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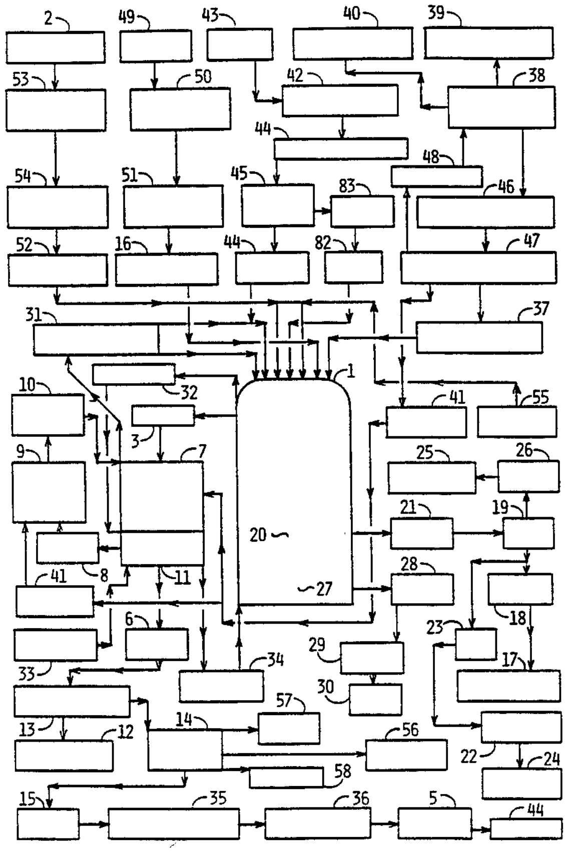
(54) Title: PROCESSES AND MEANS FOR WASTE RESOURCES UTILIZATION

(57) Abstract

Gasification, slagging, melting, and vaporizing components of waste materials and reactive carbon fuel, in variable proportions, at low pressures, using oxygen and steam reactants, effects very high temperatures, producing syngas (14) (hydrogen and carbon monoxide), molten slag (24) and molten metals (32). Integration provides steam and electricity from cogeneration plants (47). Treatment of coal or thermal separation of coal-methanol suspensoids, delivered by pipeline, provides the reactive carbon fuel. Syngas is cleaned and purified, then used to produce methanol (15), ammonia, or methanol and ammonia. Foamed light-weight nodules (aggregates) (22) and dense rock-like aggregates (27) are produced from molten slag. Recovery of molten metals effects optimum recycling. Some metals are produced by thermochemical reduction reactions. Byproducts of syngas cleaning are recovered and marketed. No remaining solids, no disposal problems.



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PROCESSES AND MEANS FOR WASTE RESOURCES UTILIZATION

FIELD OF THE INVENTION

This invention relates to combined gasification, slagging and metals production from combined feedstocks of solid waste materials and coal or lignite-derived particulate carbon fuel; integrated with cogeneration facilities for providing steam and electric energy and an air reduction oxygen plant for providing reactant oxygen; and having facilities for syngas cleaning, recovery of byproducts of syngas cleaning, production of methanol or ammonia (or methanol and ammonia) from syngas, recovery of molten metals, and production of building materials from moloten slag.

REFERENCES CITED

Pertinent are the following U. S. Patent Documents:

4,953,479	9/4/90	Keller; Stanton
4,742,784	5/10/88	Keller; Stanton
4,192,651	3/11/80	Keller
4,164,366	3/27/79	Keller
4,097,217	6/27/78	Keller
4,095,092	8/30/77	Keller
3,306,501	2/28/67	Keller

BRIEF DESCRIPTION OF THE DRAWINGS

The drawings are provided to facilitate the understanding of the present invention and the advantages and significance thereof:

Figure 1 is a flow diagram of the processes and facilities for the combined utilization of solid waste resources and coal or lignite resources, and for fuel methanol production, and co-product and byproduct recovery and utilization portions of the preferred embodiment.

Figure 2 is a schematic representation, in a vertical cross-sectional view, of the gasifying furnace used in the preferred embodiment.

Figure 3 is a horizontal cross-sectional view through the upper portion of the primary reaction zone within the gasifying furnace of the preferred embodiment.

Figure 4 is a vertical cross-sectional view taken on the centerline of the conical feed hopper, the feeder-distributor, the rotatable hollow center shaft and the rotatable circular feeder table of the preferred embodiment.

