

(51) International Patent Classification:
F23G 5/44 (2006.01)(21) International Application Number:
PCT/GB2012/050409(22) International Filing Date:
23 February 2012 (23.02.2012)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
1103156.4 24 February 2011 (24.02.2011) GB(71) Applicant (for all designated States except US): **MAIN SYSTEMS TRANSITIONS LTD.** [GB/GB]; Beach Road, Newhaven Sussex BN9 0BX (GB).

(72) Inventors; and

(75) Inventors/Applicants (for US only): **BAILEY, John** [GB/GB]; c/o Main Systems Transitions Ltd., Beach Road, Newhaven Sussex BN9 0BX (GB). **MAINSTONE, Steven** [GB/GB]; c/o Main Systems Transitions Ltd., Beach Road, Newhaven Sussex BN9 0BX (GB).(74) Agent: **HANCOX, Jonathan**; 200 Aldersgate, London, Greater London EC1A 4HD (GB).

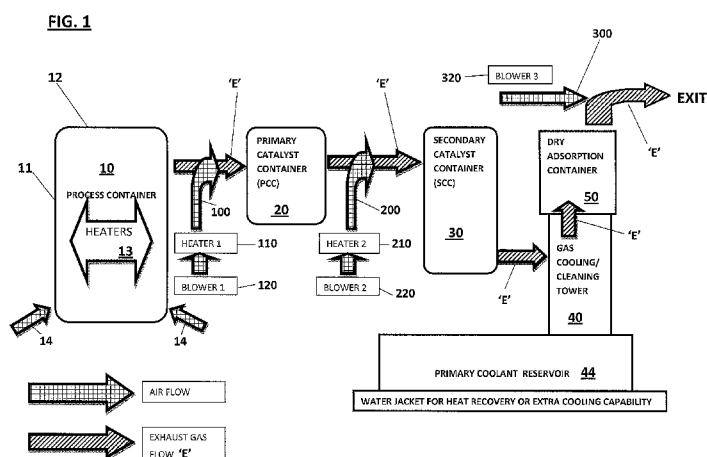
(81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:

— without international search report and to be republished upon receipt of that report (Rule 48.2(g))

(54) Title: APPARATUS AND METHOD FOR THE TREATMENT OF MATERIAL



(57) **Abstract:** Apparatus and method for the treatment of material are disclosed, for treating material such as waste material by the application of heat. A process container (10) includes heaters (13). Waste material is introduced into the process container (10) and is heated in the presence of little or no oxygen to a temperature sufficient to effect pyrolysis. Oxygen (14) is subsequently introduced into the process container (10) to effect (10) combustion of the waste material. An exhaust path E is provided for conveying exhaust gases from process container (10). An extracting gas flow is provided along an extracting path (300) which converges with the exhaust path E and assists in the extraction of exhaust gases from the chamber. The apparatus also has a primary catalyst (20) and a secondary catalyst (30). An input gas flow is provided along an inlet path (100,200) upstream of each catalyst, the inlet path (100,200) converging with the exhaust path E. The input gas flow can be used to heat and/or cool the catalyst, provide oxygen to the catalyst, and to control the flow of exhaust gas in exhaust path E.

Apparatus and Method for the Treatment of Material

The present invention relates to an apparatus and method for the treatment of material, such as waste material, and more specifically to an apparatus and method in
5 which the material is treated by the application of heat.

Processes for treating waste material by the application of heat exist in the art, usually for the purpose of decomposing, decontaminating or otherwise treating the waste so that it can be further processed, transported or disposed of. Processes may range from
10 a simple heat treatment, for example to remove water from the waste by causing the water to evaporate or boil off as steam, through to processes such as pyrolysis or combustion which involve a more significant decomposition of the waste.

The present invention is directed towards any process for thermally-treating material, such as waste material, in which the treatment is expected to result in gases of any sort
15 being given off. These exhaust gases may be harmless, e.g. water vapour, or potentially harmful, e.g. carbon monoxide, volatile organic compounds (VOCs), hydrocarbons, nitrogen oxides, toxic fumes, etc.

20 Pyrolysis is the decomposition of a substance by heat in the presence of little or no oxygen. If oxygen is then introduced, combustion will take place. The treatment of waste, such as sanitary waste, by sequential pyrolysis and then combustion has been suggested in the art as a way of conveniently processing such waste, avoiding the need for landfill sites and overcoming disadvantages with other waste processing systems
25 such as pure incineration and pure pyrolysis.

WO00/20801 in the name of Morgan Automation Ltd. discloses a sanitary waste disposal unit in which the waste is introduced into a chamber which is then evacuated to remove substantially all the oxygen. The chamber is then heated to approximately
30 300-500°C to sterilise the waste material (i.e. to effect pyrolysis), after which it is cooled to approximately 150°C and air introduced to allow combustion of the waste material to take place. The sanitary waste disposal unit has a pump which evacuates the chamber and draws off volatile gases during the pyrolysis phase and which continues to draw off combustion gases during the combustion phase.

WO2007/104954 in the name of Morgan Everett Ltd. discloses a waste treatment apparatus and method in which waste is introduced into a chamber which is then heated to a temperature of 400-700°C to effect pyrolysis of the waste. Oxygen is then introduced to effect combustion of the waste at a temperature of at least 400°C, after
5 which the chamber is flushed with water. The apparatus employs a compressor to supply air which is injected into the chamber to begin the combustion phase.

It is an object of the invention to provide an improved material treatment apparatus and method compared to prior art systems.

10

In accordance with a first aspect, the invention provides apparatus for treating waste or other material, comprising a chamber for containing material during treatment, means for heating the material in the chamber, an exhaust path leading from the chamber for conveying exhaust gases from the chamber, a catalyst material in the exhaust path, an
15 inlet path for conveying an input gas flow which converges with the exhaust path upstream of the catalyst material, the input gas flow being used to control the flow of exhaust gases from the chamber, and an extracting path for conveying an extracting gas flow which converges with the exhaust path downstream of the catalyst material, the extracting gas flow assisting in the extraction of exhaust gases from the chamber.

20

The chamber is provided with heating means. Any conventional heating means which achieves the desired process temperatures may be used. The heaters may be electric, gas or oil. Preferably, electric heaters are employed for ease of manufacture and convenient operation. Electric heating elements can be located in or directly adjacent
25 the walls of the chamber. Suitable insulation can be provided around the outside of the chamber to prevent heat loss and to direct the heat to the inside of the chamber.

Means for cooling the chamber may also be provided, to cool the whole or a part of the chamber, for example when a treatment cycle has completed. For example, the lid may
30 be cooled to a safe opening temperature to allow access to the chamber so that a new treatment cycle can be commenced. A conventional fluid (e.g. water) cooling system may be employed for this purpose.

In preferred embodiments, the apparatus is designed to pyrolyse and/or combust the
35 material. The means for heating the material in the chamber will therefore need to be able to heat the material to a temperature sufficient to effect pyrolysis and/or

combustion. The apparatus preferably also includes means for controlling the introduction of oxygen into the chamber to selectively effect pyrolysis or combustion of the material. Preferably, this comprises one or more valves which can be selectively opened to allow oxygen into the chamber and combustion to commence. The oxygen
5 may be in the form of a pressurised supply, e.g. at a pressure greater than atmospheric, so that the chamber is more quickly charged with oxygen. The oxygen may be supplied in the form of pure oxygen, or it can be supplied in combination with other gases. Preferably, the oxygen is supplied in the form of air.

