown gas flame projected in the processing chamber to attain a high temperature. The member may be supported on supporting means. For example, the mesh-grid block may be supported on metal frames. Incoming flue gas into the processing chamber may be made to pass through the heated member for better heating efficiency. In particular, the

incoming flue gas may be made to pass through the heated glowing mesh-grid block to effect thermo-chemical reaction that completely oxidises the flue gas constituents such as carbon monoxide, nitrous oxides and other particulates in the flue gas. The treated flue gas may be used for other applications, or be further treated before being discharged into the atmosphere.

There may be one or more processing chambers comprised in the assembly. For example, there may be one, two, three, four, five or six processing chambers. In particular, there are three processing chambers. The advantage of having more processing chambers is that the residence time of the flue gas being heated increases and therefore, complete oxidation of flue gas constituents may be achieved. When there is more than one processing chamber, a possible way of arranging the processing chambers is in a series arrangement, such that flue gas passes through each of the three processing chambers sequentially.

The heated flue gas may be used in other applications. Accordingly, the assembly may further comprise a heat-extracting chamber adapted to receive the heated flue gas from the at least one processing chamber. In particular, the heat-extracting chamber may comprise a boiler unit. Even more in particular, the heat-extracting chamber comprises a steam boiler unit.

The heat-extracting chamber may comprise a boiler unit for producing steam, such that the heat for producing the steam is derived from the heated flue gas ducted to the boiler unit from the at least one processing chamber. Any suitable boiler unit may be used. For example, the boiler unit may be in the form of a metallic-tube or plate-type counter flow heat exchanger boiler unit. The heat-extracting chamber may comprise:

- a water inlet;

- a steam outlet; and

- a flue gas outlet,

the heat-extracting chamber arranged to permit the flue gas to heat the water to produce steam. In particular, the water from the water inlet is heated by the flue gas from the at least one processing unit, thereby producing steam and wherein the steam and flue gas are discharged from the steam outlet and flue gas outlet respectively.

The feed water into the boiler unit may be obtained from a water supply. The feed water in the boiler unit absorbs the heat from the flue gas produced by the at least one processing chamber to form steam. The steam may rise to a steam drum for further heating at elevated pressure to produce superheated steam. The feed water to the boiler unit may be pre-heated. For example, tubes of feed water may run at the roof and along the walls of the at least one processing chamber, such that the tubes are exposed to the heat from the flue gas fed into the processing chamber(s) or the heat within the processing chamber(s). The feed water within the tubes may be heated by convection and radiation heat. The volumetric flow rate of the feed water in the tubes may be controlled such that the water is heated to approximately 90°C or less. The heated feed water may then be pumped into the boiler unit for steam production.

According to a further embodiment, the assembly may further comprise a means for generating electricity in communication with the heat-extracting chamber. The means for generating electricity may comprise:

- at least one steam turbine adapted to receive steam produced by the heat-extracting chamber;

- at least one generator, in communication with the at least one steam turbine, for generating electricity; and

- means for discharging the electricity generated from the generator.

The steam from the heat-extracting chamber, in particular the boiler unit, turns the turbine producing mechanical energy which is converted into electrical energy in the at least one generator, thereby generating electricity and wherein the generated electricity is discharged. Any suitable steam turbine may be used. For example, the steam turbine may be a single-stage or multiple-stage steam turbine. The supply of steam or superheated steam to the steam turbine may be regulated by a control system. For example, the supply of steam to the steam turbine may be regulated by varying the flow rate of feed water into the boiler unit. The electricity generated may be supplied to an electricity grid. The electricity may be used for other applications within the system. Therefore, one of the advantages of the system of the present invention is that by generating electricity from steam, reliance on an external source of electrical power may be reduced.

The assembly may further comprise a heat exchanger in communication with the at least one steam turbine. In particular, the heat exchanger may be a cooling unit. The heat exchanger may comprise:

- a first inlet for receiving steam from the steam turbine; and
- a water outlet,

wherein the heat exchanger is capable of condensing the steam to produce water and wherein the water is discharged from the outlet. The water discharged from the heat exchanger may be recycled within the assembly. For example, the water discharged from the heat exchanger may be used as feed water into the boiler unit. Accordingly, the water outlet of the heat exchanger may be connected to the water inlet of the heat-extracting chamber.

The heat exchanger may also be in communication with the heat-extracting chamber. In particular, when the steam turbine has reached maximum capacity, the steam produced in the boiler unit of the heat-extracting chamber may be

ducted to the heat exchanger to be cooled into water. Accordingly, the heat exchanger may comprise a second inlet adapted for receiving steam produced by the heat-extracting chamber when the steam turbine has reached its maximum capacity.

The assembly of the present invention may also comprise a post-treatment unit for further treating flue gas before it is discharged into the atmosphere. For example, the post-treatment unit may be a scrubbing assembly. The scrubbing assembly may comprise means for scrubbing flue gas. The scrubbing assembly is adapted to receive flue gas from the portion for discharging heated flue gas and/or the flue gas outlet of the heat-extracting chamber. In particular, the means for scrubbing flue gas is a scrubber. Any suitable scrubber may be used. For example, the scrubber may be a wet scrubber, a venturi scrubber, an impingement plate scrubber or a spray tower scrubber. The means for scrubbing flue gas may comprise gravity settling chambers and mechanical collectors.

It is important that the means for scrubbing flue gas is able to transfer particles from the flue gas to the liquid stream to reduce the amount of particulates in the flue gas. This reduces the amount of particulate matter in the flue gas before the flue gas is discharged into the atmosphere. The means for scrubbing flue gas may be able to remove particulate matter having an average diameter of about 3 μm or more. The means for scrubbing flue gas may be able to simultaneously collect particulate matter and gaseous pollutants from the flue gas. The gases may be removed by absorption or chemical reaction. For example, in a scrubber, particle-laden flue gas is forced to contact liquid droplets, sheets of liquid on a packing material, or jets of liquid from a plate. The ability of a particulate wet scrubber, for example, to remove particles from a gas stream depends on the following variables:

- the size, i.e. aerodynamic diameter, of the particle;

- the velocity of the particle; and/or

- the velocity of the droplet, sheet or jet.

The means for scrubbing flue gas may further comprise pre-fliters or final filters to further remove particulate matter within the flue gas. For example, pre-filters may be installed upstream of a scrubber intended to catch particulate matter with a larger average diameter. While the scrubber itself would be able to remove this larger particulate matter as well, the removal of the larger particles before the gas stream passes through a scrubber allows the scrubber to focus more keenly and effectively on particulate matter with a smaller average diameter. A final filter may be installed downstream of the scrubber. The final filter is intended to catch particles that were not removed during the scrubbing process.

A wet scrubber may treat gas streams by removing sub-micron or larger fly ash from the gas stream. In addition to removing particulate matter from gas streams, a wet scrubber may also rapidly quench flue gas. For example, a wet scrubber may have a series of high volume, water spraying nozzles to provide rapid quenching of the flue gas.

The scrubbing assembly may further comprise a means for cooling the flue gas before being discharged into the atmosphere. Any suitable means for cooling the flue gas may be used. For example, the means for cooling the flue gas is a quencher. The means for cooling the flue gas may cool the flue gas to a temperature of less than 300°C. The advantage of cooling the flue gas prior to being discharged into the atmosphere is that this may prohibit the reformation of dioxins and furans in the atmosphere. The means for cooling may be connected to an air filter system to further remove particulates and fly ash in the flue gas.

According to a second aspect, the present invention provides a method for treating flue gas before being discharged into the atmosphere comprising the steps of:

- providing flue gas to the at least one processing chamber;
- providing Brown gas to a means for combusting Brown gas; and
- heating the flue gas to a pre-determined temperature by combusting the Brown gas.

The heating step may comprise heating the flue gas in the presence of at least one member for achieving a higher heating efficiency. The pre-determined temperature may be greater than 700°C. The means for combusting Brown gas may be a Brown gas burner.

According to a particular embodiment, flue gas is provided to three processing chambers, the flue gas passing through each of the three processing chambers sequentially. In particular, the method may comprise the steps of:

- providing flue gas to a first processing chamber;
- heating the flue gas in the first processing chamber to a first pre-determined temperature by combusting Brown gas;
- ducting the heated flue gas from the first processing chamber to a second processing chamber;
- heating the flue gas in the second processing chamber to a second pre-determined temperature by combusting Brown gas;
- ducting the heated flue gas from the second processing chamber to a third processing chamber; and

- heating the flue gas in the third processing chamber to a third pre-determined chamber by combusting Brown gas.

For example, the first pre-determined temperature may be about 800°C. The second pre-determined temperature may be about 1000°C. The third pre-determined temperature may be greater than 1200°C. In particular, the third pre-determined temperature may be about 1600°C.

The method may further comprise a step of producing steam in a heat-extracting chamber, wherein heat for producing the steam is derived from the heated flue gas. The steam produced may be fed into at least one steam turbine, in communication with a generator for generating electricity.

The method may further comprise steps to further treat the heated flue gas. For example, the method may comprise the steps of:

- scrubbing the heated flue gas in a means for scrubbing flue gas; and/or
- cooling the heated flue gas in a means for cooling flue gas.

