

A METHOD FOR PREPARING A HOMOGENOUS CELLULOSIC PRODUCT FROM CELLULOSIC WASTE MATERIALS

BACKGROUND OF THE INVENTION

The present invention relates to recycling and more particularly to the recycling of diverse pulp and paper materials by transforming such materials into a homogenous cellulosic product having a plurality of beneficial uses. The present invention also relates to a reduction in the volume of the diverse pulp and paper materials and of other components, such as plastics, contained in commingled wastes, including municipal solid waste (MSW) and biohazardous wastes, which facilitates the separation, recovery, and recycling of a variety of components contained in such wastes, including the homogenous cellulosic product and plastics. The present invention also relates to the decontamination and sterilization of microbially contaminated wastes that contain diverse pulp and paper materials and plastics, such as biohazardous laboratory and medical wastes, to yield products suitable for recycling and/or disposal in an environmentally safe manner. All of the above relate to the removal, capture, and treatment of air pollutants contained in the treated materials, such as volatile organic compounds (VOC's), to render them harmless to the environment

Fossil carbonaceous materials are finite natural resources, and these materials are rapidly being consumed. The world is also facing many environmentally significant problems associated with the depletion of such fossil materials, particularly petroleum, for the production of energy and petrochemicals. A variety of solid, liquid, and volatile organic compounds associated with petroleum extraction, transport, refining, and manufacturing operations have been and are continuing to be released into the environment. However, the release of carbon dioxide into the atmosphere during the burning of fossil fuels is the most significant environmental factor.

The use of fossil fuels has added tremendous quantities of carbon dioxide and organic chemicals to the atmosphere. Since this carbon dioxide is being released from

fossilized biomass that has long since been effectively removed from the biosphere, there is currently insufficient plant life on Earth to consume all of the carbon dioxide being produced. Therefore, the percentage of carbon dioxide in the atmosphere is increasing. Carbon dioxide and organic chemicals (e.g., VOC's), known as "greenhouse gases", allow high energy, short wavelength solar radiation to penetrate the atmosphere and heat the Earth's surface, but these same gases also impede the low energy, long wavelength radiation that dissipates the absorbed heat from the Earth. Thus, heat is trapped in the Earth's atmosphere, which is known as the "Greenhouse Effect". Reduction or elimination of the use of fossilized carbonaceous materials as combustion fuels and chemical feedstocks would halt and possibly reverse current trends in altering the biosphere. The use of renewable biomass as a replacement for fossilized combustion fuels is a formidable task, but it is an environmentally beneficial task that is well worth the effort, especially when considering the long term effects of continuing current trends.

Another environmental concern facing today's Earth is the production and disposal of waste, including MSW and biohazardous wastes. The ability to recycle a greater quantity of MSW productively and efficiently could significantly reduce the current volume of unused and discarded waste. The diverse pulp and paper materials contained in MSW would also provide a significant quantity of renewable biomass that can replace fossilized combustion fuels and chemical feedstocks. The ability to reduce the volume, decontaminate, and sterilize biohazardous wastes allows environmentally safe recycling and/or disposal of such materials.

MSW includes, but is not limited to, cellulosic and noncellulosic materials such as office wastes, business wastes, institutional wastes, industrial wastes, residential wastes, diverse pulp and paper materials, inks, glues, plastics, glass, metals, food wastes, and yard wastes. The cellulosic components (e.g., diverse pulp and paper materials) account for a relatively large portion of MSW by weight, and particularly by volume. Therefore, there is a particular need to recycle and utilize the cellulosic components to reduce the amount of MSW disposal, both by weight and volume.

Many attempts have been made to use MSW for energy production in so-called resource recovery facilities. Some such facilities incinerate the MSW without any prior separation of potentially recyclable materials, with the possible exception of curbside or drop-off source recycling, to produce steam and/or electricity. These facilities are known as "mass-burn" incinerators, which are very expensive to site, permit, construct, and operate, in addition to producing large quantities of hazardous or toxic gases and airborne particulates, as well as large quantities of hazardous or toxic fly ash and sometimes bottom ash that must be landfilled in specially designed and monitored sites called "monofills". Some other such facilities incinerate MSW after it has been shredded and some of the noncombustibles have been removed for energy recovery, which are known as "refuse derived fuel" ("RDF") incinerators. RDF incinerators tend to emit lesser amounts of hazardous or toxic air pollutants and to produce lesser amounts of hazardous or toxic ash than mass-burn incinerators. Still other such facilities use a combination of manual labor and mechanical devices to separate recyclable materials from the MSW, which are known as MSW materials recovery facilities ("dirty MRFs"). The non-recyclables from dirty MRFs are usually shredded and either incinerated on-site or off-site for energy recovery. The incinerator fuel from dirty MRFs produces lesser amounts of air pollutants and ash than either mass-burn or RDF incineration facilities.

Some attempts have also been made to cap and recover the gases from MSW landfills for energy production. Landfill gas recovery and use reduces the emission of greenhouse gases that would otherwise be emitted to the atmosphere, particularly VOC's from household and industrial chemicals contained in MSW and the methane and carbon dioxide from the anaerobic digestion of the putrescible materials in MSW buried in landfills.

Carbon dioxide from the incineration of chemically unaltered biomass (e.g., wood, yard wastes, and food wastes) and even chemically altered biomass (e.g., diverse pulp and paper materials, leather, rubber, and some other polymers of plants) does not result in a net increase in the concentration of carbon dioxide in the atmosphere, unlike fossilized biomass. The recent biomass, as opposed to fossil biomass, is renewable, since growing

plants fix sufficient carbon dioxide into new biomass to essentially recycle the atmospheric carbon dioxide produced by their eventual decay or combustion. As pointed out earlier, the combustion of fossilized biomass (e.g., petroleum, coal, etc.) does cause a net increase in atmospheric carbon dioxide.

The use of renewable plant biomass, including materials such as diverse pulp and paper materials in MSW, for producing solid, liquid, and gaseous fuels, chemicals, fertilizers, and other useful products, in addition to energy via direct combustion, as well as inclusion in composite materials and drilling fluids, would reduce or eliminate dependence on fossilized biomass materials and the unwanted secondary effects of their use as noted above, and, at the same time, would reduce the quantities of unused and discarded waste.