10 The chamber or process container contains the material during treatment. In embodiments where the apparatus is designed to pyrolyse and/or combust the material, the chamber needs to be able to withstand the temperatures encountered during these processes. Preferably, the chamber is constructed from metal, and more preferably from steel or stainless steel. The chamber will typically be provided with a
15 lid or other means of opening to allow the material to be placed inside. The lid should make an effective seal with the rest of the chamber to ensure that no gases escape this way and to minimise heat loss. Preferably, a flexible seal is provided for this purpose. A wire or mesh basket may be used to contain the material while it is in the chamber, and if the basket is removable from the chamber, the material can be pre-loaded into
20 the basket to facilitate the chamber loading operation.

The treatment apparatus has an exhaust path leading from the chamber for conveying exhaust gases from the chamber. An exhaust path will be understood typically to mean the path taken by the exhaust gases between the chamber and their exit point from the
25 apparatus. The exit point is where the exhaust gases are no longer substantially constrained along a path, for example where the gases vent to the atmosphere or into a collection vessel. Preferably, the exhaust path includes one or more pipes for conveying the exhaust gases from the chamber.

30 The treatment apparatus is also provided with an extracting path for conveying an extracting gas flow. The extracting path converges with the exhaust path, downstream of the chamber. The extracting gas flow assists in the extraction of exhaust gases from the chamber. The extracting gas flow also serves to dilute the exhaust gases, which may be advantageous if certain emissions criteria need to be met, and may also cool the
35 exhaust gases.

The extraction effect is achieved through the extracting gas flow effectively pulling the exhaust gas flow along with it, by virtue of the creation of a lower pressure in the exhaust path at the point where the exhaust gas flow converges with the extracting gas flow.

5

In order to provide the extraction assistance, the extracting gas flow preferably has a higher velocity than the exhaust gas flow at the point of convergence. Alternatively or in addition, the extracting gas flow preferably has a higher flow rate than the exhaust gas flow at the point of convergence. In preferred embodiments, the ratio of the
10 extracting gas flow rate to the exhaust gas flow rate is between 20:1 and 100:1.

In order to provide the higher velocity and/or flow rate, and in order that the extracting gas can be introduced into the exhaust path, the extracting gas is supplied at a pressure greater than that of the exhaust gas at the point of convergence. If the exhaust gas is at
15 atmospheric pressure, for example, clearly the extracting gas will need to be supplied at a pressure greater than atmospheric. The extracting gas may be supplied from a pressurised source, such as a pressurised container or reservoir, or apparatus may be provided in the extracting path which serves to increase the pressure of the extracting gas compared to the exhaust gases. The apparatus preferably comprises means for
20 forcing the extracting gas flow into the exhaust path. This will typically be a fan or blower of any suitable type, which can be located in the extracting path upstream of the point of convergence of the two gas flows.

In a preferred embodiment, the velocity, flow rate and pressure of the extracting gas
25 flow at the point of convergence are all higher than those of the exhaust gas flow. In a more preferred embodiment, these properties are all sufficiently higher than those of the exhaust gas flow such that the extraction effect continues to operate even when the exhaust gas flow is operating at its maximum velocity, flow rate or pressure (for example, during the air injection phase discussed below). In preferred embodiments,
30 the extracting gas flow operates throughout the entire process cycle, and preferably with largely the same properties (pressure, speed, flow rate) throughout. However, it would be possible to vary the pressure, flow rate or speed of the extracting gas flow if process conditions required, for example if the properties of the exhaust gas flow changed appreciably, such as during the air injection phase.

35

The physical arrangement of the apparatus at the point of convergence of the two gas flows may take one of a variety of forms to achieve the desired extraction effect. Where two gas paths converge, a T-piece or Y-piece of some form will be required in order to combine the two gas flows into one. Preferably, the exhaust path and the extracting path converge at an acute angle, as is provided in a Y-piece for example. Preferably, the acute angle is less than 45 degrees. In a more preferred embodiment, the apparatus includes a curved or radial T-piece at which the extracting path converges with the exhaust path, the exhaust path being curved or radial and the extracting path converging tangentially.

10

In all of the above arrangements, it is preferred that the extracting path remains substantially straight as the exhaust path converges with it. This will reduce turbulence in the extraction gas flow at the point of convergence and therefore improve the efficiency of the extraction.

15

The extracting path may have a smaller or larger cross-sectional area than the exhaust path at the point of convergence, or the cross-sectional areas may be the same. Preferably, the extracting path has a smaller cross-sectional area. The ratio of the exhaust path cross-sectional area to the extracting path cross-sectional area may be at least 1:1, preferably at least 2:1 or at least 5:1. Preferred ranges for the ratios are between about 2:1 and about 20:1, or more preferably between about 5:1 and about 10:1. A ratio of about 7:1 has been shown to work effectively in practice.

As mentioned above, if the extracting gas flow properties are to be varied during the process cycle, one way of achieving this would be to vary the cross-sectional area of the extracting path as required. Preferably however, the cross-sectional area of the extracting path is fixed.

For clarification, the gas flow downstream of the point of the convergence of the two gas flows is considered to be a continuation of the exhaust path, still containing an exhaust gas flow, which comprises the two converged gas flows.

The exhaust path cross-sectional area downstream of the point of convergence may be greater, less than or the same as the combined cross-sectional areas of the extracting path and exhaust path upstream of the point of convergence. In one preferred embodiment, the exhaust path cross-sectional area downstream of the point of

35

convergence is less than the combined cross-sectional areas of the extracting path and exhaust path upstream of the point of convergence. More preferably, the exhaust path cross-sectional area downstream is the same as the exhaust path cross-sectional area upstream.

5

The extracting gas may be any suitable gas for the purpose of performing the described functions. It may be designed to be reactive with the exhaust gases, for example to reduce or neutralise components of the exhaust gases, or it may be inert relative to the exhaust gases. Preferably, the extracting gas flow is air.

10

In order to reduce emissions from the apparatus, such as VOCs (volatile organic compounds), the treatment apparatus includes a catalyst material located in the exhaust path. The convergence of the extracting path and the exhaust path is downstream of the catalyst material.

15

The apparatus further comprises an inlet path for conveying an input gas flow which converges with the exhaust path, the convergence of the inlet path and the exhaust path being upstream of the catalyst material.

20 The input gas flow can have several functions. As with the extracting gas flow, the input gas flow may serve to dilute the exhaust gases. The input gas flow may have the function of priming the catalyst or improving the efficiency of its operation, for example by ensuring that its operating temperature is reached quickly and/or remains within a specified range. It may therefore have a heating or cooling function. It may also be
25 used to supply essential or desirable process gases to the catalyst to enable or enhance the catalytic reaction, such as oxygen for example.

Another function which can be performed by the input gas flow is that of a controllable valve or switch. By selecting an appropriate flow rate for the input gas, due to the
30 presence of the catalyst material in the exhaust path downstream of the convergence of the inlet and exhaust paths, back-pressure can be generated which is transmitted back along the exhaust path, upstream of the point of convergence of the inlet and exhaust paths. In this way, the input gas flow can be used to control (i.e. increase, reduce, stop or reverse) the flow of exhaust gas upstream of the point of convergence of the inlet and
35 exhaust paths. The input gas flow can therefore be used effectively to shut off the

exhaust path from the chamber, without the need for physical valves or other equipment (such as blowers or fans) in the exhaust path.

5 The physical arrangement of the apparatus at the point of convergence of the two gas flows may take one of a variety of forms to achieve the desired effect. As with the extracting path, a T-piece or Y-piece of some form will be required in order to combine the input and exhaust gas flows into one. Again, for clarification, the gas flow downstream of the point of the convergence of the two gas flows is considered to be a continuation of the exhaust path, still containing an exhaust gas flow, which comprises
10 the two converged gas flows.

Preferably, the inlet path and the extracting path converge at an acute angle, such as in a Y-piece for example. Preferably, the acute angle is less than 45 degrees, more preferably less than 30 degrees. An angle of around 15 degrees has been shown to work
15 effectively in practice. In a preferred embodiment, the inlet path is curved upstream of the Y-piece, such that the angle between the paths (or the angle between the tangents) decreases until the acute angle of convergence is reached.