Figure 5 is a horizontal cross-sectional view taken on the plane A-A, shown in Figure 4, looking upward at the curved vertical-band spiral elements of the horizontal mounting plate above them, and the surge-preventing circular table mounted on the rotatable hollow center shaft of the preferred embodiment.

DETAILED DESCRIPTION OF THE INVENTION

The present invention makes use of new technologies, accumulated knowledge and other inventions, which have evolved during the past several years, in both related and unrelated fields, and adds thereto the unique new features necessary to provide practically, technically and economically feasible and environmentally beneficial answers for the very difficult problems encountered in attempts to provide practical, acceptable means for the disposal of municipal solid waste and other solid wastes, referred to collectively herein as solid waste materials. This is made possible by providing the processes and means of the invention for essentially complete chemical and physical restructuring and subsequent utilization of the resultant products from most non-radioactive solid waste resource materials which can be reduced by fragmentation, or shredding, to relatively small particle sizes, including most medical and biological waste materials and many materials classified as hazardous waste.

The smaller particle sizes of solid waste materials achieved by fragmentation facilitates the very rapid high-temperature complete oxidation, partial oxidation and gasification reactions of preheated oxygen with the combustible portions of the solid waste feedstock materials, simultaneous with the gasification reactions of pre-mixed oxygen and superheated steam, with the highly reactive coal or lignite-derived particulate carbon fuel also used as gasification feedstock material. The processes and means provided effect sufficiently high gasification reaction temperatures to liquefy (or slag) all of the non-metallic, non-combustible components in the combined feedstock materials and in the additives used; to melt or vaporize all the metals therein; to reduce some metals in metal-bearing compounds present to the metallic form; and to leave no solid residue or waste materials which require the use of landfills or other means of storage to effect disposal thereof. Essentially all of the components of the feedstock materials and additives are converted to marketable products, coproducts and byproducts, except for relatively minor amounts of the inert gases, carbon dioxide and nitrogen.

Referring to Figure 1, the integrated process flow diagram depicts a principal portion of the preferred embodiment of the present invention. An improved solid waste gasifying furnace 1, described in more detail hereinafter, is used in unique ways for simultaneously gasifying, slagging, melting and vaporizing the components of the solid waste materials 2, to produce a gaseous mixture, often called synthesis gas, hereinafter referred to as "syngas" 3. The syngas exiting the gasifying furnace is a gaseous mixture containing principally hydrogen and carbon monoxide, with relatively small amounts of inert gases such as carbon dioxide and nitrogen, very small amounts of vaporized metals, some entrained unreacted carbon, and inorganic mineral dust.

Such syngas is used, after adequate preparation described hereinafter, as feedstock for the production of methanol 4, using conventional catalysts, methods and facilities for the methanol plant 5 for methanol production, in the preferred embodiment. In other embodiments, the syngas may be converted to ammonia or synthetic natural gas (methane). Such conversion to methanol facilitates optimum utility and economics for the processes and means of the invention, which make the complete utilization of most solid waste resource materials profitable, practically feasible, and environmentally most desirable. The integrated processes and means of the present invention can provide new, low-cost sources for great quantities of methanol, which can serve many economically beneficial and environmentally desirable purposes, as will be shown.

The mole ratio of two moles of hydrogen to one mole of carbon monoxide must be provided in the cooled syngas 6, to provide acceptable feedstock for the standard methanol production facilities used for producing the methanol. This ratio must be adjusted, because there is not sufficient hydrogen in the initial syngas, as it is produced in the gasifying furnace. This mole ratio adjustment is accomplished by use of the carbon monoxide shift reaction, a conventional chemical process further described hereinbelow, to produce the additional hydrogen needed for this purpose.

The syngas produced is first cooled sufficiently, in the syngas cooling steam generator 7, to provide cool syngas 8 to allow operation of a carbon monoxide shift reactor 9, for producing a stream of high hydrogen content syngas 10, which is used for adjusting the ratio of hydrogen to carbon monoxide in the cooled syngas 6. After the ratio adjustment is completed, the syngas is cooled sufficiently, in the syngas cooling steam generator and its feedwater heater 11, to allow cleaning of the syngas by the removal of particulate materials 12 (dust or mud) in the particulate removal plant 13. The syngas is then purified by removing contaminants and diluents from the cooled syngas in the syngas cleaning plant 14; using conventional syngas cleaning methods and equipment. The proven and available methods and equipment most often used for the cleaning and purification of syngas, produced by coal or lignite gasification, are described in "Chemistry of Coal Utilization, Supplementary Volume, H. H. Lowery, Editor, Copyright 1963, by John Wiley and Sons, Inc., pages 1014 to 1022". Such methods and equipment have recently been commercially demonstrated and used in the United States, for syngas cleaning in coal and lignite gasification projects.