In order to be able to fully utilize renewable plant biomass as a replacement for fossilized carbonaceous materials, except as a solid combustion fuel without further modification, it is necessary to transform the plant biomass, particularly woody biomass, into a form that is easily accessible to various chemicals, enzymes and/or microbes that convert the biomass into the desired end products. Natural biodegradation is an excellent and environmentally safe means to break down plant biomass to its basic constituents, but the process is too slow to meet the demand for raw materials in industrialized societies. Therefore, if plant biomass is to be effectively used, it must be rapidly degraded.

Woody biomass is a hard substance that provides few points of entry for chemicals, enzymes and microbes to gain access to the composite molecules. The pulp and paper industry has already devised ways to at least partially break down the structure of woody biomass through mechanical size reduction and chemical treatments, but the desired end products of this industry must retain a fibrous consistency with tensile strength and rigidity. Additional treatments are necessary to transform these diverse pulp and paper materials into a homogenous cellulosic product suitable for inclusion in various composite materials, such as fiberboard, concrete aggregate, plastic lumber, etc. and drilling fluids, or for the final breakdown of the composite molecules into other useful products, such as liquid and gaseous fuels, chemicals and fertilizers.

The principal and most abundant type of organic material of plant biomass is the structural component called lignocellulose. This material is composed mostly of three distinct biopolymers: cellulose, hemicellulose, and lignin. These composite molecules are an abundant source of renewable energy and carbonaceous material that can and will eventually replace fossilized carbonaceous materials for the production of fuels, chemicals, fertilizers, composites, drilling fluids, and energy.

Prior attempts have been made and a few processes have been developed to separate diverse pulp and paper materials from commingled mixtures of waste and to break down the pulp and paper materials for varied uses. Previous methods have relied primarily on physical shearing of such materials to simply reduce the particle size. There are a variety of these so-called "dry" methods that subject these materials to either high-speed hammer mills or low-speed grinders to produce a fairly uniform particle size product, called "fluff". This fluff is usually prepared from commingled waste, such as MSW, and after separation of dense materials, such as glass, grit, ferrous metals, and high moisture contaminants that have also been reduced in particle size during the shredding process, the dry fluff is used as RDF for direct combustion to produce energy.

Another so-called "wet" method utilizes a device called a hydropulper, which is the equivalent of a large kitchen blender, to shred such materials suspended in a large volume of water. This is a popular method used by the pulp and paper industry to reduce the particle size of such material so that it may be recycled into the manufacture of new pulp and paper products.

These methods do yield pulp and paper products of a fairly uniform size, but none of these methods is intended to, nor do they, alter the physical and chemical structure of the basic lignocellulose component of the pulp and paper materials to facilitate their inclusion in composite materials and drilling fluids or the intercalation of chemicals, enzymes, or microbes into the structure to bring about a more efficient and complete breakdown of the polymeric molecules comprising the fibrous materials.

Biohazardous wastes, such as laboratory and medical wastes, also contain significant quantities of diverse pulp and paper materials commingled with a variety of other components, including food, plastics, glass, textiles, rubber, adhesives, medicines, chemicals, metallic sharps, laboratory animal carcasses and/or animal or human flesh, fluids, and wastes. Such commingled wastes have in the past been incinerated on-site. However, small on-site medical waste incinerators have fallen under strict environmental regulations resulting in the closure of many such facilities. The various components of these biohazardous wastes are now segregated for disposal by different means. The wastes are typically collected and stored in specially marked plastic boxes or bags. The wastes are then collected by specially permitted haulers for transport to remote sites for disposal. Unscrupulous haulers and disposal site operators have occasionally illegally dumped such wastes resulting in pollution of both land and water-front properties. Since large off-site medical waste incinerators have also been placed under strict environmental and permitting regulations, the primary method of treatment has become sterilization followed by landfill disposal in sanitary landfills. Such sterilization is typically carried out in a large autoclave in which the waste containers are placed and subjected to minimal conditions for sterility, which is 103.5 kPa pressure with saturated steam (121°C) for 15 minutes without agitation. Although this procedure has been deemed adequate by regulatory agencies, more rigorous steam treatment (e.g., higher pressure and temperature for longer time periods with agitation of the wastes to achieve a more uniform heat transfer) would provide greater assurance of adequate treatment prior to landfilling in a typical sanitary landfill.

Accordingly, one objective of the invention is to provide improved processes for transforming diverse pulp and paper materials into a homogeneous cellulosic product.

Another objective of the invention is to provide processes for the volume reduction of the diverse pulp and paper materials and of other components, such as plastics, contained in commingled wastes, such as MSW and biohazardous wastes, which facilitates the separation, recovery, and recycling of a variety of components contained in

the commingled wastes, including the homogenous cellulosic product and plastics. A further objective of the invention is to provide processes for reducing the volume of MSW and biohazardous wastes while producing components during that process for use as replacements for fossilized biomass material.

Still another objective of the invention is to provide an improved process for transforming diverse pulp and paper materials, including such materials contained in MSW and biohazardous wastes, into a homogeneous cellulosic product useful for energy production, inclusion into composite materials and drilling fluids, and/or conversion into fuels, chemicals, fertilizers, and other useful products.

An additional objective is to provide a process for reducing the emissions of volatile organic chemicals, VOC's, and other air pollutants present in wastes containing diverse pulp and paper materials, such as MSW and biohazardous wastes, by promoting the evaporation of such pollutants, capturing the pollutants, and treating the pollutants to render them harmless to the environment.