In an alternative embodiment, the apparatus includes a curved or radial T-piece at
20 which the inlet path converges with the exhaust path, the inlet path being curved or radial and the exhaust path converging tangentially with it.

In the above embodiments, it is preferred that the exhaust path remains substantially straight as the inlet path converges with it, to minimise deviation of the exhaust path.
25 However, the paths could be the other way round.

The inlet path may have a smaller or larger cross-sectional area than the exhaust path at the point of convergence, but preferably the cross-sectional areas are the same. The exhaust path cross-sectional area downstream of the point of convergence may be
30 greater, less than or the same as the combined cross-sectional areas of the inlet path and exhaust path upstream of the point of convergence. Preferably, however, the exhaust path cross-sectional area downstream of the point of convergence is the same as the exhaust path cross-sectional area upstream.

35 The input gas may be any suitable gas for the purpose of performing the described functions. It may be designed to be reactive with the exhaust gases, for example to

reduce or neutralise components of the exhaust gases, or it may be inert relative to the exhaust gases. Alternatively or in addition, the input gas may be designed to be reactive with the catalyst which is located downstream of the point of convergence with the exhaust gas. For example, the input gas may contain one or more components which
5 are designed to effect or improve the operation of the catalyst. Some catalysts may require the presence of oxygen to operate, for example, and therefore the input gas may comprise or contain oxygen. Preferably, the input gas flow is air.

In order that the input gas is introduced into the exhaust path, the input gas will need
10 to be at a pressure equal to or greater than the exhaust gas at the point of convergence. To achieve a greater pressure, the input gas may be supplied from a pressurised source, such as a pressurised container or reservoir, or apparatus may be provided in the inlet path which serves to increase the pressure of the input gas. The apparatus preferably
15 comprises means for forcing the input gas flow into the exhaust path. This will typically be a fan or blower of any suitable type, which can be located in the inlet path upstream of the point of convergence of the two gas flows. Input gas may be drawn into the exhaust path without the need for any active increase in pressure of the input gas if the exhaust gas is at the same or a lower pressure, for example as a result of the effect of the
20 extracting gas flow downstream.

The input gas flow can have a variable flow rate in order to control the exhaust gas flow, as discussed above. When operating, the input gas flow may for example be anything from 1 to 1000 litres per minute. The input gas flow rate may be controlled by the means for forcing the input gas flow into the exhaust path. Upstream of the means for
25 forcing, the inlet path may in some preferred embodiments be open to the atmosphere so that, if the means for forcing is not operating, the inlet path is effectively open to the atmosphere. With the extraction gas flow operating continuously through the process cycle, even if the means for forcing is not operating, air (oxygen) can be drawn into the exhaust path and through the catalyst, ensuring that any reactive exhaust gases are
30 dealt with by the catalyst. By being open to the atmosphere, the build-up of a negative pressure up-stream of the catalyst is also prevented. A one-way valve may be used to allow input gas into the system, but to prevent gases escaping from the system at this point.

35 As mentioned above, the input gas may have the function of ensuring that the catalyst's operating temperature is reached quickly and/or remains within a specified operating

temperature range. Preferably therefore, the apparatus further includes means for heating the input gas flow. The means for heating is preferably located in the inlet path, and it may be upstream or downstream of the means for forcing if present. For convenience, the means for heating the input gas is preferably electric, although other
5 suitable forms of heater, e.g. gas or oil-powered, could be employed.

The input gas can therefore be used to heat the catalyst material to its operating temperature before the exhaust gases pass through, which ensures that the exhaust gases will be properly processed by the catalyst. Not only will this improve the
10 efficiency of the treatment apparatus, but there is then no danger that the exhaust gases contain components which should normally have been processed by the catalyst material. The input gas can also be used to control the operating temperature of the catalyst during a treatment cycle, and so it may have the function of heating or cooling the catalyst material.

15 In a further preferred embodiment of the treatment apparatus, a second catalyst material is provided in the exhaust path, downstream of the first (primary) catalyst material. By having two catalysts, the control of emissions from the apparatus can be improved. The secondary catalyst material may be the same as the primary, in which
20 case it will be performing essentially the same function as the primary catalyst but increasing the overall efficiency of the catalyst function. Alternatively, the secondary catalyst may contain or comprise different material from the primary catalyst, in which case its function will be to target a different component or components of the exhaust gas.

25 The or each catalyst material may be any suitable material designed for the purpose. The catalyst material may be metallic (e.g. a transition metal such as platinum, palladium, rhodium) or it may be formed from other materials such as multifunctional solids (e.g. zeolites, alumina, higher-order oxides, graphitic carbon, nanoparticles,
30 nanodots, and facets of bulk materials). Specific examples of catalyst materials that may be suitable for use in the present invention are available from companies such as Sud-Chemie (e.g. catalysts sold in their ActiSorb® range) and Haldor Topsoe.

When two catalysts are provided, the apparatus preferably has two inlet paths, each
35 conveying an input gas flow to converge with the exhaust path, one inlet path converging with the exhaust path upstream of the primary catalyst and one converging

with the exhaust path between the primary and secondary catalysts, upstream of the secondary catalyst. The second inlet path can of course have any of the optional and preferred features described above in relation to the first inlet path. In this embodiment, the convergence of the extracting path and the exhaust path is preferably downstream of the secondary catalyst material.

Clearly, it will be understood that further catalyst materials and corresponding inlet paths may be provided in the exhaust path, as necessary.

The treatment apparatus in accordance with at least preferred embodiments may include further components for treating the exhaust gas before it leaves the apparatus. For example, the exhaust gas may be cooled, filtered, scrubbed or otherwise cleaned before it leaves the apparatus. The component or components which perform these functions may be located at any appropriate place on the exhaust path, upstream or downstream of any other components (e.g. catalysts, extracting or inlet path convergence points, etc.). When one or more catalysts are provided, it is preferred that the additional components for treating the exhaust gas are downstream of the or each catalyst, since it is usually preferable for the catalyst(s) to be located close to the chamber where the exhaust gases are hottest.

The apparatus may include means for adsorbing carbon dioxide in the exhaust gas flow, such as an activated carbon filter. It may include means for scrubbing the exhaust gas, such as an exhaust gas scrubber located in the exhaust path. In preferred embodiments, the scrubber is in the form of a wetted wall cleaner, and more preferably a cyclonic wetted wall cleaner.

In any embodiments including further components for treating the exhaust gas, the convergence of the extracting path and the exhaust path is preferably downstream of these further components. As discussed above, it is preferred that the convergence of the extracting path and the exhaust path is substantially at the end of the exhaust path, after all other components. With the extracting gas flow operating substantially continuously throughout the process cycle, all gases including exhaust and any input gases are drawn through the system, minimising the chance of pressure build-ups and potential leaks. If there are any leak points or openings to atmosphere (deliberate or accidental), the extracting gas flow will draw air in at these points, and therefore

exhaust gases cannot escape to the atmosphere without being treated and processed by the apparatus.

5 The present invention, including the optional and preferred features discussed above, provides an improved material treatment apparatus and method compared to prior art systems. The extracting gas flow arrangement provides a means for drawing the exhaust gases through the apparatus with out the need for fans, blowers or other similar equipment located directly in the exhaust path. This avoids the need for equipment with moving parts, bearings, etc. to be exposed directly to the exhaust gases, 10 which by their nature can be dirty, hot and corrosive, so prolonging the life of the equipment and potentially reducing service intervals.

The input gas flow allows complete control of the exhaust gas flow, as discussed above, with the input gas and inlet path functioning as a controllable valve or switch in the 15 exhaust path, again avoiding the need for physical valves or other equipment (such as blowers or fans) in the exhaust path. The input gas flow can also have the function of priming the catalyst or improving the efficiency of its operation, by ensuring that it is up to working temperature for example.