The flue gas may be cooled to a suitable temperature. For example, the flue gas is cooled to a temperature of less than 300°C.

Brief description of the figures

It will be convenient to further describe the present invention with respect to the accompanying drawings that illustrate possible arrangements of the invention. Other arrangements of the invention are possible, and consequently the particularity of the accompanying drawings is not intended to be limiting of the present invention.

Figure 1 is a schematic diagram of the system according to one embodiment of the present invention.

Figure 2 is a schematic diagram of an absorptive chiller, according to a further embodiment of the present invention.

Figure 3 is a schematic diagram of an incinerator unit, according to a further embodiment of the present invention.

Figure 4 is a schematic diagram of a localized production, storage and delivery system for piped Brown Gas and hot and chilled water to a multi-storey building, according to a further embodiment of the present invention.

Figure 5 is a schematic diagram of the system according to a further embodiment of the present invention.

Figure 6 is a schematic diagram of a system utilising the heat from the flue gas produced by a combustion chamber according to a further embodiment of the present invention.

Figure 7 is a schematic diagram of a system utilising the heat from the flue gas produced by a combustion chamber according to a further embodiment of the present invention.

Figure 8 is a schematic diagram of the assembly according to a further embodiment of the present invention.

Detailed description of the invention

Figure 1 shows a part of the isolated system of one embodiment of the present invention. In particular, Figure 1 shows the generation of Brown gas and the use of Brown gas in a boiler and burner unit in an isolated system. Brown gas is generated in a Brown gas generator **116**, one form being described in US Patent No. 4,081,656. The generator **116** may include an electrolysis chamber. An electricity supply **104** is connected to a control panel **106** which monitors and controls the operating parameters such as electricity supply to the

generator **116** via power lines **114**. There is also provided a water supply **102**. The water supply **102** may be in the form of a water storage tank. Water from the water supply **102** is passed through a reverse osmosis (RO) water filter **108** and the filtered RO water is stored in a RO water tank **110**. Water from the RO water tank **110** is fed into the generator **116** by means of a pump **112**.

Consequently, the generator **116** takes in the RO water and electricity to dissociate oxygen and hydrogen gases in an electrolysis process. The mixture of the generated oxygen and hydrogen gases are piped to a Brown gas storage tank **122** via pipe **121**. The generator **116** further comprises a heat exchanger **118**. The immediate by-product of the electrolysis process is heat from the dissociation of water into its constituents. The heat exchanger **118** is water cooled. Water is supplied to the heat exchanger **118** from the water supply **102** through pipe **152**. Subsequently, pre-heated water is piped out of the heat exchanger **118** by pipe **154**.

The Brown gas storage tank **122** is partially filled with a liquefied hydrocarbon. In this case, the liquefied hydrocarbon is hexane **124**. There is also provided a hexane storage tank **126**. Hexane **124** from the hexane storage tank **126** is pumped into the Brown gas storage tank **122** by means of a pump **127**. The mixture of oxygen and hydrogen gas mix with the hexane vapours **124** to form Brown gas **120**. The Brown gas storage tank **122** is further equipped with a relief valve **128**.

The control panel **106** also monitors and controls other operating parameters such as the RO water supply to the generator **116** from the RO water tank **110**, hexane **124** supply to the Brown gas storage tank **122**, gas pressure within the generator **116** and the Brown gas storage tank **122**, operating temperature of the generator **116**, and flow rate of the mixture of oxygen and hydrogen gases from the generator **116**.

The Brown gas **120** from the Brown gas storage tank **122** may be supplied directly to end users via a piping network **130**. The pipes may be equipped with at least one check valve **132** to ensure that the flow of the gas proceeds in one direction only. The pipe **130** further comprises a pressure regulator **133**, control valve **134** and a flash arrestor **136**. In addition to supplying the Brown gas **120** directly to end users, the Brown gas **120** may also be supplied to a boiler and burner unit **146** for producing hot water.

In particular, the Brown gas **120** is supplied to the burner **148** of the boiler and burner unit **146** by pipe **138**. The pipe **138** comprises a check valve **140**, a pressure regulator **141**, a control valve **142** and a flash arrestor **144**. The burner **148** is a standard industrial gas burner with means for gas ignition, means for flame shape and pattern control and means to detect flame. The burner **148** operates on Brown gas **120** and has a motor driven blower, gas supply solenoid valve and a gas nozzle. The burner **148** is configured to produce a flame at a temperature of up to 1000°C. The burner **148** projects a flame into the boiler.

The boiler **150** is a cylindrical structure with space within to house water-tube bundles (not shown) to store feedwater supplied to the boiler **150** to be heated to produce hot water. In addition, within the boiler **150**, there is a layer of reactive metal element which is placed in the path of the flame burning the Brown gas **120** to effect reactive combustion that helps to further elevate the flame temperature. Hot gas produced from the combustion of Brown gas **120** in the burner **148** comes into contact with the tube bundles and consequently, the feedwater within the tubes get heated. To retain the heat of combustion as much as possible, the exterior of the boiler **150** is clad in a layer of thermal insulation materials. The heat from the combustion of Brown gas **120** in the burner **148** is used to heat the feedwater supplied to the boiler **150** in order to produce hot water.

Feedwater to the boiler **150** comes from three sources. Firstly, as make-up water from the water supply **102**. The water is pumped into the boiler by pump **158** along pipe **156**. Secondly, as pre-heated water in pipe **154** discharged from the heat exchanger **118** in the Brown gas generator **116**. Thirdly, as pre-heated water in pipe **157** discharged from at least one solar thermal collector **159**. The at least one solar thermal collector **159** takes in water from the water supply **102** and discharges pre-heated water to be fed into the boiler and burner unit **146** via pipe **157**. In particular, the water from pipes **154**, **156** and **157** is combined and pumped into the boiler and burner unit **146** by pump **158**. The hot water produced by the boiler **150** may be used for space heating, sanitary and washing applications. The hot water produced by the boiler **150** may be mixed with water from the water supply **102** through a blender valve to achieve a temperature of about 50°C to 70°C, depending on the applications, before using the water for space heating, sanitary and washing applications. The hot water produced may be stored in a hot water storage tank.

Figure 2 shows a further unit which is included in the system of the present invention. In particular, Figure 2 shows the arrangement of an absorptive chiller **200**. The absorptive chiller **200** produces chilled water, which may be used for space cooling applications. The absorptive chiller **200** is divided into four sections: condenser **202**, generator **204**, evaporator **206** and absorber **208**. The absorptive chiller **200** operates on a thermochemical process of evaporating a refrigerant at near vacuum to absorb heat from its surroundings.

The evaporator **206** and the absorber **208** sections are maintained at near vacuum conditions. In particular, the conditions at the evaporator **206** are as follows: the evaporator **206** is maintained at a vacuum state to effect evaporation at a lower temperature. For example, the pressure may be about 1 kPa and the temperature may be about 4°C.The absorptive chiller **200** is heated by a heat exchanger **205** running hot water from the hot water tank **201**. In addition, to supplement the heat, it may be placed in close proximity to a burner

148 of the boiler and burner unit **146**. Lithium bromide (LiBr) **210**, an absorber, and water **212**, a refrigerant, is fed into the generator section **204** of the absorptive chiller **200**. The heat produced from the hot water produced by the boiler and burner unit **146**, or from the burning of the Brown gas **120** by the burner **148**, vapourises the water content in the LiBr solution **210** in the generator section **204**. The refrigerant vapour in the form of water vapour **214** circulates to the condenser section **202** and gives up its latent heat to the cooling water **242** in a heat exchanger **216** in the condenser section **202**. In the process, the water vapour **214** condenses back into refrigerant water **212**.

The refrigerant water **212** flows through the pipe **218** which comprises an expansion valve **220** to form a refrigerant spray **222** in the evaporator section **206**. The water from the spray **222** is sprayed on a bundle of chilled water tubes **224** in the evaporator section **206**. The water from the spray **222** is partly absorbed by the concentrated LiBr **230** in the absorber section **208** and partly collected at **223** of the evaporator section **206** and recycled back to the condenser section **202** though pipe **218** with the help of pump **238**. The temperature of the water of the refrigerant spray **222** is cool and therefore the water of the refrigerant spray **222** absorbs the heat from the warm water **246** in the chilled water tubes **224** and evaporates (under vacuum). Consequently, chilled water is discharged from the chilled water tubes **224**. The refrigerant vapour produced in the process is absorbed by the concentrated LiBr **230** in the absorber section **208**. This rapid absorption of the refrigerant vapour creates a vacuum state at the evaporator **206**, as the evaporator **206** and the absorber **208** are interconnected. In particular, there is a pump (not shown) connected to the evaporator 206 and absorber 208. The pump creates a high vacuum of less than 1.0% of atmospheric pressure. Concentrated LiBr is produced in the generator section **204**. When the water content in the LiBr solution evaporates in the generator section 204, concentrated LiBr is formed. The concentrated LiBr flows to the absorber section **208** through pipe **226**, which comprises an

expansion valve **228**, to form a LiBr spray **230**. The LiBr from the LiBr spray **230** is collected at the bottom of the absorber section **208** to form a pool of diluted LiBr solution **232** as it combines with the refrigerant vapour from the evaporator **206**, which is recycled back to the LiBr pool **210** in the generator section **204** by a pump **236**. The LiBr spray **230** sprays LiBr on a heat exchanger **215** in the absorber section **208**. The heat exchanger **215** has cooling water **240** of temperature of approximately 25°C being fed into the heat exchanger from a cooling tower **250**, while water of a slightly higher temperature **242** is discharged from the heat exchanger **215** and fed into heat exchanger **216** in the condenser section **202**. Consequently, high temperature water **244** is discharged from the heat exchanger **216** after absorbing the heat from the refrigerant vapour **214** in the condenser section **202**, and fed into the cooling tower **250**.