SUMMARY OF THE INVENTION

The present invention is a method for treating diverse pulp and paper materials from waste paper and commingled wastes containing such materials, including MSW and biohazardous wastes, to produce a homogenous cellulosic product that can be used without further modification as a solid combustion fuel, refined into additives for inclusion into composite materials and drilling fluids, or converted into other solid, liquid, or gaseous fuels, chemicals, fertilizers and other useful products. More specifically, the homogenous cellulosic product derived using the present invention is concerned not only with depletion rates of the finite sources of fossilized biomass materials and reduction of the generation of excess carbon dioxide and organic chemicals released from the burning or consumption of such fossil materials, but also with the reduction in the volume of unused and discarded MSW and biohazardous wastes. Various aspects of the present invention provide methods

for the improved processing of diverse pulp and paper materials, including such materials contained in MSW and biohazardous wastes, for use in energy production, as additives in composite materials and drilling fluids, and as feedstocks for chemical, enzymatic, and microbial conversions into fuels, chemicals, and fertilizers. The invention also provides methods for the removal of volatile air pollutants, present in wastes containing diverse pulp and paper materials, such as MSW and biohazardous wastes. Such volatile air pollutants are captured as they are vented from the process and treated to render them harmless to the environment.

Diverse pulp and paper materials in relation to the present invention means any and all known materials produced by the pulp and paper industry through the mechanical and chemical treatment of woody biomass and plant fibers to convert such biomass materials into reformulated products. Examples of such pulp and paper materials include, but are not limited to, Kraft paper, sulfite paper, bond paper, ledger paper, computer paper, printer's mixed paper, special file stock, pressed board, box board, card board, corrugated card board, and packaging materials and components.

The most abundant and cheapest sources of diverse pulp and paper materials are waste paper and MSW, with MSW often containing 50% or more pulp and paper materials, both by weight and volume. While this invention is primarily designed for using waste paper, it is also capable of utilizing MSW and biohazardous wastes as a source of diverse pulp and paper materials for transformation into a homogenous cellulosic product to be used as a solid combustion fuel, as an additive for composite materials and drilling fluids, and for the chemical, enzymatic, and microbial conversions into fuels, chemicals, and/or fertilizers.

The present invention thus contemplates a method of transforming diverse pulp and paper materials, including wastes containing such materials, into a homogenous cellulosic product that is an ideal additive for inclusion in composite materials and drilling fluids and an ideal feedstock for chemical, biological, and/or thermal conversion to yield a variety of fuels, chemicals, fertilizers, and/or energy.

Diverse pulp and paper materials are abundant, cheap, and renewable materials made from woody biomass that have already undergone extensive mechanical and chemical degradation of the lignocellulose components, but the present invention contemplates further transformation into homogenous cellulosic products that are soft and porous with tremendous surface area that facilitates combustion and inclusion into composite materials and drilling fluids, and also promotes access by chemicals, enzymes, and microbes to be able to achieve a rapid and effective conversion to its major chemical components. The major chemical components of cellulose and hemicellulose, particularly the sugars, glucose, mannose, and xylose, can be further converted into useful fuels and chemicals by biological fermentations. The other chemical components, mainly from lignin, can be converted into a variety of hydrocarbon products by chemical and thermochemical decomposition.

One transformation process, according to one embodiment of the present invention, includes the following steps:

- (a) feeding diverse pulp and paper materials into a vessel;
- (b) introducing steam into the vessel while agitating the materials;
- (c) purging gases from the vessel while agitating the materials;
- (d) capturing said gases and treating the gases to render any volatile air pollutants present in the gases harmless to the environment;
- (e) sealing the vessel so that the vessel is pressure tight;
- (f) saturating the materials with steam at sufficient temperature and pressure to expand the physical and chemical structure of the materials;
- (g) depressurizing the vessel to further enhance the physical and chemical expansion of the materials; and
- (h) discharging the processed products from the vessel.

The process of the present invention is environmentally conscious, in that it allows any volatile organic compounds (VOC's), air polluting compounds, and any other undesirable gases associated with the diverse pulp and paper materials, MSW, or biohazardous wastes to be purged from the vessel in a controlled manner, captured and rendered harmless. Furthermore this process physically and chemically transforms the diverse pulp and paper materials into the desired end product, namely a homogenous cellulosic product, that can be used as a combustion fuel, refined for inclusion in composite materials or drilling fluids, and/or converted into other fuels, chemicals, fertilizers, and other useful products.

Accordingly, one object of the present invention is to improve the management and collection of VOC's, hazardous air pollutants, and any other undesirable gases that would usually be emitted from MSW buried in landfills, and particularly such substances that would be emitted during the transformation process of the present invention.

An alternative transformation process according to the present invention, comprises the following steps:

- (a) feeding diverse pulp and paper materials into a vessel;
- (b) sealing the vessel so that the vessel is pressure tight;
- (c) injecting steam into the vessel while agitating the products;
- (d) saturating the materials with steam at a temperature in the range of about 140°C to about 160°C and at a pressure in the range of about 275 kPa to about 450 kPa to expand the physical and chemical structure of the materials;
- (e) depressurizing the vessel to further enhance the physical and chemical expansion of the materials;
- (f) capturing any gases released during said depressurization and treating said gases to render any volatile organic compounds and any other air pollutants present in the gases harmless to the environment; and
- (g) discharging the processed products from the vessel.

Like the previous process, this process may further include the step of purging gases from the vessel for the same reasons as cited above at any time during the process prior to the depressurization step. Such flexibility in the timing of the purging step can be used, not only to capture the volatile air pollutants at higher temperatures, but also, to remove excess moisture from the wastes being processed to yield a homogenous cellulosic feedstock with a more consistent and lower moisture content.

In either process, it is desirable to capture any remaining VOC's or other pollutants during the depressurizing step. Such VOC's and other pollutants can then be treated prior to release to the atmosphere. In fact, the collection of VOC's and other pollutants from the vessel can be separated into condensables and noncondensables which would be likely treated differently. For example, condensers can be used to condense some of the purged gases prior to cooking the products, and condense the decompression steam, which may contain some VOC's and/or other pollutants that are volatilized at temperatures above 100°C. The capture of condensable and noncondensable components during the depressurizing step aids in cooling and drying the processed products. The VOC's and other air pollutants may be collected, captured, and treated in any devices for such purposes that are known in the art, such as thermal oxidizers, adsorbents, etc.

If starting with MSW, preferably the discharging step includes the step of screening discharged products, thus separating larger sized cellulosic products and returning these larger sized cellulosic products to a second similar transformation process. It is also desirable to separate any remaining noncellulosic components from the cellulosic products by any suitable process, including screening, ferro-magnets, eddy currents, air classification, etc. If starting with biohazardous wastes containing needles, scalpels, etc., termed "sharps", preferably the cellulosic product containing said sharps would be subjected to a fine grinding device to render said sharps harmless prior to using the cellulosic product containing said sharps for any subsequent use that may require facility workers to come in direct contact with said product.