20 In accordance with a second aspect, the invention provides an exhaust system for an apparatus for treating waste or other material, comprising an exhaust path for conveying exhaust gases, a catalyst material in the exhaust path, an inlet path for conveying an input gas flow which converges with the exhaust path upstream of the catalyst material, the input gas flow being used to control the flow of exhaust gases, and 25 an extracting path for conveying an extracting gas flow which converges with the exhaust path downstream of the catalyst material, the extracting gas flow assisting in the extraction of exhaust gases along the exhaust path.

Preferred and optional features of or relating to the exhaust path, where discussed in 30 relation to the apparatus for treating material, are of course envisaged.

In accordance with a third aspect, the invention provides a method for treating waste or other material, comprising the steps of heating material in a chamber, providing an exhaust path for conveying exhaust gases from the chamber, the exhaust path including 35 a catalyst material through which the exhaust gases pass, providing an input gas flow along an inlet path which converges with the exhaust path upstream of the catalyst

material, the input gas flow being used to control the flow of exhaust gases from the chamber, and providing an extracting gas flow along an extracting path which converges with the exhaust path downstream of the catalyst material and which assists in the extraction of exhaust gases from the chamber.

5

In a preferred embodiment, the method comprises the step of heating the material in the presence of little or no oxygen to a temperature sufficient to effect pyrolysis, and subsequently introducing oxygen into the chamber to effect combustion of the material. In this embodiment, the extracting gas flow is preferably provided at least during the combustion phase, but not necessarily during the pyrolysis phase. It is however
10 preferable to provide the extracting gas flow continuously throughout the treatment process.

Preferred and optional method steps corresponding to the various apparatus and
15 functional features discussed above are of course envisaged.

In summary, the present invention provides a very flexible and controllable treatment system, and in particular a system for handling the exhaust gases of such a system, which is able to meet the increasingly strict environmental requirements while at the
20 same time improving the control and reliability of such a system.

An embodiment of the invention will now be described, by way of example only, with reference to the accompanying drawings, in which:

25 Fig. 1 shows a schematic layout of a waste treatment apparatus in accordance with a preferred embodiment of the invention, together with typical gas flow paths;

Fig. 2 shows a cross-section through a Y-piece where the input and exhaust gases converge;

30

Fig. 3A shows a side elevation of a wetted wall cleaner in accordance with a preferred embodiment of the invention;

Fig. 3B shows a schematic plan view of the cyclonic wetted wall cleaner of Fig. 4A,
35 showing the gas flow path; and

Fig. 4 shows a cross-section through a radial T-piece where the exhaust and extracting gases converge.

5 With reference to Fig. 1, a thermal waste treatment apparatus in accordance with a preferred embodiment of the invention is shown, which is designed to effect pyrolysis and then combustion of waste material. The apparatus comprises a process container 10, primary catalyst container 20, secondary catalyst container 30, wetted wall cleaner 40 and dry adsorption container 50.

10 The exhaust path is shown generally by arrows labelled E, and leads from process container 10 via various components which will be described in more detail below, until it exits the apparatus.

15 Process container 10 consists of a vessel 11, a lid 12 (complete with seals and locking mechanism, not shown), heaters 13 and air inlet points 14. The process container 10 may also include a lid opening and closing mechanism, water spray bars for cleaning, a removable waste container and several temperature sensing devices. The removable waste container may contain heat transfer projections or spikes, and/or mechanical components for breaking up the waste prior to or during processing. The outside of the
20 vessel will typically be clad in insulation material.

Exhaust path E leads from the process container, and in this preferred embodiment there is only one exhaust gas stream outlet. More than one outlet may of course be advantageous in some applications, depending on the gas flow requirements.

25

First inlet path 100 converges with exhaust path E downstream of the process container 10 and upstream of the primary catalyst 20. Located in first inlet path 100 are heater 110 and blower 120. First inlet path 100 is open to the air upstream of blower 120.

30 Heater 110 is mounted onto a stainless steel tube assembly that forms the inlet to a Y-piece, where the input and exhaust gas flows converge, discussed further below. The heater is connected via a flexible (e.g. plastic) pipe to the outlet of blower 120. A one-way valve is fitted in the flexible pipeline, allowing gas to pass into the apparatus but not out of it. The heater and blower controls are configured such that the heater 110
35 cannot be used without blower 120 running, but the blower 120 can be used without the

heater 110 operating. There is a “free flow air path” through the blower 120, flexible pipe and heater 110 when the blower 120 is not running.

5 The input gas flow has several functions. When the blower 120 is running, the input gas flow can be used to create a situation of “nil gas flow” from the process container 10 due to the back-pressure generated by the catalyst material and therefore it can be used to control the exhaust gas flow from the process container. Using the combination of blower 120 and heater 110, the input gas flow is also used as the initial heat source for the catalyst material in the primary catalyst container 20. The blower 120 is then used
10 to regulate the temperature in the primary catalyst container 20 when required during a waste treatment cycle by forcing air at relatively low temperature into the catalyst material. The input gas flow also conveys oxygen to the catalyst material to promote the catalytic reaction.

15 Turning to Fig. 2, the convergence of the first inlet and exhaust paths is shown in more detail. A Y-piece 130 is employed to converge the two gas flows, which is formed from stainless steel tubing. The exhaust path E follows an essentially straight path through the Y-piece 130, and the pipe diameter is the same at the inlet as at the outlet. The inlet path I converges with exhaust path E at an acute angle, which is approximately 30
20 degrees. The inlet path I is curved upstream of the straight section of the Y-piece, such that the angle between the paths (or strictly the angle between the exhaust path E and the tangent of the inlet path I) decreases until the angle of convergence is reached. Heater 110 and blower 120 (not shown) are located in the inlet path I, upstream of the Y-piece 130.

25 Returning to Fig. 1, primary catalyst container 20 contains approximately 3 litres of ceramic bead-based catalyst material. The PCC 20 can be modular, so that it can easily be replaced as one unit, but it can also be configured so that the catalyst material can be removed and replaced without removing the module from the system. The PCC 20 will
30 be provided with one or more temperature sensors so that the catalyst material temperature can be determined, and heater 110 and blower 120 operated correspondingly. PCC 20 can also serve as a “fly ash” collector. Because of the operating temperatures involved, the container is clad in insulating material.

35 Because the material in the primary catalyst container 20 is the first catalytic material to come into contact with the exhaust gases, it is important that the catalytic material is

above its minimum operating temperature (for example, greater than 200 C but less than 600 C) before it is exposed to the exhaust gases. As explained above, this is achieved by running heater 110 and blower 120 until the desired temperature of the catalyst is achieved.

5

Second inlet path 200 converges with exhaust path E downstream of the primary catalyst 20 and upstream of the secondary catalyst container 30. Located in second inlet path 200 are heater 210 and blower 220. First inlet path 200 is open to the air upstream of blower 220.

10

The second inlet path 200 and exhaust path E converge in a similar manner to the first inlet path 100 exhaust path E, and the Y-piece design of Fig. 2 is preferably used for this purpose also.

15

Similar to the first inlet path 100, heater 210 is mounted onto a stainless steel tube assembly that forms the inlet to a Y-piece, where the second input and exhaust gas flows converge. The heater is connected via a flexible (e.g. plastic) pipe to the outlet of blower 220. A one-way valve is fitted in the flexible pipeline, allowing gas to pass into the apparatus but not out of it. The heater and blower controls are configured such that the heater 210 cannot be used without blower 220 running, but the blower 220 can be used without the heater 210 operating. There is a "free flow air path" through the blower 220, flexible pipe and heater 210 when the blower 220 is not running.