The chilled water **248** produced in the evaporator section **206** is piped to a storage tank or directly to the end users for use in various applications, such as space cooling applications. For example, the chilled water **248** can flow to an air handling unit (a heat exchanger with a blower) of respective households to provide for space cooling application.

The system of the present invention also includes an incinerator unit **300**. The arrangement of the incinerator unit **300** is shown in Figure 3. In particular, the incinerator unit **300** uses Brown gas **120** generated by the Brown gas generator **116** as fuel. The incinerator unit **300** oxidises domestic and industrial waste on site of the system. The incinerator unit **300** operates on Brown gas **120**, which is obtained from the Brown gas storage tank **122**. The Brown gas **120** is piped from the storage tank **122** to a combustion chamber **312** and a re-oxidation chamber **314** by pipe network **302**. The pipe network **302** further comprises a pressure regulator **304**, a check valve 303 at the outlet of the Brown gas storage tank **122** and a multivalve **306** to split the flow of Brown gas **120** into the combustion chamber **312** and the re-oxidation chamber **314**. The pressure

regulator **304** controls and maintains a uniform outlet Brown gas **120** pressure in pipe network **302**. Each of the combustion chamber **312** and the re-oxidation chamber **314** is equipped with a Brown gas burner **313** and **315** respectively. The Brown gas burners **313** and **315** are standard industrial gas burners with means for gas ignition, means for flame shape and pattern control and means to detect a flame. The Brown gas burners **313** and **315** operate on Brown gas **120** and also have a motor driven blower, a gas supply solenoid valve and a gas nozzle. The burners **313** and **315** are configured to produce a flame at a temperature of up to 1500°C in the combustion chamber **312** and re-oxidation chamber **314**. There is also provided a flash arrestor **308** and **310** and control valve **305** and **307** at the inlet of each of the combustion chamber **312** and the re-oxidation chamber **314** respectively.

The incinerator unit **300** also comprises pre-treatment units **316** and **318**. Pre-treatment unit **316** is for the pre-treatment of solid waste, while pre-treatment unit **318** is for the pre-treatment of liquid waste. Pre-treatment unit **316** comprises a collection unit **320**, a sorter **322** and a dryer **324**. The collection unit **320** collects the solid waste, while the sorter **322** sorts the waste. The solid waste may be sorted physically through visual means by manual sorters to remove glass, grit, metal and other bulky items. Moisture content of the waste is reduced in the dryer **324**, where the waste is heated. The waste is heated by tubular bundles. The tubular bundles have steam passing through the tubes of bundle to heat the bundles, and therefore heating the waste. The waste from the dryer **324** is then fed into the combustion chamber **312**. Similarly, for the pre-treatment of liquid waste, there is provided in the pre-treatment unit **318** a collection unit **326** for collecting the liquid waste, a filter **328** to remove sludge from the liquid waste and an evaporator **330** to remove the water content from the sludge. The filter **328** may be any suitable filter. For example, the filter may be a fabric or membrane filter. Alternatively, filter presses or centrifugal filters may also be used. The pre-treatment process for liquid waste may include a

solid-water separation to filter out sludge from raw water. The sludge may be collected in an evaporator for dewatering. The filtered raw water may then be chemically treated before discharging to a drainage system. The treated waste is then fed into the combustion chamber **312**.

The combustion chamber **312** is heated up by the burning of the Brown gas **120** to reach a temperature of up to 1500°C, which is above the flash point of most solid waste. Once the combustion chamber **312** attains a temperature of about 1000°C from the burning of waste and Brown gas **120**, the Brown gas burner **313** ceases operation. The Brown gas burner **313** only re-ignites when the temperature of the combustion chamber **312** drops to below 1000°C. The combustion chamber **312** may also have a heat exchanger **338** within itself. The heat exchanger **338** may maximise heat recovery. For example, circulating water contained in the tube bundle of the heat exchanger **338** absorbs the heat of combustion from the combustion chamber **312** and releases the heat at the waste dryer **324**, where the heat may be used in removing the moisture from the solid waste. A circulatory system is also included in the incinerator unit **300** to provide feed water to the heat exchangers in the incinerator unit **300**. The circulatory system comprises multivalves **348**, **350**, **352**, a steam settling tank **344**, a pump **346** and piping network **342**.

Flue gas **332** which is produced as a result of the burning of the waste in the combustion chamber **312** is fed into a re-oxidation chamber **314** to completely decompose any waste remaining in the flue gas **332** by further oxidising the organic material and other harmful materials.

The re-oxidation chamber **314** is maintained at temperatures of 1000°C or above by the combustion of flue gas **332** and supplementary burning of Brown gas **120** by burner **315**. The re-oxidation chamber **314** is equipped with a means to be supplied fresh air for oxygen enriched burning of the flue gas **332**. The re-oxidation chamber is heated up by the burner **315** to reach a

temperature of about 1000°C, which is the auto-ignition temperature of flue gas constituents such as carbon monoxide (CO), hydrogen (H_2) and methane (CH_3). Once the re-oxidation chamber **314** attains a temperature of about 1000°C from the burning of the flue gas **332** and supplementary burning of Brown gas **120**, the burner **315** stops operating. The burner **315** starts burning Brown gas **120** when the temperature of the re-oxidation chamber **314** drops to below 1000°C. The re-oxidation chamber **314** is further equipped with a mesh-grid block **311** supported on a metal frame within the re-oxidation chamber **314**. The highly permeable perforated mesh-grid block **311** may be made of platinum, steel, nickel-chromium alloy or other nickel alloys. The cell of the mesh-grid block **311** can be of any suitable shape such as square, triangle or polygonal shape. The mesh-grid block **311** may be constructed as an interlaced, multi-layer structure to maximise contact with the incoming flue gas **332**, and its exposure to Brown gas flame produced by the burner **315**.

The orientation of the direction of flow of the flue gas **332** and the Brown gas flame produced by the burner **315** in relation to the mesh-grid block **311** is such that they are perpendicular to each other or parallel to one another. The mesh-grid block **311** is positioned such that it is in line with the Brown gas flame produced by the burner **315**. The flue gas **332** from the combustion chamber **312** is channelled to pass through the mesh-grid block **311**. Upon direct exposure to the Brown gas flame produced by the burner **315**, the mesh-grid block **311** glows and attains a temperature capable of reacting with the incoming flue gas **332**. In this process, the flue gas constituents such as carbon monoxide (CO), hydrogen (H_2) and other gaseous hydrocarbon compounds are oxidised into forms which are less harmful to the environment, such as carbon dioxide (CO_2), water and other less harmful gases.

The resulting flue gas **335** from the re-oxidation chamber **314** is passed through a chamber **334** comprising a wet scrubber **336** before it is discharged into the atmosphere as exhaust gas **340**. The wet scrubber **336** treats the resulting flue

gas **335** to remove sub-micron or larger fly ash. The wet scrubber **336** may have a series of high volume, water spraying nozzles to provide rapid quenching of the flue gas **335** to a temperature of about 200°C to 300°C before it is released as exhaust gas **340** to prohibit the re-formation of dioxins and furans in the atmosphere. Feed water to the wet scrubber **336** is obtained from the water supply **102**. The exhaust gas **340** released from the chamber **334** may be connected to an air filer system.

Figure 4 shows an example of the arrangement of the various units of the system as described above. In particular, Figure 4 shows how the units, such as the Brown gas generator **116**, the boiler and burner unit **146**, the absorptive chiller **200** and the incinerator unit **300** can be used in an isolated system for producing Brown gas, storing the Brown gas and delivering the Brown gas for various applications in a multi-storey building.

Figure 5 shows a general isolated system of one embodiment of the present invention. In particular, Figure 5 shows the generation of Brown gas and the use of Brown gas in a combustion chamber in an isolated system. Brown gas is generated in a Brown gas generation system **1113**, wherein the Brown gas generation system **1113** comprises a Brown gas generator **1114**, a heat exchanger **1116** and a Brown gas storage tank **1122**. In particular, Brown gas is generated in the Brown gas generator **1114**, one form being described in US Patent No. 4,081,656. The generator **1114** may include an electrolysis chamber. An electricity supply **1104** is connected to a control panel **1106** which monitors and controls the operating parameters such as electricity supply to the generator **1114** via power lines **1112**. There is also provided a water supply **1102**. The water supply **1102** may be in the form of a water storage tank. Water from the water supply **1102** is passed through a reverse osmosis (RO) water filter **1108** by means of a pump **1110** and the filtered RO water is fed into the electrolysis chamber of the generator **1114**.