In yet another alternative process, a plurality of process vessels, each capable of treating wastes containing diverse pulp and paper materials as noted above, are interconnected via their respective vent valves to a common manifold that includes means to join any two of said vessels and to facilitate the transfer of the depressurizing steam from any pressurized vessel to any other vessel that has been prepared for the purging step of the process. Thus, the depressurization steam of one vessel may be used to accomplish the purging step of any other of the plurality of vessels. The transfer of high pressure steam and heat from a pressurized vessel into a vessel containing wastes at ambient air temperature and atmospheric pressure, not only conserves energy, but also facilitates depressurization of the pressurized vessel, since most of the water vapor in the steam entering the lower pressure vessel and wastes is condensed, resulting in a pressure differential that promotes the flow of steam from the higher pressure vessel to the lower pressure vessel. This effect is well known to those skilled in the art, due to the 22-fold decrease in volume upon condensation of a gaseous vapor.

The processed products from a plurality of process vessels is discharged from each of said vessels and conveyed to a common separation system for recovery of various non-cellulosic components for recycling in addition to the homogenous cellulosic product (when MSW or biohazardous wastes are processed). Larger sized cellulosic components are also separated and recovered to be processed a second time to complete the desired transformation.

Accordingly, the present invention provides a process of transforming diverse pulp and paper materials into a homogenous cellulosic product which provides a renewable substitute combustion fuel that can reduce the dependency upon fossil fuel materials and correspondingly reduces carbon dioxide production from the combustion of fossil fuel materials; provides a means of reducing the quantity of unused and discarded wastes; and provides a means to capture volatile organic compounds and other environmentally damaging gases from wastes.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a schematic view of a process vessel used in accordance with the present invention;

Fig. 2 is a partial, cross-sectional view of Fig. 1 taken along line 2-2;

Fig. 3 is a schematic view of the process vessel oriented in a filling position;

Fig. 4 is a schematic view of the process vessel oriented in a discharging position; and

Fig. 5 is a flow chart in accordance with one embodiment of the present invention.

DETAILED DESCRIPTION

The method for treating diverse pulp and paper materials and wastes containing such materials for producing a homogenous cellulosic product that can be used generally with any known suitable vessels. However, by way of example, the discussion regarding the method of the present invention will be related to the process vessel as shown in Fig. 1. As shown in Fig. 1, the process vessel, generally designated 10, includes a cylindrical housing 12 with a closed end 14, except for a centrally disposed penetration port 16, which is connected to a rotary union 18 for steam injection and/or depressurization. The opposite end 20 of the vessel 10 includes a doorway 22 for introduction of the materials to be processed into the vessel interior 24, and for discharge of the processed products. The doorway opening 22 may be the same diameter as the cylindrical housing 12. Alternatively, the cylindrical housing 12 may be tapered to a smaller diameter 26 for large

diameter vessels for economical and mechanical reasons related to the door closure and weight thereof. The door 28 is preferably completely detachable from the vessel 10 to allow free rotation of the vessel 10 about its horizontal axis (line 2-2) in either a clockwise or a counter-clockwise direction, either with the door 28 attached and closed as generally shown in Fig. 1 or with the door 28 open and detached (not shown). The door 28 includes a second penetration port 30 which is also connected to a rotary union (not shown, but similar to 18) for the addition of a vent valve (not shown). The vessel 10 includes an over-pressure relief valve (not shown).

As shown in Fig. 2, the vessel interior 24 is preferably equipped with two or more helical flights 32 that traverse the entire length of the vessel 10, including the closed end 14 and the tapered end 20, if present. The number of flights is determined on the basis of the vessel diameter, and the flights would be positioned equidistant from each other around the circumference of the vessel interior 24, for example, two flights would be 180° apart, four flights would be arranged such that a single flight is 90° apart from an adjacent flight. The flights are attached to the interior walls of the cylindrical housing 12, the closed end 14, and the tapered end 26 (if present) and would radiate toward the horizontal axis (line 2-2). The optimum height of the flights from the wall toward the horizontal axis and the frequency of the spiral along the length are determined empirically. Depending on the length of the cylindrical housing 12, at least two equally disposed sparging lines (not shown) may be attached to the interior wall of the cylindrical housing 12 or alternatively, attached to the exterior wall of the cylindrical housing 12 with penetrations into the interior 24 of the cylindrical housing 12 through which steam may be injected into the interior of the housing 12. The sparging lines could be parallel to the horizontal axis or alternatively combined with the helical flighting. Holes or other penetrations would exist in the sparging lines to provide high velocity steam injection when the pressure differential is great.

The vessel 10 is mounted in a frame, generally designated 33, that allows rotation of the vessel in either a clockwise or counter-clockwise direction about its horizontal axis (line 2-2). The frame is capable of being pivoted to allow the door end 20 of the vessel 10

to be raised such that the vessel 10 may be tilted at a predetermined angle above horizontal, as shown in Fig. 3, for loading waste materials to be processed or lowered such that the vessel may be tilted to a predetermined angle below horizontal, as shown in Fig. 4, for discharging the processed materials, while simultaneously rotating the vessel in either rotational direction. The means of tilting the vessel 10 while allowing rotation is known in the art. The maximum and optimum tilt angle above and below horizontal would be determined empirically. Alternatively, the vessel 10 mounted in its frame may be positioned either horizontally or at a fixed angle of repose with respect to its horizontal axis (line 2-2), such that the closed end 14 is lower than the door end 20. The optimum fixed angle would be determined empirically.

The vessel 10 further includes a means of support (generally shown as 33) to allow rotation in either rotational direction to prevent flexing of the vessel 10 along its horizontal axis (line 2-2). The vessel 10 would also include means of support (not shown) to allow the unit to be tilted above or below horizontal, or alternatively, to allow the unit to be mounted horizontally or at a fixed angle from horizontal as recited above while simultaneously allowing rotation in either direction. The vessel 10 further includes a means of rotation in either direction which shall be continuously variable in rotational speed from about 0 to about 10 rpm, with the optimum rotation speed during processing to be determined empirically.