20

The second input gas flow has several functions. Using the combination of blower 220 and heater 210, the second input gas flow is used as the initial heat source for the catalyst material in the secondary catalyst container 30. The blower 220 is then used to regulate the temperature in the secondary catalyst container 30 when required during a waste treatment cycle by forcing air at relatively low temperature into the catalyst material. The second input gas flow also conveys oxygen to the catalyst material to promote the catalytic reaction.

30

Secondary catalyst container 20 contains approximately 30 litres of ceramic bead-based catalyst material. The SCC 30 can be modular, so that it can easily be replaced as one unit, but it can also be configured so that the catalyst material can be removed and replaced without removing the module from the system. The SCC 30 will be provided

35

with one or more temperature sensors so that the catalyst material temperature can be determined, and heater 210 and blower 220 operated correspondingly.

5 The main purpose of the SCC 30 is to be the long term catalyst, i.e. this material should last longer than the catalyst material in the PCC 20. The secondary catalytic material will essentially deal with any reactive gases that get past the PCC 20 as a result of any reduction in efficiency of the primary catalyst or the amount of gas overwhelming the primary catalyst. The latter situation will only occur when the air injection phase takes place (see below) and at that time the catalyst in the SCC 30 will be above its minimum
10 operating temperature (e.g. 200 C) and will be fully operational.

As with the primary catalyst, it is equally important that the secondary catalyst is above its minimum operating temperature (for example, greater than 200 C but less than 600 C) before it is exposed to the exhaust gases, so that any reactive gases which have
15 passed through the primary catalyst can be dealt with. As explained above, this is achieved by running heater 210 and blower 220 until the desired temperature of the catalyst is achieved. Because of the operating temperatures involved, the container is clad in insulating material.

20 With reference now to Figs. 3A and 3B, cyclonic wetted wall cleaner 40 will be described in more detail. This module enables the contact of water with the exhaust gases, with the purpose of removing particulates being carried in the exhaust gas as well as having a cooling effect on the gas.

25 Wetted wall cleaner 40 comprises a cylindrical housing 41 with an inlet 42 and an outlet 43. Inlet 42 is located at the bottom of the cylinder and outlet 43 at the top. Both inlet and outlet paths are tangential to the cylindrical wall of the housing 41. The interior cylindrical wall of the housing 41 is wetted by means of water continuously running down it, provided by means of a pump (not shown) which pumps water from
30 the primary coolant reservoir 44 (Fig. 1). The water returns from the bottom of the interior wall to the primary coolant reservoir 44 by means of gravity, where it is cooled (by mass transfer) and can be cleaned or filtered before being pumped around again.

35 Exhaust gas entering the housing 41 is directed along a tangential path initially and then into contact with the wetted interior cylindrical wall. The exhaust gas is subsequently forced in a spiral pattern around and up through the housing, all the time

being in contact with the wetted wall so that particles in the gas can be removed. If the gas flow is appropriately configured, a “cyclonic” effect can be achieved, which can increase the efficiency of the device.

- 5 A water curtain may also be provided inside the wetted wall cleaner. This may take the shape of a cone-shaped spray or a radial spray. The latter may be provided by a multi-jet disc spraying jets radially which impact the wetted wall of the cylinder.

Returning to Fig. 1, dry adsorption container 50 is connected to the exhaust gas flow E
10 exiting from wetted wall cleaner 40. It houses activated carbon pellets, which provide the functions of CO₂ adsorption, exhaust gas drying and odour control.

Extracting path 300 converges with exhaust path E downstream of dry adsorption container 50. Located in extracting path 300 is blower 320, which supplies an
15 extracting gas flow (air) into the exhaust path E, at a higher pressure than atmospheric. As discussed further below, blower 320 runs continuously during a waste treatment cycle. The effect of blower 320 on the rest of the system will be dependent on whether the other two blowers 110 and 210 are running or not, but the general function of the extracting gas flow is to ensure that there is a continuous draw of exhaust gases from
20 the chamber and through the system. The extracting gas flow also serves to dilute and cool the exhaust gas before it finally exits the apparatus.

While blower 320 runs continuously during a waste treatment cycle, its speed may be variable during the process cycle so that the extraction effect can be increased or
25 decreased depending on process conditions.

With reference to Fig. 4, the convergence of the extracting and exhaust paths is shown in more detail. A curved T-piece 330 is employed to converge the two gas flows, which is formed from stainless steel tubing. Exhaust path E follows a generally circular path,
30 turning through 90 degrees from the inlet to the outlet of the T-piece 330. The extracting path X converges tangentially with the exhaust path E, and the combined gas flow exits the T-piece 330 on the same tangential path.

The extraction effect is achieved through the extracting gas flow effectively pulling the
35 exhaust gas flow along with it, by virtue of the creation of a lower pressure in the exhaust path at the region where the exhaust gas flow converges with the extracting gas

flow, shown generally as LP in Fig. 4. The extracting gas is injected into the T-piece at a suitable pressure, velocity and flow rate which causes the lower pressure in the exhaust path.

5 The diameter of the exhaust path E is the same at the inlet to the T-piece 330 as at the outlet. The diameter of the extracting path X however is less than that of the exhaust path E. The extracting path may have a uniform diameter, or it may have a diameter which reduces in size down to the final diameter where the two gas streams converge. Clearly, it is the final diameter of the extracting path X which determines the effect that
10 the extracting gas flow has on the exhaust gas flow.

In a preferred embodiment, the diameter of the extracting path X should be less than about half the diameter of the exhaust path E. For example, the diameter of the exhaust path E could be about 50mm, in which case the diameter of the extracting path
15 X could be in the range of 10-25mm. A preferred diameter is about 18-20mm.

In practice, the diameter of the extracting path X can be designed to achieve the desired extraction speed, depending on the volume and flow of exhaust gas arriving at the T-piece 330 for a given set of apparatus. The extracting path may have a fixed cross-
20 sectional area or it may be variable, so that the speed of extraction can be varied depending on the position in the process cycle, for example.

Although not shown in the Figures, the apparatus will be provided with an enclosure to house the system components. The enclosure is designed to ensure that a minimum
25 footprint for the unit is achieved with the external design being safe, aesthetic and ergonomic. The enclosure will be provided with an operator panel an emergency button. A facility for weighing the waste load prior to placing it inside the process chamber can be provided, which allows for the optimum process protocol to be determined before the waste treatment cycle commences. Inlet and outlet
30 arrangements for the services required for the unit will be provided as well as suitable features to ensure that vermin/pests have no opportunity to penetrate into the unit. The enclosure design will also take account of the likely issues involved with cleaning and maintenance of the unit, including the replacement of consumables, having particular regard to safety and efficiency.

General Process Description

Having described the various components of the apparatus, a typical process will now be described in general terms, followed by an example of a process protocol.

5

The waste load contained within process container 10 is heated using the heating elements 13 located within the container, until a temperature of around 500°C is achieved within the container. Typically, the temperature is measured by one or more sensors (not shown) which measure the temperature of the walls of the container, the
10 gases within the container, or the waste itself. The temperatures given here typically refer to the temperature of the gases within the container, surrounding the waste and/or at the exhaust outlet of the container, which can conveniently be measured by standard techniques.

15

The heating of the waste is carried out with little or no air present (i.e. no air is deliberately introduced into the process container 10) so that combustion is unable to take place. During this period of pyrolysis (sometimes referred to as thermolysis), it is expected that Volatile Organic Compounds (VOCs) and other off-gases will be formed due to the fact that little or no air is present.

20

In parallel with and in advance of the process container 10 being heated, both the primary catalyst container (PCC) 20 and the secondary catalyst container (SCC) 30 are heated by means of heaters 110,210 and blowers 120,220 to at least their minimum operating temperatures so that they are able to react to the VOCs and off-gases that
25 may result from the pyrolysis/thermolysis reaction in the process container 10. During this time, blower 120 also creates a back-pressure back towards the process container 10, so that gases are contained within the process container and do not pass down the exhaust path.