Consequently, the generator **1114** takes in the RO water and electricity to dissociate oxygen and hydrogen gases in an electrolysis process. The mixture of the generated oxygen and hydrogen gases are piped to a Brown gas storage tank **1122** via pipe **1121**. The Brown gas generation system **1113** further comprises a heat exchanger **1116**. The immediate by-product of the electrolysis process is heat from the dissociation of water into its constituents. The heat exchanger **1116** is water cooled. Cool water is circulated to the heat exchanger **1116** from a cooling tower **1118** through pipe **1117**. Subsequently, warm water is piped out of the heat exchanger **1116** by pipe **1119** and returned to the cooling tower **1118**.

The Brown gas storage tank **1122** is partially filled with a liquefied hydrocarbon. In this case, the liquefied hydrocarbon is hexane **1124**. There is also provided a hexane storage tank **1126**. Hexane **1124** from the hexane storage tank **1126** is pumped into the Brown gas storage tank **1122** by means of a pump (not shown). The mixture of oxygen and hydrogen gases mix with the hexane vapour to form Brown gas **1120**. The Brown gas storage tank **1122** is further equipped with a relief valve **1128**. A relief valve is a valve that is set to open at a certain pressure level to prevent the pressure in a container or system from reaching unsafe levels.

The Brown gas **1120** from the Brown gas storage tank **1122** may be supplied directly to a combustion chamber **1142** via a piping network **1130**. The pipes of piping network **1130** may be equipped with at least one check valve **1132** to ensure that the flow of the Brown gas **1120** proceeds in one direction only. The piping network **1130** further comprises at least one pressure regulator **1134**, at least one control valve **1136** and at least one flash arrestor **1138**. A pressure regulator is a device used for controlling and maintaining a uniform outlet gas pressure to a piping, while a flash arrestor is a device which prevents "flashback" from an external fire through an open safety faucet.

In particular, the Brown gas **1120** is supplied to at least one burner **1140** of combustion chamber **1142** by piping network **1130**. Burner **1140** is a standard industrial gas burner with means for gas ignition, means for flame shape and pattern control and means to detect flame. Burner **1140** operates on Brown gas **1120** and has a motor driven blower, gas supply solenoid valve and gas nozzle. Burner **1140** is configured to produce a flame at a temperature of more than 1200°C. Burner **1140** may be located at the side of combustion chamber **1142** and projects a flame into combustion chamber **1142**. When waste is burnt in combustion chamber **1142**, flue gas is produced. The heat from the flue gas may be utilised for generating electricity, as will be described in detail below.

Figure 6 shows the arrangement of the system of the present invention in which the heat from the flue gas produced by combustion chamber **1142** is utilised in various further applications. The combustion chamber shown in Figure 6 comprises a single-stage combustion unit **1142a**. The combustion unit **1142a** uses Brown gas **1120** generated by the Brown gas generation system **1113** as fuel to burn combustion material. The combustion material may be waste, which may include domestic and industrial waste. The Brown gas **1120** from the Brown gas generation system **1113** is piped to combustion unit **1142a** by piping network **1130** as described in Figure 5 above. Pressure regulator **1134** controls and maintains a uniform outlet Brown gas pressure suitable for combustion unit **1142a** in piping network **1130**. For example, the gas pressure may be about 11 inches of water (i.e. about 2738 Pa).

The inner wall of combustion unit **1142a** is lined with a refractory material to contain the heat of combustion within the combustion unit **1142a** and to protect the structure of the combustion unit **1142a**. For example, the refractory material may include hard, heat resistant materials capable of working in an acidic environment. Examples of refractory material include, but are not limited to, alumina, silicon carbide, fire clay, bricks and silica. Intermittent jets of compressed air are supplied to combustion unit **1142a** through perforations at

the side or the base of combustion unit **1142a**. The compressed air serves to enhance turbulence mixing of waste that is to be burnt in the combustion unit **1142a** with air. The intermittent jets of compressed air help to prevent choking of the perforations supplying compressed air to the combustion unit **1142a**. A grating (not shown) at the base of combustion unit **1142a** separates dry solid waste from ashes. Bottom ash **1201** from the combustion of the waste in the combustion unit **1142a** is collected through a hopper (not shown) at the base of the combustion unit **1142a** for disposal.

Flue gas **1202** is produced as a result of the burning of the waste in the combustion unit **1142a**. Some of the flue gas **1202** is ducted from the combustion unit **1142a** to a water tube steam boiler **1204**. Water is pumped into the steam boiler **1204** by a pump **1212**. In the steam boiler **1204**, the water circulates in tubes **1206** which are heated externally by the flue gas **1202** ducted to the steam boiler **1204** from the combustion unit **1142a**. For example, the flue gas may be at 900 °C. As the water-filled tubes **1206** comprised in the steam boiler **1204** are exposed to the high temperature flue gas **1202**, the temperature of the water in the tubes **1206** rises, and due to thermosiphon effect, hot water rises to steam drum **1208** in steam boiler **1204**. Further heating of hot water in steam drum **1208** by flue gas **1202** produces steam **1214**. Steam **1214** is drawn off the top of steam drum **1208** and optionally further heated in a superheater (not shown) to produce superheated steam. Flue gas **1202** is then ducted to a post-treatment unit **1230** via channel **1228a** for treating flue gas **1202** before it is discharged into the atmosphere as exhaust gas **1236**. Post-treatment unit **1230** is described in more detail below.

Steam **1214** or superheated steam is then used to drive steam turbine **1216**. For example, the superheated steam may be at 390°C or higher. Steam turbine **1216** may be a single-stage or multiple stage steam turbine. Steam turbine **1216** is connected to a generator **1220** for generating electricity by shaft **1218**. Steam **1214** is fed under high pressure of about 23 bar (2.3×10^6 Pa) to the

steam turbine **1216**. Steam turbine **1216** spins, causing shaft **1218** to spin as well. As a result of the spinning of shaft **1218**, a magnet comprised in generator **1220** is also turned. The magnet has wires coiled around it. As the magnet inside generator **1220** turns, an electric current is produced in the wires. Generator **1220** converts the mechanical energy into electrical energy. The electricity generated by generator **1220** is then transmitted to a series of electrical devices for adjusting the voltage and current for use by the Brown gas generation system **1113** to generate Brown gas **1120**, or to an electricity grid located within the system which is the electricity supply **1104** for the system.

Steam **1214** or superheated steam passing through steam turbine **1216** is then channelled to a heat exchanger **1222**. Steam **1214** is cooled in heat exchanger **1222** to condensate into water. The condensed water is then pumped back into tubes **1206** of steam boiler **1204** by pump **1212** for absorbing heat from flue gas **1202** for the production of steam **1214**. Feed water flowing into heat exchanger **1222** for cooling the steam **1214** or superheated steam from steam turbine **1216** is obtained from water supply **1102** by pipe network **1224**. Heat exchanger **1222** also cools excess superheated steam or excess steam **1214**. Steam **1214** is considered excess when steam turbine **1216** has reached its maximum capacity and is unable to take in any more steam **1214** or superheated steam. When this happens, the excess steam **1214** or excess superheated steam is channelled to heat exchanger **1222** via bypass pipe **1226**. As described above, the excess steam **1214** and excess superheated steam is cooled and condensed into water in heat exchanger **1222**. The water is then pumped back into tubes **1206** of steam boiler **1204** by pump **1212** for absorbing heat from flue gas **1202** for the production of steam **1214**.

The combustion chamber **1142** also comprises a pre-treatment unit **1242**. In particular, pre-treatment unit **1242** is for the pre-treatment of solid waste. Pre-treatment unit **1242** comprises a dryer to reduce the moisture content of the waste before it is fed into the combustion unit **1142a** for burning. The waste is

heated by tubular bundles **1243** found within the dryer. Tubular bundles **1243** have flue gas **1202** passing through the tubes of the bundles which externally heat the waste. In particular, the tubes of the tubular bundles **1243** are highly conductive. Some flue gas **1202** from combustion unit **1142a** is ducted to tubular bundles **1243** via channel **1229**. Flue gas **1202** from steam boiler **1204** is also ducted to tubular bundles **1243** via channel **1228b**. Flue gas **1202** passing through the tubular bundles **1243** is then ducted into post-treatment unit **1230** via channel **1244** for treating flue gas **1202** before it is discharged into the atmosphere as exhaust gas **1236**. Post-treatment unit **1230** is described in more detail below.

Flue gas **1202** from steam boiler **1204** and pre-treatment unit **1242** is ducted into post-treatment unit **1230** via channels **1228a** and **1244** respectively. Post-treatment unit **1230** comprises wet scrubber **1232** and quencher **1234**. Flue gas **1202** from steam boiler **1204** and pre-treatment unit **1242** is washed down in wet scrubber **1232**. Wet scrubber **1232** may be a chemical wet scrubber. For example, the chemical used in the chemical wet scrubber may be aqueous slurry formed from calcium hydroxide or sodium hydroxide. Wet scrubber **1232** may be an enclosure with multiple interconnected chambers. Each chamber may be formed by perforated plates to slow down the passage of flue gas **1202** passing though wet scrubber **1232**. Wet scrubber **1232** treats flue gas **1202** to remove sub-micron or larger fly ash, dust and particulates. Wet scrubber **1232** may have a series of high pressure, fluid spraying nozzles. For example, the fluid may be an alkaline solution such as sodium hydroxide or calcium hydroxide. The alkaline solution neutralises flue gas **1202** which may be acidic. The alkaline solution also washes away fly ash and large particulates in flue gas **1202**.