The door 28 of the vessel 10 should allow the vessel 10 to be rotated in either rotational direction either with the door 28 open or closed. Preferably, the door closure member 28 should be completely detachable from the vessel housing 12.

The closed end 14 of the vessel 10 includes a centrally disposed penetration port 16 connected externally with a rotary union 18 that allows the vessel 10 to be rotated in either rotational direction while being connected to a stationary conduit for delivery of steam or for venting the vessel 10. The stationary conduit may be of flexible high pressure construction to allow the vessel 10 to be tilted while connected to the stationary conduit. The penetration port 16 on the closed end 14 may be connected internally with the

sparging lines to provide a means for 10 steam to be injected via high velocity openings into the vessel interior 24.

The doorway 22 may be of the same diameter as the cylinder housing 12 or a smaller diameter for large diameter vessels in which the door end 20 of the cylinder housing 12 is conically tapered. A smaller doorway may be more economical and lighter in weight to facilitate removal of the closure member 28. The doorway 22 is centrally disposed and is not less than 3 feet in diameter. The closure member 28 is preferably completely detachable from the vessel 10 to allow rotation in either direction with the closure member 28 closed or removed. A penetration port 16 is centrally disposed in the closure member 28 for the connection of a vent valve generally designated 30. A rotary union (not shown, but similar to 18) may also be connected to the penetration port 16 to allow the vessel 10 to rotate in either direction while connected to a stationary conduit for collection of vapors released via the vent valve 30.

For introduction of materials to be processed into the vessel 10, the vessel door 28 is opened or preferably removed, and the vessel 10 may remain in a horizontal repose or preferably may be either fixed or tilted to a predetermined angle above horizontal with the doorway opening 22 in the raised end position as best shown in Fig. 3. The vessel 10 is rotated in the direction that 25 the helical fighting 32 provides a means of conveyance of materials away from the doorway 22 and toward the closed end 14 of the vessel 10.

A predetermined amount of water may be introduced into the vessel 10, if deemed necessary, either prior to or concurrently with the introduction of the material to be processed. The amount of water added is dependent upon the moisture content of the material to be processed. The water added does not need to be potable water, and thus contaminated water and even sewage sludges may be used as the wetting agent. A predetermined weight of the solid materials to be processed are then introduced into the vessel 10 while simultaneously rotating the vessel 10 in the above described direction. A low flow of steam is also simultaneously injected via port 16 as the materials are introduced into the vessel 10 to provide lubrication to the rotary valve 18 but also

introduces both heat and additional moisture as steam condensate into the materials to be processed. The steam thus preheats the vessel and its contents which along with the agitation provided by the rotation of the vessel and conveyance of the materials by the helical flights 32 toward the closed end of the vessel 14 provides a means of compaction and uniform wetting of the solid materials. Fugitive vapors that may escape from the open doorway during the above described process of introducing materials into the vessel for processing would be collected into and vented via an overhead exhaust hood for capture and treatment of the vapors as is known in the art.

Prior to introduction into the vessel 10, the moisture content of the solid materials to be processed should be at least 20% by weight, preferably in the range of 20%-60% by weight. The introduction of solids is continued until the predetermined weight of material has been introduced into the vessel 10. The volume of the vessel interior 24 filled or occupied by the waste material will vary with the density of the material. Steam introduction and vessel rotation are then suspended, and the door closure member 28 is then replaced and sealed.

The vent 30 on the door 28 is opened and connected to an appropriate means to collect the vapors and condensate to be emitted. The vessel 10 may remain in a horizontal repose or preferably either the tilt angle of the vessel 10 is adjusted to or is fixed at a predetermined angle above horizontal for processing. Rotation of the vessel and steam introduction are resumed.

Steam is introduced via the penetration port 16 in the closed end 14 and into the vessel interior 24 via the high velocity openings in the sparging lines, if present. As the steam is introduced into the vessel interior 24, the steam simultaneously transfers heat and moisture to the vessel 10 contents (waste materials) and saturated steam purges and/or displaces the air, vapors and other gases within the vessel 10 and its contents. This heating and purging step is continued until the purged gases escaping the vent 30 on the door reach a temperature above 100°C, and the vent 30 is then closed. The vessel 10 is continuously rotated and steam is continuously introduced via a steam pressure regulator

that has been preset to the desired operating pressure and temperature within the vessel 10 to initiate the physical and chemical expansion of the diverse pulp and paper materials. During the initial introduction of steam, while the vent 30 is open and before significant internal steam pressure is reached, the saturated steam enters at a high velocity due to the pressure differential. This high velocity steam along with the vessel rotation exposes the contents to shearing forces, and the steam also melts and tears any film plastic containers, thus spilling their contents. The high velocity steam also forces both moisture and heat into the diverse pulp and paper materials and other biomass or water absorptive materials. The steam thus initiates an expansion of the physical and chemical structural matrix of the diverse pulp and paper materials making them more fragile for size reduction due to the mixing and shearing action taking place in the vessel.

The desired mixing action within the vessel interior 24 is for the helical fighting 32 to convey the materials near the vessel wall up and toward the closed end 14 of the vessel 10, but as the vessel 10 rotates, the material is also rolled and spilled over the edge of the fighting and falls due to gravity through an atmosphere of saturated steam, thus exposing the materials to mixing as well as both heat and moisture. The preferred angle of the helical fighting and the inclined angle of the vessel, if any, is determined empirically.

In the purging and heating process, absorbed moisture within the diverse pulp and paper-materials to be transformed and additional moisture from the condensate provided by the injected steam both displace entrapped gases and act as a heat transfer conduit. After the purge vent is closed, steam injection continues, and the temperature of the water in the material increases above the boiling point of water (100°C). The water eventually makes the transition from liquid to vapor, which is effective to permit the heated water to expand into a gas that is about 22 times the volume of an equivalent weight of water, within the materials, opening up the materials and greatly expanding the physical and chemical structure of the materials, thereby, producing a cellulosic feedstock product of great surface area, which is open to air for faster and more complete combustion, open to liquids for inclusion in composite materials and drilling fluids, and open to chemical, enzyme, and microbial treatments, for producing fuels, chemicals, fertilizers, and other useful products.