30

The temperature of 500°C is maintained in the process container 10 for about 30, with no introduction of air so that pyrolysis continues. This phase can be considered to be a “dwell time” to allow for the bulk of the liquids to be removed from the waste by the process of evaporation.

35

When the 30 minutes’ dwell time has elapsed, heaters 110,210 and blowers 120,220 are switched off (if they are still on) and air is introduced into the process container

through air inlet points 14, at a rate of approximately 35 litres per minute. This relatively slow rate allows for any large volume of VOCs and other off-gases to be moved through the system, encountering the two catalysts en route. The air inlet flow rate is designed to allow the gases to spend enough time (dwell time) with the catalysts so that they are sufficiently reacted. The air inlet phase lasts for a total of 10 minutes and promotes an increase in the temperature in the waste load. During this time it is expected that the temperature in the process container 10 will rise above 500°C, with a new target temperature being about 600°C.

After the 10-minute air inlet phase, excess air at a rate of at least 200 litres per minute is introduced into the process container 10. This initiates the carbonisation phase. Most if not all of the liquid has been removed from the waste and the applied heat enables the thermal destruction to ash of most of the solid waste that remains. This process continues for 30 minutes, the temperature being controlled to approximately 600°C for this duration by switching heating elements 13 on and off as needed.

The final phase is the cooling phase, in which the process container 10 is allowed to cool to a point where it is safe to introduce water into the container. The water has a two-fold function, to further and more quickly cool the process container 10 and to wash the ash to the base of the container. Water/ash collecting at the base can be removed via a suitable drain point. Once the process container 10 has reached a safe temperature, it can be opened and is ready to accept another waste load.

General Process Protocol

The following is an example of a typical process protocol which may be used to operate the apparatus of a preferred embodiment of the invention:

1. Waste load placed inside process container 10, container lid sealed, all air injection ports 14 closed.
2. Start blowers 120, 220 and 320.
3. Switch on heaters 110 and 210.
4. When internal temperature in either the PCC 20 or the SCC 30 reaches 200°C, turn on process container heaters 13.
5. When the PCC 20 internal temperature reaches approximately 500°C, turn off heater 110 and 30 seconds later turn off blower 120. Maintain PCC internal

temperature between 450°C and 550°C. If PCC internal temperature goes above 550°C without heater 110 on, blower 120 should be turned on to reduce temperature.

6. When the SCC 30 internal temperature reaches approximately 500°C, turn off heater 210 and 30 seconds later turn off blower 220. Maintain SCC internal

5 temperature between 450°C and 500°C for the duration of the cycle by turning blower 220 and heater 210 on and off as necessary. If SCC 30 temperature goes above 620°C without heater 210 on, blower 220 should be turned on to reduce temperature.

7. Once the temperature of process container 10 has reached 500°C, maintain temperature at around 500°C for a period of 30 minutes, using heaters 13 as necessary.

10 8. At the end of the 30 minute period, switch off heaters 110,210 and blowers 120,220. Introduce air at rate of approximately 20-40 litres/minute into process container 10 via air inlets 14, for approximately 10 minutes. Blowers 120 and 220 cannot be turned on during this period unless the air inlet is first stopped.

9. After the 10-minute air inlet period has elapsed, introduce excess air at a rate of
15 at least 200 litres per minute into process chamber 10. This creates a rapid temperature rise of the waste load, typically to around 600°C. Maintain temperature of approximately 600°C for a further 30 minutes. Blowers 120,220 and heaters 110,210 can be switched on and off as necessary to control temperatures of PCC 20 and SCC 30 without any detrimental effect on the process cycle.

20 10. Once the 30-minute excess air phase has elapsed, switch off all heaters (container heaters 13, heaters 110,210) and allow the apparatus to cool. Blowers 120,220 can be left on or turned on to assist in the cooling phase. Blower 320 remains on.

11. All of the system components should now cool down, with the possible
25 exception of the PCC 20 whose temperature may rise slightly depending on its relative temperature to that of the process container 10.

12. When all temperatures, including that of the process container, are below
300°C, introduce water via spray bars into the process container in five 5-second bursts with 20 second intervals between. Repeat after 5 minutes initially, then decreasing to
30 2-minute intervals as the temperatures drop, until all temperatures are below 50°C, then allow process container lid to be opened.

Claims

1. Apparatus for treating waste or other material, comprising:
5 a chamber for containing the material during treatment,
means for heating the material in the chamber,
an exhaust path leading from the chamber for conveying exhaust gases from the chamber,
a catalyst material in the exhaust path,
10 an inlet path for conveying an input gas flow which converges with the exhaust path upstream of the catalyst material, the input gas flow being used to control the flow of exhaust gases from the chamber, and
an extracting path for conveying an extracting gas flow which converges with the exhaust path downstream of the catalyst material, the extracting gas flow assisting
15 in the extraction of exhaust gases from the chamber.
2. The apparatus of claim 1, in which the exhaust path and the extracting path converge at an acute angle.
- 20 3. The apparatus of claim 1 or 2, further comprising a curved or radial T-piece at which the extracting path converges with the exhaust path, the exhaust path being curved or radial and the extracting path converging tangentially.
4. The apparatus of any preceding claim, in which the extracting path has a
25 smaller cross-sectional area than the exhaust path at the point of convergence.
5. The apparatus of claim 4, in which the ratio of the exhaust path cross-sectional area to the extracting path cross-sectional area at the point of convergence is in the range of 2:1 to 20:1.
30
6. The apparatus of claim 4, in which the ratio of the exhaust path cross-sectional area to the extracting path cross-sectional area at the point of convergence is in the range of 5:1 to 10:1.

7. The apparatus of any preceding claim, in which the exhaust path cross-sectional area remains the same before and after the convergence of the extracting and exhaust paths.
- 5 8. The apparatus of any preceding claim, further comprising means for forcing the extracting gas flow into the exhaust path.
9. The apparatus of any preceding claim, in which the extracting gas flow converges with the exhaust gas flow at a higher velocity than the exhaust gas flow.
- 10 10. The apparatus of any preceding claim, in which the extracting gas flow converges with the exhaust gas flow at a higher flow rate than the exhaust gas flow.
11. The apparatus of claim 10, in which the ratio of the extracting gas flow rate to
15 the exhaust gas flow rate is between 20:1 and 100:1.
12. The apparatus of any preceding claim, in which the extracting gas flow is air.
13. The apparatus of any preceding claim, further comprising a second catalyst
20 material located in the exhaust path, downstream of the first catalyst material.
14. The apparatus of claim 13, further comprising a second inlet path for conveying a second input gas flow which converges with the exhaust path between the first and second catalyst materials.
- 25 15. The apparatus of any preceding claim, in which the exhaust path and the or each inlet path converge at an acute angle, preferably less than 30 degrees.
16. The apparatus of claim 15, further comprising a Y-piece at which the or each
30 inlet path converges with the exhaust path.
17. The apparatus of any preceding claim, in which the or each inlet path has the same cross-sectional area as the exhaust path at the point of convergence.