After flue gas **1202** passes through wet scrubber **1232**, the semi-treated flue gas **1202** is then washed down in quencher **1234** for rapid quenching. Quencher **1234** has a series of high volume, water spraying nozzles to provide

the rapid quenching of flue gas **1202** to a temperature of about 200°C to 300°C before flue gas **1202** is released as exhaust gas **1236** to prohibit the re-formation of dioxins and furans in the atmosphere. Quenching also reduces the odour of the semi-treated flue gas **1202**. Feed water to quencher **1234** is obtained from water supply **1102**. The water from water supply **1102** is pumped to quencher **1234** by pump **1239** via pipe network **1238**. Fluid containing fly ash and large particulates collected at the base of post-treatment unit **1230** may pass though a filter system before being recycled back to the spraying nozzle of wet scrubber **1232** via pump **1233**. At regular intervals, the fluid at the base of post-treatment unit **1230** may be discharged to treatment unit **1240** where it is chemically treated. The chemically treated fluid may be recycled back into wet scrubber **1232** or be discharged to a drainage system.

Optionally, exhaust gas **1236** released from quencher **1234** may be connected to an air filter system for further treatment before being discharged to the atmosphere. Exhaust gas **1236** may also comprise saturated water vapour. Therefore, an evaporator may be installed at the gas outlet of quencher **1234** to remove the saturated vapour in exhaust gas **1236** so as to prevent the formation of plume in the atmosphere. As a further option, the treated flue gas **1202** may also be passed through a gas filtration system before being discharged into the atmosphere to remove submicron sized particles.

A further arrangement of the system of the present invention in which the heat from the flue gas produced by the combustion chamber **1142** is utilised in various further applications is shown in Figure 7. The system of Figure 6 and that of Figure 7 is essentially the same, with the exception of the combustion chamber **1142**. The combustion chamber **1142** shown in Figure 7 comprises a two-stage combustion chamber. In particular, the combustion chamber **1142** of Figure 7 comprises combustion unit **1142a** and re-oxidation chamber **1302**. Re-oxidation chamber **1302** may be a thermal re-oxidation chamber. As with combustion unit **1142a**, re-oxidation chamber **1302** also uses Brown gas **1120**

generated by the Brown gas generation system **1113** as fuel. Accordingly, Brown gas **1120** is piped from the Brown gas generation system **1113** to the re-oxidation chamber **1302** by pipe network **1130**. Pipe network **1130** may comprise a multivalve **1303** to split the flow of Brown gas **1120** into the combustion unit **1142a** and re-oxidation chamber **1302**. Pipe network **1130** further comprises check valve **1304**, pressure regulator **1306**, control valve **1308** and flash arrestor **1310**. Pressure regulator **1306** controls and maintains a uniform Brown gas pressure in pipe network **1130**.

Re-oxidation chamber **1302** is equipped with a Brown gas burner **1312**. Brown gas burner **1312** is a standard industrial gas burner with means for gas ignition, means for flame shape and pattern control and means to detect a flame. Brown gas burner **1312** operates on Brown gas **1120** and also has a motor driven blower, a gas supply solenoid valve and a gas nozzle. Brown gas burner **1312** may be configured to produce a flame at a temperature of more than 1200°C in the re-oxidation chamber **1302**. In particular, the re-oxidation chamber **1302** is maintained at a temperature of about 1000°C, which is the reduction reaction temperature of flue gas constituents such as carbon monoxide (CO), hydrogen (H_2) and methane (CH_4).

At the start up of the incineration (burning) process, the Brown gas burners **1140** and **1312** of the combustion unit **1142a** and re-oxidation chamber **1302** respectively fire Brown gas **1120** to heat up the furnace space within the combustion unit **1142a** and re-oxidation chamber **1302**. The flow rate and duration of firing of the Brown gas **1120** are controlled to attain a preset temperature in the combustion unit **1142a**. Typically, in the absence of waste, the combustion unit **1142a** can attain a temperature of more than 1000°C. During the incineration process, dry waste is constantly fed to the combustion unit **1142a** to be burnt. At steady state, with the constant supply of waste, the combustion unit **1142a** can reach temperatures of more than 1200°C. In the burning process, flue gases rich in carbon monoxide, gaseous hydrocarbon

compounds and oxides of nitrogen (NO_x) are produced. The flue gas **1202** generated is carried to the re-oxidation chamber **1302** for further treatment. The re-oxidation chamber **1302** may be of an elongated structure to allow for a minimum of two seconds of dwelling time for the complete combustion of flue gas **1202**. Alternatively, the re-oxidation chamber **1302** may be made of two or more interconnected small furnaces of similar or different construction for a more complete treatment of the flue gas **1202** by increasing the exposure time of the flue gas **1202** to treatment.

The re-oxidation chamber **1302** is equipped with a mesh-grid block **1313** supported on a metal frame within re-oxidation chamber **1302**. The highly permeable perforated mesh-grid block **1313** may be made of platinum, steel, nickel-chromium alloy or nickel alloys. The mesh-grid block **1313** reacts positively with the Brown gas flame produced by Brown gas burner **1312** to attain a high temperature within the re-oxidation chamber **1302**. The cell of the mesh-grid block **1313** can be of any suitable shape such as square, triangle or polygonal shape. In particular, the mesh-grid block **1313** can be constructed as an interlaced, multi-layer structure to maximize contact with the incoming flue gas **1202**, and its exposure to Brown gas flame produced by Brown gas burner **1312**.

The orientation of the direction of flue gas flow and the Brown gas flame produced by the Brown gas burner **1312** with regards to the mesh-grid block **1313** is such that they are perpendicular to each other or parallel to one another. The mesh-grid block **1313** is positioned such that it is in line with the Brown gas flame produced by the Brown gas burner **1312**. The flue gas **1202** from the combustion unit **1142a** is channelled to pass through the mesh-grid block **1313**. Upon direct exposure to the Brown gas flame produced by the Brown gas burner **1312**, the mesh-grid block **1313** glows and attains a temperature capable of reacting with the incoming flue gas **1202**. In the process, flue gas constituents such as CO, H_2 and other gaseous hydrocarbon

compounds are oxidised into forms which are less harmful to the environment, such as carbon dioxide (CO_2), water and other less harmful gases. In particular, the nitrogen-containing flue gas **1202** reduces into elemental constituents of nitrogen and oxygen before the oxygen further reacts with the hydrogen in the Brown gas **1120**, thereby producing nitrogen and water vapour.

As described in Figure 6 above, a portion of flue gas **1314** from the re-oxidation chamber **1302** is ducted to steam boiler **1204** for the production of steam (or superheated steam) for driving steam turbine **1216** and generator **1220** to generate electricity. A portion of flue gas **1314** from re-oxidation chamber **1302** is also ducted to tubular bundles **1243** via channel **1315** for drying the waste in pre-treatment unit **1242**.

Throughout the incineration process, both the combustion unit **1142a** and the re-oxidation chamber **1302** are maintained at a negative pressure to ensure a correct draught is created for the flow of flue gas **1202** from the combustion unit **1142a** and re-oxidation chamber **1302** to steam boiler **1204** and pre-treatment unit **1242**. For example, the pressure may be about -50 Pa. The negative pressure in the combustion unit **1142a** and re-oxidation chamber **1302** may be achieved via a suction fan installed either at the flue gas discharge end of combustion unit **1142a** (in the case of the system shown in Figure 6), at the flue gas discharge end of re-oxidation chamber **1302** (in the case of the system shown in Figure 7), or at the exhaust end of the post-treatment unit **1230**.

Figure 8 shows a general assembly of one embodiment of the present invention. In particular, Figure 8 shows the treatment of flue gas emitted from a flue gas emitter before the flue gas is released into the atmosphere. Flue gas **2103** from flue gas emitter **2102** is ducted into first processing chamber **2104**. Flue gas emitter **2102** may be any system which emits flue gas. For example, flue gas emitter **2102** may be an incineration unit, a coal fired kiln and the like. Flue gas **2103** may be rich in carbon monoxide, gaseous hydrocarbon

compounds and oxides of nitrogen (NO_x). Flue gas **2103** typically has a temperature of about 300°C or more. In first processing chamber **2104**, flue gas **2103** is further heated. For example, flue gas **2103** is further heated to about 800°C in first processing chamber **2104**. The heated flue gas **2103** is then ducted into second processing chamber **2106** for further heating. For example, flue gas **2103** may be heated to a temperature of about 1000°C in second processing chamber **2106**. The heated flue gas **2103** from second processing chamber **2106** is ducted into third processing chamber **2108** to be heated to a temperature of greater than 1200°C. In particular, the temperature in third processing chamber **2108** is about 1600°C.