The diverse pulp and paper materials are thus transformed into a homogenous cellulosic product more treatable than materials provided in other processes. Due to the transformation of the diverse pulp and paper materials into a homogenous cellulosic product, the desired product is easily separated from any oversize cellulosic product and any co-processed noncellulosic materials.

The vessel 10 and its contents are heated and pressurized to a maximum of about 450 kPa or a minimum of about 275 kPa with saturated steam, more preferably about 380 kPa. Once the operating pressure is reached, the material is continuously mixed by rotating the vessel while simultaneously maintaining the pressure for at least 30 minutes up to a maximum of 1 hour. Preferably, the vessel 10 is rotated at a rotational speed in the range of about 0 to 10 rpm, with the optimum to be determined empirically.

Alternatively, with a properly insulated vessel, the steam injection may be continued until the maximum pressure of about 450 kPa is reached, and then the steam injection may be discontinued, but the mixing would be continued for the desired time period. This period of continuous mixing with or without continuous steam injection is to provide a period of time for the contents to reach equilibrium or uniformity of composition--a state when the contents are uniformly mixed and transformed into the desired product with the combination of agitation, moisture and heat. After the desired equilibrium period, the vessel is depressurized via the vent 30 on the door 28 while simultaneously and continuously mixing the contents to achieve as much heat and vapor loss as possible. As the steam atmosphere in the vessel is expelled, at least a portion of both the free moisture on the surfaces and the absorbed moisture in the contents within the vessel 24 are also vaporized, which both cools and partially dries the materials. The vaporization of the absorbed moisture in the cellular and capillary areas of the cellulosic materials causes a further expansion of the physical and chemical structures of the materials due to the 22-fold increase in the volume of liquid water upon conversion to the vapor phase, thus further enhancing the transformation of the diverse pulp and paper materials into the homogenous cellulosic product.

After depressurization to atmospheric pressure, the processed materials remain hot and moist. Optionally, the vessel 10 would then be evacuated while continuously mixing to both further cool and dry the materials by using the latent heat and evaporating the moisture in the materials. Once the materials are cooled and dried to the extent desired, the vessel 10 is returned to atmospheric pressure. The door closure member 28 is opened and preferably detached from the vessel. The door end 20 of the vessel 10 preferably is lowered to tilt the vessel 10 to a predetermined angle below horizontal (Fig. 4), and the vessel is rotated in the reverse direction to convey the processed products toward the open doorway 22. The contents are thus discharged from the vessel 10. If there is no mechanism of lowering the vessel 10 below horizontal, or if the vessel 10 is mounted at a fixed angle of incline above horizontal, the contents will also be discharged from the vessel 10 by the helical fighting 32 when rotated in reverse direction, but the unloading process usually takes considerably longer.

As generally represented schematically in Fig. 5 for example, the processed materials are preferably discharged onto a means of conveyance, such as a belt conveyor, for transport typically to a screening device, such as a vibratory or rotary trommel screener, for separation based on size. The particle size of the cellulosic product may be determined empirically based on the desired end use of the cellulosic biomass. Very few cellulosic materials, other than cotton textiles, woody plant biomass, or lumber contaminants, are found in the processed material that are larger than 5 centimeters particle size. Typically, about 80% of the cellulosic biomass will be obtained in the less than 2.5 centimeters screen fraction. Preferably the screening process would take place with a heated air stream blowing over the materials to achieve further drying. This would be particularly effective in an enclosed rotary trommel with a hot air stream blowing through it. Contaminating materials from a mixed waste stream, such as MSW or biohazardous wastes, that are larger than 5 centimeters would typically include ferrous and nonferrous scrap metals and cans, polyethylene terephthalate (PETE) plastic containers, polypropylene (PP) plastic films and molded products, miscellaneous textiles, rubber, leather, and wood, and these materials may be sorted manually and/or mechanically for recycling. If an intermediate screen fraction of less than 5 centimeters, but greater than 1.3 centimeters is obtained, this fraction

would include a small percentage of a mixture of the same materials as those found in the greater than 5 centimeter fraction (see above), but the 1.3 - 5 centimeter fraction would consist mostly of broken glass, a variety of small plastic items, including amorphous aggregates of plastics that were formed from a variety of that melted at the processing temperature, but solidified as a mixed plastic mass as the temperature dropped below their melting points during depressurization of the vessel, and incompletely transformed cellulosic materials, including some diverse pulp and paper materials. These materials may also be sorted into recyclable products. If the desired homogenous cellulosic product is to be less than 1.3 centimeters, then the 1.3 - 5 centimeter pulp and paper materials would be separated from the noncellulosic components by various means such as an air knife, and recovered for reprocessing either by including these materials in a subsequent batch of unprocessed materials or combining with similar fractions from several different batch processes to be reprocessed together as a single batch. The mixture noncellulosic components from this step may be sorted by various means into recyclable products, such as ferrous metals, nonferrous metals, mixed plastics, mixed color glass cullet, etc., or due to their small volume and composition all or some of these noncellulosic materials may be discarded in an inert landfill.

The smallest particle size fraction from the screening step which would typically be less than 5 centimeters, preferably less than 1.3 centimeters, from a commingled waste stream, such as MSW and biohazardous wastes, would typically be contaminated with significant quantities of broken glass, ceramics, plastic items, and amorphous aggregates of mixed plastics, and minor amounts of ferrous and nonferrous metals. Most of these contaminants may be removed by various means, such as a stoner or air classifier, preferably using a hot air stream to dry and suspend the homogenous cellulosic product in the air stream. The heavy fraction from this step may also be sorted into recyclable products, such as ferrous metals, nonferrous metals, mixed plastics, mixed color glass cullet, etc., or due to their small volume and composition, these materials may be discarded in an inert landfill. The smallest particle sized biomass fraction from the initial screening of the processed materials, preferably that has been further processed to remove the noncellulosic contaminating materials, is the homogenous cellulosic product.