18. The apparatus of claim 17, in which the exhaust path cross-sectional area remains the same before and after the convergence of the or each inlet path and the exhaust path.
- 5 19. The apparatus of any preceding claim, in which the or each input gas flow is air.
20. The apparatus of any preceding claim, in which the or each input gas flow is heated.
- 10 21. The apparatus of claim 20, further comprising means for heating the or each input gas flow.
22. The apparatus of any preceding claim, in which the or each inlet path is open to the atmosphere.
- 15 23. The apparatus of any preceding claim, in which the or each input gas flow is forced into the exhaust path.
24. The apparatus of claim 23, further comprising means for forcing the or each input gas flow into the exhaust path.
- 20 25. The apparatus of any preceding claim, further comprising means for cooling the exhaust gas flow.
- 25 26. The apparatus of any preceding claim, further comprising means for adsorbing carbon dioxide in the exhaust gas flow.
27. The apparatus of claim 26, in which the means for adsorbing carbon dioxide in the exhaust gas flow includes activated carbon.
- 30 28. The apparatus of any preceding claim, further comprising means for scrubbing the exhaust gas flow.
29. The apparatus of claim 28, in which the means for scrubbing the exhaust gas flow comprises an exhaust gas scrubber located in the exhaust path.
- 35

30. The apparatus of claim 29, in which the scrubber comprises a wetted wall cleaner.

31. The apparatus of any of claims 28 to 30, in which the convergence of the
5 extracting path and the exhaust path is downstream of the means for scrubbing.

32. The apparatus of any preceding claim, further comprising means for controlling the introduction of oxygen into the chamber to selectively effect pyrolysis or combustion of the
10 material.

33. An exhaust system for an apparatus for treating waste or other material, comprising:
an exhaust path for conveying exhaust gases,
15 a catalyst material in the exhaust path,
an inlet path for conveying an input gas flow which converges with the exhaust path upstream of the catalyst material, the input gas flow being used to control the flow of exhaust gases, and
an extracting path for conveying an extracting gas flow which converges with
20 the exhaust path downstream of the catalyst material, the extracting gas flow assisting in the extraction of exhaust gases along the exhaust path.

34. A method for treating waste or other material, comprising the steps of:
heating material in a chamber,
25 providing an exhaust path for conveying exhaust gases from the chamber, the exhaust path including a catalyst material through which the exhaust gases pass,
providing an input gas flow along an inlet path which converges with the exhaust path upstream of the catalyst material, the input gas flow being used to control the flow of exhaust gases from the chamber, and
30 providing an extracting gas flow along an extracting path which converges with the exhaust path downstream of the catalyst material and which assists in the extraction of exhaust gases from the chamber.

35. The method of claim 34, further comprising the steps of heating the material in
35 the presence of little or no oxygen to a temperature sufficient to effect pyrolysis, and subsequently introducing oxygen into the chamber to effect combustion of the material.

36. The method of claim 35, in which the extracting gas flow is provided in both the pyrolysis and combustion phases.

5 37. The method of any of claims 34 to 36, in which the extracting gas flow is provided continuously throughout the treatment process.

38. The method of any of claims 34 to 37, in which the extracting gas flow converges with the exhaust gas flow at a higher velocity than the exhaust gas flow.

10

39. The method of any of claims 34 to 38, in which the extracting gas flow converges with the exhaust gas flow at a higher flow rate than the exhaust gas flow.

40. The method of claim 39, in which the ratio of the extracting gas flow rate to the
15 exhaust gas flow rate is between 20:1 and 100:1.

41. The method of any of claims 34 to 40, in which the extracting gas flow is air.

42. The method of any of claims 34 to 41, further comprising the step of passing the
20 exhaust gases through a second catalyst material in the exhaust path, downstream of the first catalyst material, the convergence of the extracting path and the exhaust path being downstream of the second catalyst material.

43. The method of claim 42, further comprising the step of providing a second input
25 gas flow along a second inlet path which converges with the exhaust path between the first and second catalyst materials.

44. The method of any of claims 34 to 43, in which the or each input gas flow is air.

30 45. The method of any of claims 34 to 44, in which the or each input gas flow is heated.