Flue gas **2103** is heated in first processing chamber **2104**, second processing chamber **2106** and third processing chamber **2108** by combusting Brown gas. Brown gas may be generated in a Brown gas generator, one form being described in US Patent No. 4,081,656. Brown gas may be supplied directly to processing chambers **2104**, **2106** and **2108** from a Brown gas storage tank **2110** by pipe network **2112**. Brown gas storage tank **2110** may be equipped with a relief valve **2111**. A relief valve is a valve that is set to open at a certain pressure level to prevent the pressure in a container or system from reaching unsafe levels. Pipe network **2112** may be equipped with at least one check valve **2114**. Pipe network **2112** may further comprise multivalve **2116** to split the flow of Brown gas to each processing chamber **2104**, **2106** and **2108**. For example, the flow of Brown gas may be split such that Brown gas is supplied to first processing chamber **2104**, second processing chamber **2106** and third processing chamber **2108** by pipe networks **2118**, **2120** and **2122** respectively. Each pipe network **2118**, **2120**, **2122** may comprise at least one pressure regulator **2124**, **2132**, **2140**, at least one control valve **2126**, **2134**, **2142** and at least one flash arrestor **2128**, **2136**, **2144**, respectively. A pressure regulator is a device used for controlling and maintaining a uniform outlet gas pressure to a piping, while a flash arrestor is a device which prevents "flashback" from an

external fire through an open safety faucet. Pressure regulators **2124**, **2132** and **2140** control and maintain a uniform outlet Brown gas pressure suitable for processing chambers **2104**, **2106** and **2108** in pipe networks **118**, **2120** and **2122** respectively. For example, the gas pressure may be about 11 inches of water (i.e. about 2738 Pa).

In particular, Brown gas is supplied to burners **2130**, **2138** and **2146** of first processing chamber **2104**, second processing chamber **2106** and third processing chamber **2108** respectively. Burners **2130**, **2138** and **2146** may be standard industrial burners with means for gas ignition, means for flame shape and pattern control and means to detect flame. Burners **2130**, **2138** and **2146** operate on Brown gas and have a motor driven blower, gas supply solenoid valve and gas nozzle. Burners **2130**, **2138** and **2146** are configured to produce a flame at a temperature of more than 1200°C. Burners **2130**, **2138** and **2146** may be located so as to project a flame into processing chambers **2104**, **2106** and **2108** respectively.

Brown gas burners **2130**, **2138** and **2146** are configured to produce a flame at a temperature of about 800°C, 1000°C and 1200°C in first processing chamber **2104**, second processing chamber **2106** and third processing chamber **2108** respectively. In particular, the auto-ignition temperature of flue gas constituents such as carbon monoxide (CO), hydrogen (H_2) and methane (CH_4) is between about 800°C and 1600°C. Once the desired temperature is attained in processing chambers **2104**, **2106** and **2108** from the burning of flue gas **2103** and supplementary burning of Brown gas, Brown gas burners **2130**, **2138** and **2146** stop operating. Brown gas burners **2130**, **2138** and **2146** start burning Brown gas when the temperature of first processing chamber **2104**, second processing chamber **2106** and third processing chamber **2108** drop below 800°C, 1000°C and 1200°C respectively. At the start-up of the treatment process, Brown gas burners **2130**, **2138** and **2146** fire Brown gas to heat up the furnace space within first processing chamber **2104**, second processing

chamber **2106** and third processing chamber **2108** respectively. The flow rate and duration of firing of Brown gas are controlled to attain a preset temperature in each of processing chambers **2104**, **2106** and **2108**.

First processing chamber **2104**, second processing chamber **2106** and third processing chamber **2108** may be of an elongated structure to allow for a minimum of two seconds of dwelling time for the complete combustion of flue gas **2103**. Alternatively, each first processing chamber **2104**, second processing chamber **2106** and third processing chamber **2108** may be made of two or more interconnected small furnaces of similar or different construction for a more complete treatment of flue gas **2103** by increasing exposure time of flue gas **2103** to treatment. At least one of first processing chamber **2104**, second processing chamber **2106** and third processing chamber **2108** may be further equipped with a mesh-grid block (not shown).

The mesh-grid block may be supported on a metal frame within the at least one first processing chamber **2104**, second processing chamber **2106** and third processing chamber **2108**. The highly permeable perforated mesh-grid block may be made of platinum, steel, nickel-chromium alloy, nickel alloy, or a combination thereof. The mesh-grid block reacts positively with the Brown gas flame produced by Brown gas burners **2130**, **2138** and **2146** to attain a high temperature within first processing chamber **2104**, second processing chamber **2106** and third processing chamber **2108**. The cell of the mesh-grid block may be of any suitable shape and size. For example, the shape of the cell of the mesh-grid block may be square, triangle or polygonal. In particular, the mesh-grid block can be constructed as an interlaced, multi-layer structure to maximise contact with incoming flue gas **2103**, and its exposure to the Brown gas flame produced by Brown gas burners **2130**, **2138** and **2146**.

The orientation of the direction of flue gas flow and the Brown gas flame produced by the Brown gas burners **2130**, **2138** and **2146** with regards to the

mesh-grid block is such that they are perpendicular to each other or parallel to one another. The mesh-grid block is positioned such that it is in line with the Brown gas flame produced by the Brown gas burners **2130**, **2138** and **2146**. The flue gas **2103** from the flue gas emitter **2102**, first processing chamber **2104** or second processing chamber **2106** is channelled to pass through the mesh-grid block in first processing chamber **2104**, second processing chamber **2106** or third processing chamber **2108** respectively. Upon direct exposure to the Brown gas flame produced by the Brown gas burners **2130**, **2138** and **2146**, the mesh-grid block glows and attains a temperature capable of reacting with the incoming flue gas **2103**. In the process, flue gas constituents such as CO, H_2 and other gaseous hydrocarbon compounds are oxidised into forms which are less harmful to the environment, such as carbon dioxide (CO_2), water and other less harmful gases. In particular, the nitrogen-containing flue gas **2103** dissociates into elemental constituents before reacting with the hydrogen in the Brown gas, thereby producing nitrogen.

Some of the heated flue gas **2103** from each first processing chamber **2104**, second processing chamber **2106** and third processing chamber **2108** may be ducted into a post-treatment unit. The post-treatment unit may be a scrubbing assembly **2176** which will be described in more detail below. Alternatively, some of the heated flue gas from the processing chambers, in particular, third processing chamber **2108**, is ducted to a water tube steam boiler **2148**. Water is pumped into steam boiler **2148** by pump **2170**. In steam boiler **2148**, water circulates in tubes **2150**, which are heated externally by the heated flue gas **2103** ducted to steam boiler **2148** from third processing chamber **2108**. As the water-filled tubes **2150** comprised in steam boiler **2148** are exposed to the high temperature flue gas **2103**, the temperature of the water in the tubes **2150** rises, producing steam **2154** which then rises to steam drum **2152** in steam boiler **2148**. Steam **2154** is drawn off the top of steam drum **2152** and optionally further heated in a superheater (not shown) to produce superheated steam.

Flue gas **2103** is then ducted to a post-treatment unit for treating flue gas **2103** before it is discharged into the atmosphere as exhaust gas **2194**. The post-treatment unit may be scrubbing assembly **2176**, which will be described in more detail below.

Steam **2154** or superheated steam is then used to drive steam turbine **2156**. For example, the superheated steam may be at 250°C or higher. Steam turbine **2156** may be a single-stage or multiple stage steam turbine. Steam turbine **2156** is connected to a generator **2158** for generating electricity by a shaft **2160**. Steam **154** is fed under high pressure to steam turbine **2156**. Steam turbine **2156** spins, causing shaft **2160** to spin as well. As a result of the spinning of shaft **2160**, a magnet comprised in generator **2158** is also turned. The magnet has wires coiled around it. As the magnet insider generator **2158** turns, an electric current is produced in the wires. Generator **2158** converts the mechanical energy into electrical energy. The electricity generated by generator **2158** is then transmitted to an electricity grid **2168**.

Steam **2154** or superheated steam passing through steam turbine **2156** is then channelled to heat exchanger **2166**. Steam **2154** is cooled in heat exchanger **2166** to condensate into water. The condensed water is then pumped back into tubes **2150** of steam boiler **2148** by pump **2170** for absorbing heat from flue gas **2103** for the production of steam **2154**. Feed water flowing into heat exchanger **2166** for cooling the superheated steam from steam turbine **2156** is obtained from water supply **2172** by pipe network **2174**. Heat exchanger **2166** also cools excess superheated steam or excess steam **2154**. Steam **2154** is considered excess when steam turbine **2156** has reached its maximum capacity and is unable to take in any more steam **2154** or superheated steam. When this happens, the excess steam **2154** or excess superheated steam is channelled to heat exchanger **2166** via bypass pipe **2162**. As described above, the excess steam **2154** and excess superheated steam is cooled and condensed into water in heat exchanger **2166**. The water is then pumped back into tubes **2150** of

steam boiler **2148** by pump **2170** for absorbing heat from flue gas **2103** for the production of steam **2154**.