An alternative transformation process utilizes a similar process vessel as shown in Fig. 1, but does not absolutely require the step of purging gases from the vessel and its contents prior to processing. However, such a purge step may be optionally used in the process at any time prior to depressurization, and most particularly after the vessel and its contents have reached the desired pressure and temperature, which is usually about 380 kPa and about 150°C. By conducting this optional purge step at the higher temperature, a more complete vaporization of the VOC's and other entrapped gases occurs, thus resulting in the removal of a greater proportion of the total VOC's contained within the materials being processed. Also, at the higher temperature, a significant quantity of water vapor can be vented simultaneous with the volatile air pollutants, thus resulting in a homogenous cellulosic product with a lower moisture content. The steps of the alternative process are substantially identical to the process recited above, except that the alternative process occurs at a specific temperature and pressure range. If the optional purge step is completely omitted from this alternative transformation process the VOC's and other potential air pollutants that would optionally be captured during an earlier purge step are captured for treatment during the depressurization step.

Preferably the residual moisture content of the processed cellulosic materials is significantly less than 65% by weight, and more preferably is less than 50% by weight. High moisture content has adverse effects on many possible processing steps subsequent to discharge from the vessel. As an example, moisture contents of the cellulosic product higher than 65% by weight are more or less "self-adhesive" and tend to form into compact, dense spheres which are difficult to dry and air classify, rather than retaining a loose, "fluffy" texture, which is a preferred objective of this process. Additionally, when the moisture content is higher than 65% by weight, the smaller cellulosic particles tend to adhere to other cellulosic particles making the resultant particle size larger than desired for screening. High moisture content cellulose also tend to adhere to noncellulosic components present in commingled wastes, such as MSW and biohazardous wastes, making such materials less desirable for recycling.

The principal purpose of moisture in the process is to insure uniform heat transfer and distribution throughout the diverse pulp and paper materials which facilitates their desired transformation. However, after the equilibration step, several steps may be included in the process to remove as much moisture as possible from the processed material, including an optional purge step in an alternative transformation process to capture and treat VOC's and other potential air pollutants at a higher temperature and pressure than purging during the heat-up step, thus also purging significant water vapor, depressurization with continuous vigorous agitation, which promotes evaporation of moisture from the exterior surfaces, cellular compartments, and capillary cavities of the cellulosic materials, evacuation after depressurization with vigorous agitation, which promotes the evaporation of additional moisture at temperatures below 100°C, screening in a hot air stream, air classifying with hot air, etc. The evaporation of retained moisture after processing also enhances the transformation of the cellulose into a fluff with extensive surface area while simultaneously cooling the products. Furthermore, a cool, dry product (less than 10% moisture by weight) may be stored for extended periods of time without odor or significant biodegradation as a result of molding or composting.

Using a prototype process vessel similar to that previously described by way of example herein and operating under conditions as disclosed in this present invention, experiments have shown that a wide variety of volatile organic compounds (VOC's) are present in MSW from both residential and institutional sources. Experiments have also shown that relatively large quantities of these volatile air pollutants can be removed from such wastes and captured for treatment as a result of processing such wastes using the method of the present invention.

For example, in one series of experiments in which several batches of residential MSW were processed, the total quantities of VOC's (U.S.E.P.A. Method 8260) recovered from processing ranged from about 3,503 to about 15,294 milligrams per metric ton of MSW (i.e., parts per million). The resultant homogenous cellulosic product contained less than 5 milligrams per metric ton, thus indicating that over 99 % of the VOC's present in the MSW were removed. When the purge step was included during the

heat-up phase of the process, the VOC's recovered from the purge step ranged from about 674 to about 5,678 milligrams per metric ton of waste (i.e., about 19 % to about 37 % of the total). The remaining VOC's (i.e., about 63 % to about 81 %) were recovered during the depressurization step. Of the total VOC's recovered, 891.5 milligrams per metric ton (about 21.2 %) were listed as hazardous by the U.S.E.P.A. Although about 66 % of the total VOC's were recovered during the depressurization step, almost 91 % of the hazardous VOC's were recovered during this step. This clearly indicates that the higher temperature of processing (e.g., about 150⁰C) is more effective for removal of VOC's from MSW than the lower temperatures of the purge step during the heat-up phase (e.g., ambient to about 100⁰C), and this is even more true for the hazardous VOC's.

As another example, in a second series of experiments in which several batches of institutional MSW were processed, , the total quantities of VOC's (U.S.E.P.A. Method 8260) recovered from processing ranged from about 3,126 to about 85,763 milligrams per metric ton of MSW (i.e., parts per million). The resultant homogenous cellulosic product contained less than 100 milligrams per metric ton, thus indicating that over 96 % of the VOC's present in the MSW were removed. When the purge step was included during the heat-up phase of the process, the VOC's recovered from the purge step ranged from about 275 to about 1,483 milligrams per metric ton of waste (i.e., about 1.7% to about 8.8 % of the total). The remaining VOC's (i.e., about 91 % to about 98 %) were recovered during the depressurization step. Of the total VOC's recovered, 6,201 milligrams per metric ton (about 18.5 %) were listed as hazardous by the U.S.E.P.A. Almost 98 % of the total VOC's were recovered during the depressurization step, and more than 88 % of the hazardous VOC's were also recovered during this step. This again clearly indicates that the higher temperature of processing (e.g., about 150⁰C) is more effective for removal of VOC's from MSW than the lower temperatures of the purge step during the heat-up phase (e.g., ambient to about 100⁰C), and this is even more true for the hazardous VOC's.

In another series of tests, using a prototype process vessel similar to that previously described by way of example herein and operating under conditions as disclosed in this present invention, it has been shown that the method is also effective for sterilization of

biohazardous laboratory and medical wastes. Microbial treatment efficacy was demonstrated to Level IV (sterilization) Microbial Inactivation criteria as recommended for alternative medical waste treatment technologies according to the *Technical Assistance Manual: State Regulatory Oversight of Medical Waste Treatment Technologies (U.S.)*. A greater than six log ($> 6 \text{ Log}_{10}$) microbial inactivation of bacterial spores (*Bacillus stearothermophilus*) was demonstrated under challenge conditions typical of those found with infectious medical wastes. The process of the present invention is also an improvement over the traditional steam sterilization process, since in a static autoclave heat transfer is primarily by conduction rather than direct steam contact. This is due to factors such as load and waste density, containment packaging, and load configuration that act as barriers to steam penetration and thus directly impact treatment efficacy. The degree of steam penetration through the waste load also has a direct influence on the time of sterilization (hours rather than minutes). With the present invention such barriers to steam penetration of the waste are eliminated since the wastes, particularly pulp and paper materials are finely macerated and film plastics are melted such that all of the components of the wastes are directly exposed to steam during the treatment process due to the continuous agitation. The present invention also provides additional improvement over traditional steam sterilization systems that typically release steam, heat, and foul odors during and after operation. The present invention eliminates such releases, particularly with respect to odors (VOC's and other air pollutants) by employing a ventilation system that directs the off-gases to a treatment process.