One such demonstration has been and is provided by the Great Plains Coal Gasification Project near Beulah, North Dakota, which provided a two billion dollar lignite gasification demonstration for producing synthetic natural gas (SNG). The project facilities have been in commercial operation for several years, and adequate gas cleaning capability has been well demonstrated on a very large scale. Another commercial demonstration was provided recently by the Cool Water Coal Gasification Program, an association of six industrial, institutional and government agency partners, which designed, constructed, operated and demonstrated the Cool Water Integrated Gasification Combined Cycle (IGCC) Power Plant at Doggett, California.

The cleaned syngas 15, of the present invention, is converted to methanol, to provide optimum utility and economics for the processes and means of the invention, for effecting the complete utilization or hydrogen and carbon in the solid waste resource materials and the particulate carbon fuel 16. The present invention provides for the co-utilization of solid waste resources and fossil fuel resources, as depicted herein as the preferred embodiment, for providing new low-cost sources for great quantities of methanol. The methanol, produced from solid waste materials and coal or lignite-derived particulate carbon fuels, requires no scarce crude oil or natural gas as feedstock, and can serve many beneficial and environmentally desirable purposes, as described hereinafter.

As is proven and very well known, methanol can be used as an automotive fuel for either specially designed, or slightly modified, conventional Otto cycle engines. It can also be used as the principal component of automotive fuels which contain small percentages of low-octane unleaded gasoline. The gasoline is used for giving color to the flame in event of accidental fires and for improving cold start capability. The gasoline also increases the fuel value of the mixture to a higher value than methanol alone.. One such example is the popularized "Mobil Formula", proposed by Mobil Oil Corporation and probably by many others. This fuel is eighty-five percent methanol and about fifteen percent gasoline, with some beneficial additives.

It has also been proven and demonstrated that methanol may be used with an additive called "Avocet", developed by Imperial Chemical Industries, ICI PLC, of Great Britain, to provide an environmentally preferable, non-petroleum replacement for diesel fuels for use in Diesel cycle engines. For reference, see "Testimony by Mr. Glenn Short of ICI Americas to the California Committee on Energy and Commerce, Sub-Committee on Health and the Environment, Los Angeles, California, January, 1989".

The methanol can also be used for producing methyl-tertiary-butyl-ether (MTBE), for use as a gasoline additive for "Reformulated Gasolines". It can also be used for blending with fuel ethanol, gasoline and additives to produce superior quality automotive fuels. One example of such blended alcohol fuels, which are called "Trinary Fuels (TF)", is approximately sixty percent methanol, thirty percent fuel ethanol, eight to nine percent low-octane unleaded gasoline, one to two percent diethyl ether and/or other ethers; with very small amounts of commercially available anti-corrosion additives and beneficial lubricants. The Trinary Fuels technologies, developed by Methacoal Corporation, can provide superior-performance blended alcohol fuels.

In other embodiments, mixtures of methanol and higher alcohols may be produced, instead of methanol, from the cleaned syngas, using conventional, well-known, and available equipment and catalysts. One such mixture of methanol and higher alcohols, and the processes and catalysts for producing such fuels were develped many years ago by Wentworth Brothers Engineering Company, of Cincinnatti, Ohio. The fuels were referred to as Methyl-Fuel, a name which was apparently trademarked by that company. The production of this or other mixtures of methanol and higher alcohols may, in some cases, prove to be more economical than producing methanol only. Cleaned syngas can also be provided as feedstock for other chemical processing purposes, such as the production of ammonia, using available conventional methods, where this proves beneficial and profitable.

The methods and equipment for the simultaneous gasification, slagging, melting and vaporizing of solid waste materials and reactive coal or lignite-derived particulate carbon fuel are depicted in Figures 2, 3, 4, and 5, and will be described in more detail hereinbelow. Referring again to Figure 1, utilizing methods and equipment provided, the coproduct materials, light-weight aggregates 17 are produced in foaming plant 18 from low-viscosity fluid slag 19, which is removed from the molten slag layer 20 by conventional state-of-the-art furnace tapping means. The fluid slag is moved away from the furnace by conventional slag runners 21, which are simply open troughs lined with refractory materials which can tolerate the high temperatures of the molten slag.