Flue gas **2103** from steam boiler **2148**, first processing chamber **2104**, second processing chamber **2106** and/or third processing chamber **2108** is ducted into scrubbing assembly **2176**. Scrubbing assembly **2176** comprises wet scrubber **2178** and quencher **2188**. Flue gas **103** from steam boiler **2148**, first processing chamber **2104**, second processing chamber **2106** and/or third processing chamber **2108** is washed down in wet scrubber **2178**. Wet scrubber **2178** may be a chemical wet scrubber. Wet scrubber **2178** may be an enclosure with multiple interconnected chambers. Each chamber may be formed by perforated plates to slow down the passage of flue gas **2103** passing though wet scrubber **2178**. Wet scrubber **2178** treats flue gas **2103** to remove sub-micron or larger fly ash, dust and particulates. Wet scrubber **2178** may have a series of high pressure, fluid spraying nozzles **2180**. For example, the fluid may be an alkaline fluid such as sodium hydroxide or calcium hydroxide. The alkaline fluid neutralises flue gas **2103** which may be acidic. The alkaline fluid also washes away fly ash and large particulates in flue gas **2103**.

After flue gas **2103** passes through wet scrubber **2178**, the semi-treated flue gas **2103** is then washed down in quencher **2188** for rapid quenching. Quencher **2188** has a series of high volume, water spraying nozzles **2190** to provide the rapid quenching of flue gas **2103** to a temperature of about 200°C to 300°C before flue gas **2103** is released as exhaust gas **2194** into the atmosphere to prohibit the re-formation of dioxins and furans in the atmosphere. Quenching also reduces the odour of semi-treated flue gas **2103**. Feed water to quencher **2188** is obtained from water supply **2172**. The water from water supply **2172** is pumped to quencher **2188** by pump **2192** via pipe network **2196**. Fluid **2182** containing fly ash and large particulates collected at the base of scrubbing assembly **2176** may pass though a filter system before being recycled back to the spraying nozzle **2180** of wet scrubber **2178** via pump **2184**.

At regular intervals, the fluid **2182** at the base of scrubbing assembly **2176** may be discharged to treatment unit **2186** where it is chemically treated. The chemically treated fluid may be recycled back into wet scrubber **2178** or be discharged to a drainage system.

Optionally, exhaust gas **2194** released from scrubbing assembly **2176** may be connected to an air filter system for further treatment before being discharged to the atmosphere. Exhaust gas **2194** may also comprise saturated water vapour. Therefore, an evaporator may be installed at the gas outlet of scrubbing assembly **2176** to remove the saturated vapour in exhaust gas **2194** so as to prevent the formation of plume in the atmosphere. As a further option, the treated flue gas **2103** may also be passed through a gas filtration system before being discharged into the atmosphere to remove submicron sized particles.

Throughout the treatment process, the first processing chamber **2104**, second processing chamber **2106** and third processing chamber **2108** are maintained at a negative pressure to ensure a correct draught is created for the flow of flue gas **2103** from the processing chambers **2104**, **2106** and **2108** to steam boiler **2148** and scrubbing assembly **2176**. For example, the pressure may be about -50 Pa. The negative pressure in the first processing chamber **2104**, second processing chamber **2106** and third processing chamber **2108** may be achieved via a suction fan installed either at the flue gas discharge end of first processing chamber **2104**, second processing chamber **2106** and third processing chamber **2108**, or at the exhaust end of the scrubbing assembly **2176**.

Claims

1. A system for the generation, storage and use of Brown gas comprising:

   - at least one Brown gas generator, in communication with an electricity supply and water supply;

   - at least one first storage chamber, in fluid communication with the generator, for storing the Brown gas generated from said generator; and

   - Brown gas application means in communication with said at least one first storage chamber,

   wherein said generator and first storage chamber are located proximate the Brown gas application means.

2. The system according to claim 1, wherein the at least one first storage tank contains a pre-determined quantity of a liquefied hydrocarbon.

3. The system according to claim 2, wherein the liquefied hydrocarbon is selected from the group comprising: hexane, heptane, methanol and ethanol.

4. The system according to any one of the preceding claims, wherein the application means comprises at least one first chamber for producing hot water, wherein heat for heating said hot water is derived from combustion of Brown gas with the Brown gas obtained from the at least one first storage chamber.

5. The system according to claim 4, wherein the at least one first chamber is a boiler and burner unit.

6. The system according to claim 4 or claim 5, wherein the at least one first chamber comprises:

- a first inlet for receiving Brown gas from the at least one first storage chamber;
- a second inlet for receiving water;
- a gas burner; and
- an outlet for discharging the hot water produced,

wherein the Brown gas from the first inlet is burnt by the gas burner, thereby heating the water from the second inlet and wherein the heated water is discharged from the outlet.

7. The system according to claim 6, wherein the second inlet for receiving water is connected to an outlet of at least one heat exchanger contained within the at least one Brown gas generator.

8. The system according to claim 6 or claim 7, further comprising at least one flash arrester before the first inlet.

9. The system according to any one of claims 4 to 8, wherein the at least one first chamber comprises a reactive metal element.

10. The system according to claim 9, wherein the reactive metal element is chosen from the group comprising: platinum, steel, nickel-chromium alloy or high temperature nickel alloys.

11. The system according to any one of claims 4 to 10, further comprising at least one second storage chamber for storing the hot water.

12. The system according to claim 11, wherein the at least one second storage chamber is connected to the outlet of the at least one first chamber.

13. The system according to any one of the preceding claims, wherein the application means further comprises at least one second chamber for producing chilled water.

14. The system according to claim 13, wherein the at least one second chamber is an absorptive chiller unit.

15. The system according to claim 13 or claim 14, wherein the at least one second chamber comprises:

- a first inlet for receiving an absorbent;
- a second inlet for receiving a refrigerant;
- a third inlet for receiving cool water;
- a fourth inlet for receiving warm water;
- a first heat exchanger;
- a second heat exchanger;
- a first outlet for discharging warm water; and
- a second outlet for discharging chilled water produced,

wherein the third inlet and first outlet are connected to the first heat exchanger, and the fourth inlet and second outlet are connected to the second heat exchanger.

16. The system according to claim 15, wherein the absorbent is selected from the group comprising: lithium bromide (LiBr) and ammonia (NH_3)..

17. The system according to claim 15 or claim 16, wherein the refrigerant is water.

18. The system according to any one of claims 15 to 17, wherein the fourth inlet is connected to the at least one second storage chamber.

19. The system according to any one of claims 13 to 18, further comprising at least one third storage chamber for storing chilled water.

20. The system according to any one of the preceding claims, wherein the application means further comprises at least one third chamber for burning waste.

21. The system according to claim 20, wherein the at least one third chamber comprises:

- a combustion unit for burning waste by combusting Brown gas;
- a first inlet connected to the combustion unit for receiving waste;
- a second inlet connected to the combustion unit for receiving Brown gas from the at least one first storage chamber; and
- an outlet connected to the combustion unit for discharging flue gas produced from the combustion unit.

22. The system according to claim 21, further comprising at least one flash arrester before the first inlet.

23. The system according to claim 21 or claim 22, further comprising a heat exchanger connected to the outlet for discharging flue gas.

24. A boiler and burner unit for producing hot water, the boiler and burner unit comprising:

- a first inlet for receiving feed water;
- a second inlet for receiving Brown gas from a Brown gas generator; and
- an outlet for discharging hot water produced,

wherein the Brown gas is burnt to produce heat which heats the feed water to produce hot water.

25. The boiler and burner unit according to claim 24, wherein the outlet for discharging hot water produced is connected to a storage tank for storing the hot water produced.

26. The boiler and burner unit according to claim 25, wherein the first inlet is connected to: the outlet of a first heat exchanger of the Brown gas generator; the outlet of at least one solar thermal collector; and/or to the storage tank for storing the hot water produced.

27. A system for recovering heat generated by burning of combustion material comprising:

- at least one Brown gas generator, in communication with an electricity supply and water supply;
- at least one first storage chamber, in fluid communication with the generator, for storing the Brown gas generated from the generator;
- at least one combustion chamber, in communication with the at least one first storage chamber, for burning the combustion material; and

- at least one heat-extracting chamber adapted to receive heat produced by the combustion chamber from the burning of the combustion material,

wherein the generator and the first storage chamber are located proximate the combustion chamber and the heat-extracting chamber.

28. The system according to claim 27, wherein the at least one combustion chamber comprises:

- a combustion unit for burning combustion material by combusting Brown gas;
- a first inlet connected to the combustion unit for receiving combustion material;
- a second inlet connected to the combustion unit for receiving Brown gas from the at least one first storage chamber; and
- an outlet connected to the combustion unit for discharging flue gas produced by the combustion unit.

29. The system according to claim 27 or claim 28, wherein the combustion material is waste.

30. The system according to claim 28 or claim 29, wherein the at least one heat-extracting chamber is a boiler unit for producing steam, such that the heat for producing the steam is derived from the flue gas produced by the combustion unit.

31. The system according to any one of claims 28 to 30, wherein the at least one heat-extracting chamber comprises:

- a water inlet;

- a flue gas inlet for receiving flue gas produced from the combustion unit;
- a first outlet for discharging the steam produced, and
- a second outlet for discharging flue gas,

such that water from the water inlet is heated by flue gas from the flue gas inlet, thereby producing steam and wherein the steam is discharged from the first outlet and flue gas is discharged from the second outlet.