Having described the invention in detail and by reference to the drawings, it will be apparent that modifications and variations are possible without departing from the scope of the invention as defined in the following claims.

Claims:

1. A method for treating diverse pulp and paper materials to produce a homogenous cellulosic product comprising the steps of:
 - feeding diverse pulp and paper materials into a vessel;
 - introducing steam into the vessel while agitating the materials;
 - purging gases from the vessel through a vent valve while agitating the materials;
 - capturing and treating said gases to render any volatile organic compounds and any other air pollutants present in the gases harmless;
 - sealing the vessel so that the vessel is pressure tight;
 - saturating the materials with steam at sufficient temperature and pressure to expand the physical and chemical structure of the materials, while agitating the materials;
 - depressurizing the vessel to further enhance the physical and chemical expansion of the materials and optionally recover any steam remaining in the vessel; and
 - discharging the processed products from the vessel.
2. The method of claim 1 wherein the method further includes the step of introducing the steam from the depressurized vessel into a second vessel containing diverse pulp and paper materials for purging gases from the second vessel prior to sealing the vessel for treatment of the materials within the second vessel.
3. The method of claim 2 wherein the method further includes the steps of discharging processed products from each of a plurality of the vessels into a common conveyed stream, separating larger components from smaller components in the stream, and recycling the larger components through at least one of the vessels.
4. The method of claim 1 wherein the saturating step occurs at a temperature in the range of about 140°C to about 160°C.
5. The method of claim 1 wherein the saturating step occurs at a pressure in the range of about 275 kPa to about 450 kPa.

6. The method of claim 1 wherein the step of recovering steam further includes the steps of condensing the steam and treating any condensable pollutants to render them harmless.
7. The method of claim 1 wherein the step of recovering the steam includes the step of recycling the steam.
8. The method of claim 1 wherein the step of depressurizing the vessel includes the steps of cooling and drying the processed products, and capturing any volatile organic compounds or any other air pollutants remaining in the vessel.
9. The method of claim 8 wherein the step of capturing volatile organic compounds and other air pollutants further includes the step of treating the volatile organic compounds and other air pollutants to render the volatile organic compounds and other air pollutants harmless.
10. The method of claim 8 wherein the step of cooling and drying further includes an evacuation step.
11. The method of claim 1 wherein said processed products are transported for use as a fuel or fertilizer.
12. The method of claim 1 wherein said diverse pulp and paper products are derived from waste paper, MSW, or biohazardous waste including medical and laboratory waste.
13. A method as claimed in claim 1, wherein the diverse pulp and paper materials for treatment are biohazardous materials derived from laboratory and medical wastes containing diverse pulp and paper products and wherein the method produces a sterile homogenous cellulosic product, the method comprising the steps of:
 - (a) feeding biohazardous materials into a vessel;
 - (b) sealing the vessel so that the vessel is pressure tight;

- (c) injecting steam into the vessel while agitating the materials;
- (d) saturating the materials with steam at a temperature in the range of about 140°C to about 160°C and at a pressure in the range of about 275 kPa to about 450 kPa to expand the physical and chemical structure of the materials;
- (e) depressurizing the vessel to further enhance the physical and chemical expansion of the materials;
- (f) capturing any gases released during said depressurizing and treating said gases to render any volatile organic compounds and any other air pollutants present in the gases harmless; and
- (g) discharging the processed products from the vessel.

14. The method of claim 1 or claim 13 wherein the method further includes the step of classifying cellulosic components of the processed products from other components.

15. The method of claim 14 wherein the step of classifying includes the step of separating the cellulosic components based on particle size and/or on density.

16. The method of claim 1 or claim 13 wherein the method further includes the steps of separating larger size components of the processed products and recycling the larger size components through the vessel for more processing.

17. The method of claim 1 or claim 13 wherein the pulp and paper materials have a moisture content of about 20% to about 60% by weight prior to the step of introducing steam.

18. The method of claim 1 or claim 13 wherein the temperature and pressure are maintained for a time sufficient for the products to be uniformly mixed and transformed into the homogenous cellulosic feedstock.

19. The method of claim 18 wherein the time is in the range of about 30 to about 60 minutes.

20. The method of claim 1 or claim 13 wherein the vessel includes a common opening serving as an inlet and outlet and the steps of feeding the diverse pulp and paper materials into the vessel and discharging the diverse pulp and paper materials from the vessel are both accomplished through the common opening.

21. The method of claim 20 wherein the vessel includes two or more internally mounted helical flights, the rotation of which agitates the pulp and paper products.

22. The method of claim 21 wherein the rotation of the helical flights in one direction causes the products to move away from the common opening and/or the rotation of the helical flights in a second direction causes the products to move toward the common opening.

23. The method of claim 21 wherein the vessel is capable of being tilted such that the common opening is positioned to not permit the products to fall out of the vessel and/or the vessel is capable of being tilted such that the common opening is positioned to permit the processed products to fall out of the vessel.

24. The method of claim 8 or claim 13 wherein the step of capturing volatile organic compounds and other air pollutants further includes the step of treating the volatile organic compounds and other air pollutants to render the volatile organic compounds and other air pollutants harmless.

25. The method of claim 24 wherein the capturing and treating any volatile organic compounds or any other air pollutants includes a thermal oxidizer and/or an absorbent filter.

26. The method of claim 14 wherein the step of classifying cellulosic components of the processed products further includes a step of grinding to render any sharps harmless.