The fluid slag is thus moved to the nearby foaming plant, where rounded granules of light-weight aggregates are formed by directing streams of fluid slag, of various controlled small diameters, into pools of water of various depths, and continually removing the foamed aggregates from the pools of water. A similar process, wherein control of the particle sizes was relatively unimportant, was used for many decades for the purpose of preparing large quantities of electric furnace slag for transportation, as water-solids slurries. This means was used for many years for moving molten slag away from the slag-tapping areas of the electric furnaces, which were used in the elemental phosphorus industry.

Properly sized high-quality granular light-weight aggregates may be used to replace expanded shale, a light-weight aggregate material produced by heating shale to incipient fusion temperatures. This coproduct of the invention thus conserves the fuel energy required for the heating of shales to produce similar, but less durable, light-weight aggregates. Various sized fractions of light-weight aggregates, prepared by screening, may also replace crushed rock, pebble and sand for concrete construction, thus conserving quarrying, processing and transportation energy and providing superior-quality low-density concrete structures. Some sized fractions of light-weight aggregates may also be used as base materials for highway, roadway, airport, parking lot, slab floor, and slab wall construction. Dense rock-like material, called dense slag-rock 22, may also be produced by cooling fluid slag delivered by slag runners, in a slag pit 23, then breaking, crushing and screening the rock-like slag to produce crushed aggregate 24.

Rock-wool insulation 25, can also be produced by blowing of molten slag with steam or air, in a conventional blowing plant 26. For reference see "McGraw-Hill Encyclopedia of Science and Technology, 1960, Vol. 6, page 208b". Rock-wool insulation materials can be thus be produced without requiring fuel usually necessary for melting the rock and clay materials used for its production.

Molten metals are recovered from the molten metals layer 27, beneath the molten slag layer, and nearer the bottom of the furnace; and are passed by metal runners 28, which are refractory-lined troughs such as those used in the iron blast furnace industry, to a casting machine 29, of the same type used in pig iron casting operations, for the production of metal ingots 30, useful for further refining (not shown) and the production of elemental metals and metal alloys. For reference see "McGraw-Hill Encyclopedia of Science and Technology, 1960, Vol. 7, page 261".

Superheated reactant steam 31, is produced by using heat energy recovered from cooling of the hot syngas in the syngas-cooling steam generator; cooling of the syngas duct-work; cooling of syngas in the carbon monoxide shift reactor; cooling of the furnace shell and other equipment to produce hot water 32; passing gas plant feedwater 33 through the feedwater heater, to provide preheated feedwater 34; interstage cooling of syngas in the syngas compression plant 35 providing pressurized clean syngas 36; and cooling of the synthesis reactor (not shown) of the methanol plant. Superheated reactant steam from the syngas-cooling steam generator, the production of which is described in more detail hereinbelow, is used in the gasification process.

Saturated reactant steam 37, useful in the gasification process and for superheating in the syngas-cooling steam generator, could be provided in another embodiment of the invention, by a fuel-fired steam generating plant (not shown) provided as an integral part of the processing facilities. However, in the preferred embodiment, some form of cogeneration steam-electric facility is used as shown, to more efficiently and economically provide both steam and electricity for the integrated facilities. This can be accomplished, in other embodiments, by building the solid waste gasifying furnace and other facilities near an existing steam-electric power plant (not shown), and installing a system for extracting steam turbine exhaust steam therefrom, to provide the heat energy for reproducing saturated steam, using feedwater with minimum treatment, in a steam-to-steam heat exchanger system (not shown). The condensate from such a steam-to-steam heat exchanger could be returned to the power plant as feedwater to conserve energy and reduce feedwater requirements and costs.

In the preferred embodiment, a new cogeneration electric power plant 38, of the fossil fuel-fired type, is provided in areas where the additional electric generating capacity and electric energy are needed, or where an existing steam-electric power plant is not available. This cogeneration electric power plant may provide the electric energy for facilities 39, and electric energy for other uses 40, and also provide the saturated reactant steam requirements, and saturated steam 41 requirements.

The cogeneration electric power plant of the preferred embodiment can also provide superheated steam (not shown), directly from superheated steam headers in the power plant, for operating steam turbines used to drive compressors (not shown) in the conventional air-reduction oxygen plant 42, which uses ambient air 43 for the production of reactant oxygen 44, which oxygen is stored in reactant oxygen storage 45, for use in the gasification process. Superheated steam is also provided for operating steam turbines used for driving syngas compressors (not shown) in the syngas compression plant. The condensate (not shown) from the exhaust of such steam turbines is returned to the cogeneration electric power plant's condensate reservoirs (not shown), to conserve power plant feedwater, thus reducing feedwater treatment requirements and costs.