32. The system according to claim 31, wherein the flue gas inlet of the at least one heat-extracting chamber is connected to the outlet of the at least one combustion chamber.

33. The system according to any one of claims 27 to 32, further comprising means for generating electricity in communication with the at least one heat-extracting chamber.

34. The system according to claim 33, wherein the means for generating electricity comprises:

- at least one steam turbine adapted to receive steam produced by the at least one heat-extracting chamber;
- at least one generator, in communication with the at least one steam turbine, for generating electricity; and
- means for discharging the electricity generated from the generator.

35. The system according to claim 34, wherein the at least one steam turbine is a single-stage or multiple-stage steam turbine.

36. The system according to any one of claims 33 to 35, wherein the electricity generated is supplied to the at least one Brown gas generator and/or to an electricity grid.

37. The system according to any one of claims 34 to 36, further comprising a heat exchanger in communication with the at least one steam turbine and the at least one heat-extracting chamber.

38. The system according to claim 37, wherein the heat exchanger comprises:

- a steam inlet for receiving steam from the steam turbine; and
- a water outlet,

wherein the heat exchanger cools the steam received from the steam inlet, thereby condensing the steam to produce water and wherein the water is discharged from the water outlet.

39. The system according to claim 38, wherein the heat exchanger further comprises a second inlet adapted for receiving steam produced by the at least one heat-extacting chamber when the steam turbine has reached its maximum capacity.

40. The system according to claim 38 or claim 39, wherein the water outlet of the heat exchanger is connected to the water inlet of the at least one heat-extracting chamber.

41. The system according to any one of claims 27 to 40, wherein the at least one heat-extracting chamber comprises a dryer for drying combustion material before it is burnt in the combustion chamber.

42. The system according to claim 41, wherein the heat for drying the combustion material is derived from flue gas discharged from the combustion unit.

43. The system according to claim 41 or 42, wherein the dried combustion material from the dryer is burnt in the at least one combustion chamber.

44. A method of recovering heat generated by the burning of combustion material, the method comprising the steps of:

- burning combustion material in at least one combustion chamber by combusting Brown gas; and
- receiving flue gas produced by the combustion chamber for recovering heat therein.

45. The method according to claim 44, further comprising the step of: producing steam in a boiler, wherein the heat for producing the steam is derived from the flue gas produced by the combustion chamber.

46. The method according to claim 45, wherein the method further comprises the steps of:

- feeding the steam produced to at least one steam turbine; and
- providing a generator in communication with the at least one steam turbine for generating electricity.

47. The method according to claim 46, wherein the electricity generated is supplied to at least one Brown gas generator and/or to an electricity grid.

48. The method according to claim 46 or 47, wherein the at least one steam turbine is a single-stage or multiple-stage steam turbine.

49. The method according to claim 44, further comprising the step of drying combustion material before burning in the at least one combustion chamber such that the heat for drying the combustion material is derived from the flue gas produced by the combustion chamber.

50. The method according to claim 49, wherein the dried combustion material is burnt in at least one combustion chamber.

51. An assembly for treating flue gas before discharging into the atmosphere comprising:

- at least one processing chamber for receiving and heating flue gas;

- means for combusting Brown gas to supply heat for heating flue gas; and

- a portion for discharging heated flue gas.

52. The assembly according to claim 51, further comprising at least one member within the at least one processing chamber, wherein heating the flue gas in proximity to the at least one member achieves a greater heating efficiency of the flue gas.

53. The assembly according to claim 52, wherein the at least one member comprises a mesh-grid block, wherein the mesh-grid block is housed within the at least one processing chamber.

54. The assembly according to claim 53, wherein the mesh grid block is made of platinum, steel, nickel-chromium alloy, aluminium-chromium alloy or a combination thereof.

55. The assembly according to any one of claims 51 to 54, wherein the means for combusting Brown gas is a Brown gas burner

56. The assembly according to any one of claims 51 to 55, wherein the at least one processing chamber is heated to a temperature of greater than 500°C.

57. The assembly according to claim 56, wherein the at least one processing chamber is heated to a temperature of between 800°C and 1600°C.

58. The assembly according to any one of claims 51 to 57, wherein the assembly comprises three processing chambers, the three processing chambers arranged such that the flue gas passes through each of the three processing chambers sequentially.

59. The assembly according to any one of claims 51 to 58, further comprising a heat-extracting chamber adapted to receive the heated flue gas.

60. The assembly according to claim 59, wherein the heat-extracting chamber comprises a boiler unit for producing steam, such that the heat for producing the steam is derived from the heated flue gas.

61. The assembly according to claim 59 or claim 60, wherein the heat-extracting chamber comprises:

- a water inlet;

- a steam outlet; and

- a flue gas outlet,

the heat-extracting chamber arranged to permit the flue gas to heat the water to produce

62. The assembly according to any one of claims 51 to 61, further comprising means for generating electricity in communication with the heat-extracting chamber.

63. The assembly according to claim 62, wherein the means for generating electricity comprises:

- at least one steam turbine adapted to receive steam produced by the heat-extracting chamber;

- at least one generator, in communication with the at least one steam turbine, for generating electricity; and

- means for discharging the electricity generated from the generator.

64. The assembly according to claim 63, wherein the at least one steam turbine is a single-stage or multiple-stage steam turbine.

65. The assembly according to any one of claims 62 to 64, wherein the electricity generated is supplied to an electricity grid.

66. The assembly according to any one of claims 63 to 65, further comprising a heat exchanger in communication with the at least one steam turbine and the heat-extracting chamber.

67. The assembly according to claim 66, wherein the heat exchanger comprises:

- a first inlet for receiving steam from the steam turbine; and

- a water outlet,

wherein the heat exchanger is capable of condensing steam to produce water and wherein the water is discharged from the water outlet.

68. The assembly according to claim 67, wherein the heat exchanger further comprises a second inlet adapted to receive steam produced by the heat-extracting chamber when the steam turbine has reached its maximum capacity.

69. The assembly according to claim 67 or claim 68, wherein the water outlet of the heat exchanger is connected to the water inlet of the heat-extracting chamber.

70. The assembly according to any one of claims 51 to 69, further comprising a scrubbing assembly, the scrubbing assembly containing means for scrubbing flue gas and wherein the scrubbing assembly is adapted to receive flue gas from the portion for discharging heated flue gas and/or the flue gas outlet of the heat-extracting chamber.

71. The assembly according to claim 70, wherein the means for scrubbing flue gas is a scrubber

72. The assembly according to claim 71, wherein the scrubber is selected from the group comprising: wet scrubbers, venturi scrubbers, impingement plate scrubbers and spray tower scrubbers

73. The assembly according to any one of claims 70 to 72, wherein the scrubbing assembly further comprises means for cooling flue gas before discharging into the atmosphere.

74. The assembly according to claim 73, wherein the means for cooling flue gas is a quencher

75. The assembly according to claim 73 or claim 74, wherein the means for cooling flue gas cools flue gas to a temperature of less than 300°C.

76. A method for treating flue gas before being discharged into the atmosphere comprising the steps of:

- providing flue gas to the at least one processing chamber;

- providing Brown gas to a means for combusting Brown gas; and

- heating the flue gas to a pre-determined temperature by combusting the Brown gas.

77. The method according to claim 76, wherein the heating step comprises heating the flue gas in the presence of at least one member for achieving a higher heating efficiency.

78. The method according to claim 76 or claim 77, wherein the means for combusting Brown gas is a Brown gas burner.

79. The method according to any one of claims 76 to 78, wherein the pre-determined temperature is greater than 700°C.

80. The method according to any one of claims 76 to 79, wherein flue gas is provided to three processing chambers, the flue gas passing through each of the three processing chambers sequentially.

81. The method according to claim 80, further comprising the steps of:

- providing flue gas to a first processing chamber;

- heating the flue gas in the first processing chamber to a first pre-determined temperature by combusting Brown gas;

- ducting the heated flue gas from the first processing chamber to a second processing chamber;

- heating the flue gas in the second processing chamber to a second pre-determined temperature by combusting Brown gas;

- ducting the heated flue gas from the second processing chamber to a third processing chamber; and

- heating the flue gas in the third processing chamber to a third pre-determined chamber by combusting Brown gas.

82. The method according to claim 81, wherein the first pre-determined temperature is about 800°C.

83. The method according to claim 81 or claim 82, wherein the second pre-determined temperature is about 1000°C.

84. The method according to any one of claims 81 to 83, wherein the third pre-determined temperature is greater than 1200°C.

85. The method according to any one of claims 76 to 84, further comprising the step of producing steam in a heat-extracting chamber, wherein heat for producing the steam is derived from the heated flue gas.

86. The method according to claim 85, further comprising the steps of:

- feeding the steam produced to at least one steam turbine; and

- providing a generator in communication with the at least one steam turbine for generating electricity.

87. The method according to any one of claims 76 to 86, further comprising the steps of:

- scrubbing the heated flue gas in a means for scrubbing flue gas; and/or

- cooling the heated flue gas in a means for cooling flue gas.

88. The method according to claim 87, wherein the flue gas is cooled to a temperature of less than 300°C.