46. The method of any of claims 34 to 45, in which the or each input gas flow is forced into the exhaust path.

35

FIG. 1

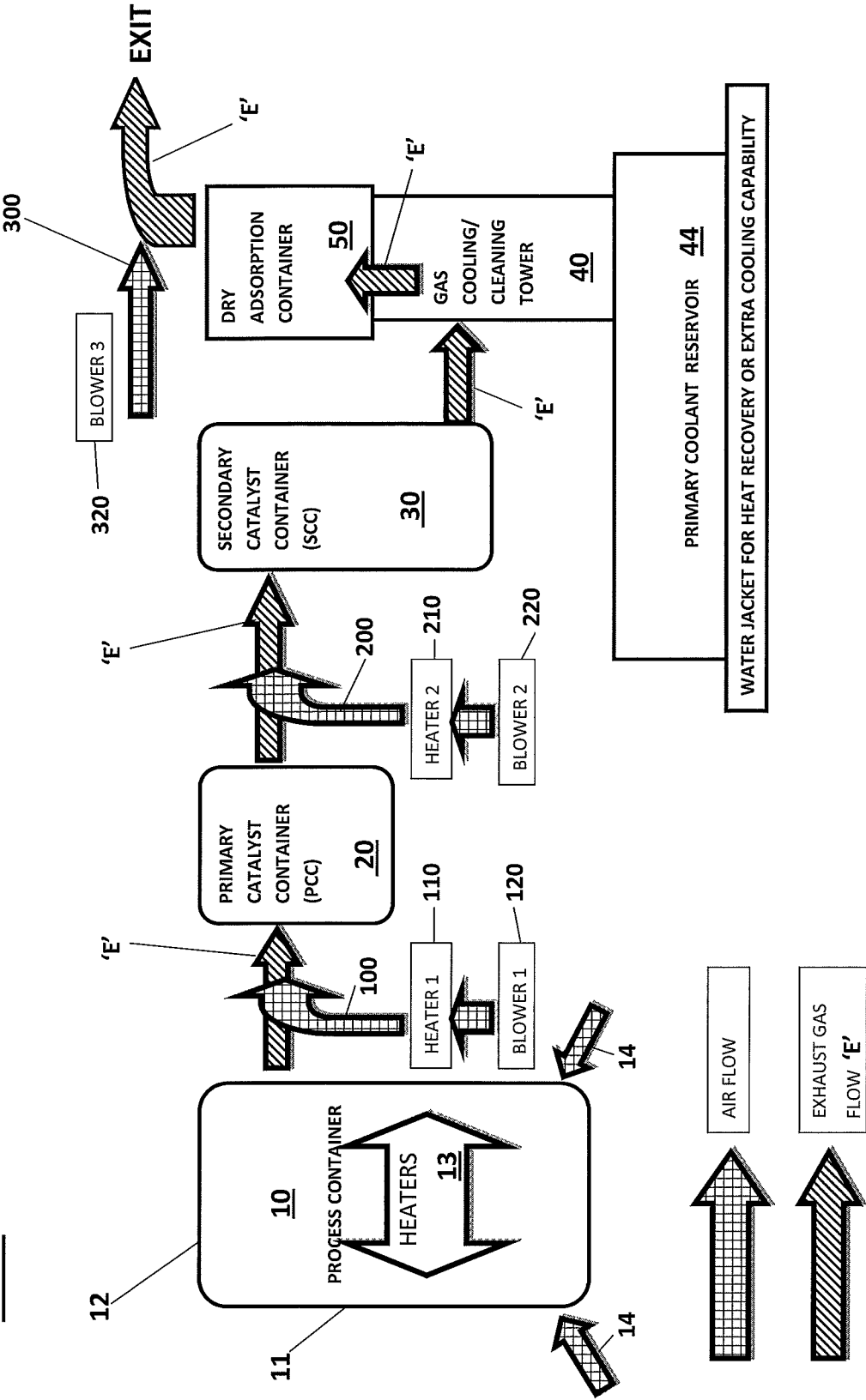


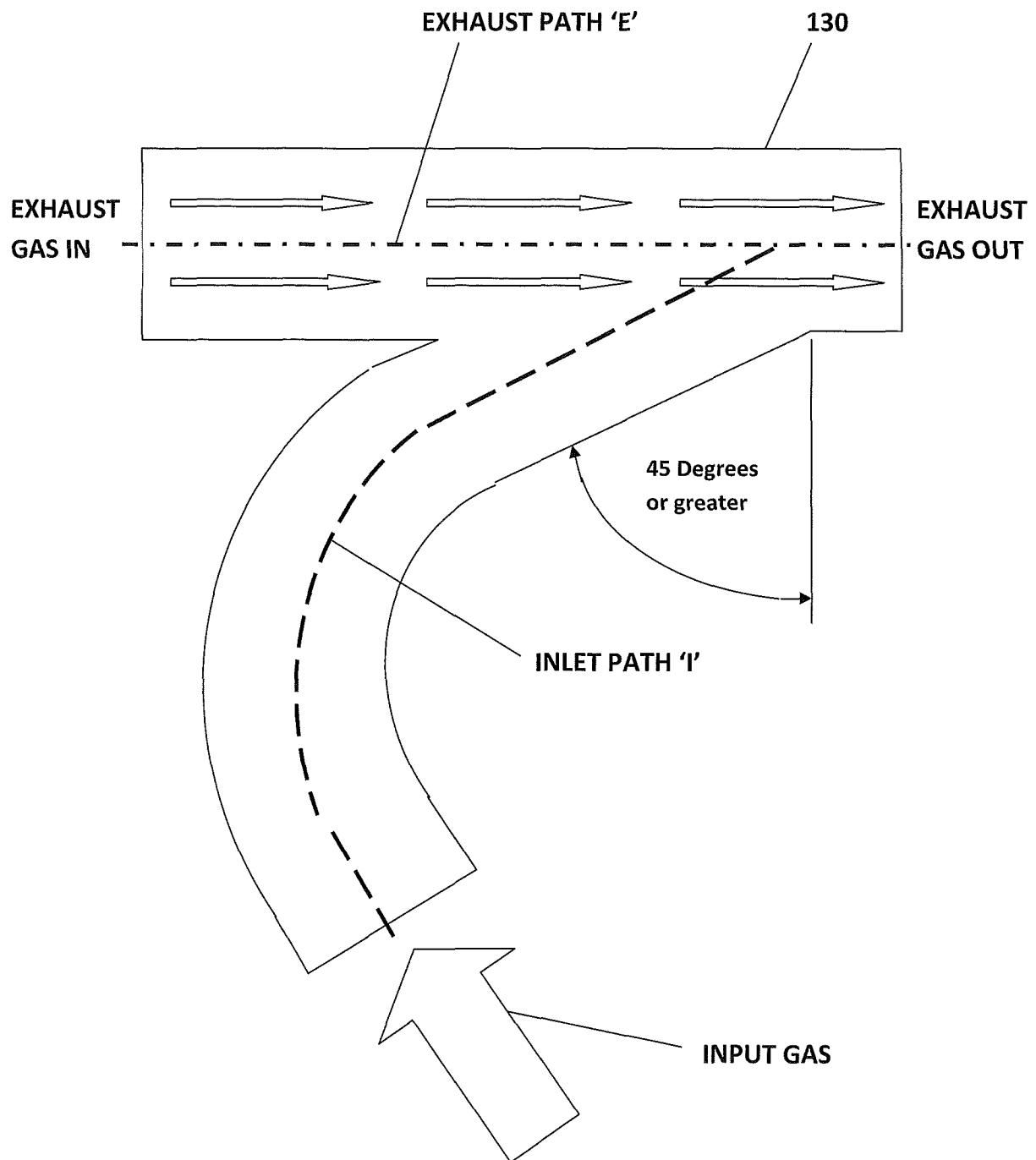
FIG. 2

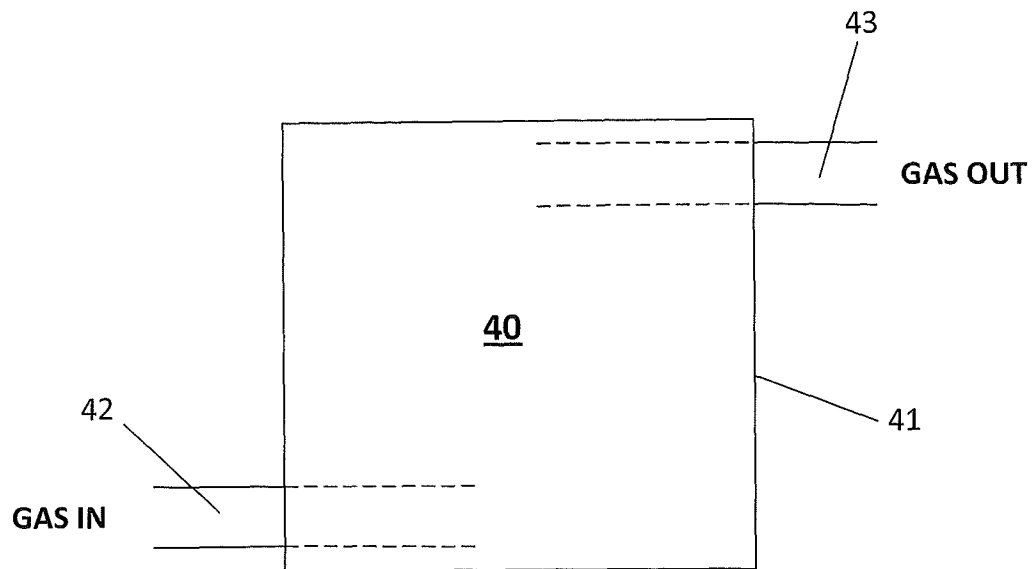
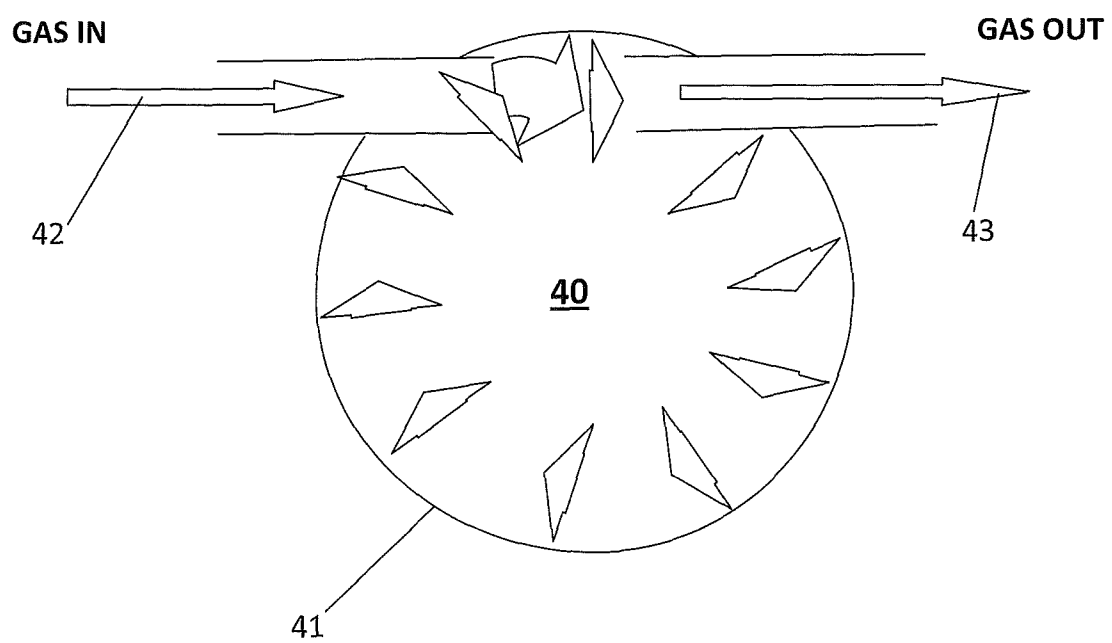
FIG. 3A**FIG. 3B**

FIG. 4