The saturated reactant steam, used for mixing with superheated reactant steam, thus supplying superheated reactant steam for the gasification reactions, may be efficiently provided from the cogeneration electric power plant, by using turbine exhaust extraction steam 46, in condensing-boiling steam generators 47, to produce the saturated reactant steam. Saturated steam is also produced in this manner for use as reactant steam in the carbon monoxide shift reactor, for superheating in the syngas cooling steam generator, and for other process and space heating purposes (not shown). This allows achieving optimum efficiencies of energy utilization, and condensate 48, from the condensing/boiling steam generator, is returned to the cogeneration electric power plant to minimize boiler feedwater treatment requirements and costs.

The particulate carbon fuel (PCF) is produced from coal or lignite 49, by pulverizing, drying if necessary, and treating with methanol in the particulate carbon fuel plant 50, then stored in particulate carbon fuel storage 51, for use as reactive feedstock for the solid waste gasifying and slagging furnace.

The present invention is facilitated by recent developments in the field of "Methacoal Fuels Technologies", see U. S. Patent No. 4,045,092, titled "Fuel Composition and Method of Manufacture"; and U. S. Patent No. 4,164,366, titled "Method of Removing Gangue Materials from Coal". These patented inventions and the associated technologies provide low-cost means for drying of the coal or lignite used, and for processing of the dried coal or lignite solids in methanol for producing Methacoal fuel, and low-cost means for delivering particulate carbon with closed-circuit Methacoal fuel delivery systems.

The Methacoal fuel is thermally separated at the pipeline terminus, in the Methacoal fuel separation plant, using helical screw processors and multiple disk processors (not shown), as the preferred means for producing the highly reactive particulate carbon fuel. Similar "pulverulent carbonaceous fuels" are described in U.S. Patent No. 4,192,651, "Method of Producing Pulverulent Carbonaceous Fuel"; and in U. S. Patent No. 4,742,784, "Methods for Reducing Nitrogen Oxides Emissions from

Power Plants Fired by Various Coals", wherein other means are employed for their production. In other embodiments of the invention, pulverulent carbonaceous fuels produced by any of these means may be used to provide the particulate carbon fuels (PCF) of the present invention. The fuel-grade methanol, sometimes called condensate liquid fuel, produced from Methacoal fuels by various means of thermal separation, may be returned and reused, again and again, as the fluid medium for producing and transporting the Methacoal fuels.

The present invention utilizes a combination of fragmented solid waste 52 and the particulate carbon fuel (PCF), as co-utilized feedstocks for the unique gasification process and equipment provided. The solid waste materials are processed and fragmented in a solid waste processing plant 53, in which the recovery of materials for recycling is optional, and the solid waste materials are reduced in particle sizes to the ranges of about minus one inch or two inch top sizes. Fragmented solid waste is then stored, for short periods of time only, in fragmented solid waste storage 54, of limited capacity, for subsequent feeding to the gasifying furnace. In the gasifier, the solid waste materials are exposed to pure oxygen, admitted at either near-ambient temperatures or at elevated temperatures, in such a manner that some of the materials are partially oxidized and some are completely oxidized, by oxidation reactions which take place very rapidly. This provides carbon monoxide and carbon dioxide for subsequent reactions with carbon and water, which can produce additional carbon monoxide and some of the additional hydrogen required, as will be further described hereinafter.

The particulate carbon fuel, PCF, is highly reactive as the result of the coal or lignite being dried (if not already low in moisture content) before the production of the PCF; as the result of the particle sizes being smaller than about one hundred microns; and as the result of multi-molecular layers of methanol molecules, remaining attached to both the internal and the external coaliferous surfaces of the coal or lignite-derived particles. This highly reactive PCF allows achieving the very rapid gasification reactions and very high initial gas temperatures necessary in the furnace, at near-atmospheric pressures, to liquefy, melt or vaporize essentially all of the non-combustible solids from the fragmented solid waste, from the reactive particulate carbon fuels, and from the mineral additives 55, which are used for controlling the slag chemical composition and the molten fluid characteristics of the slag. See previous reference "Chemistry of Coal Utilization, pages 955 to 957".

The low operating pressures used in the gasifying furnace, and the high initial gas temperatures achieved during gasification, cause the formation of primarily carbon monoxide and hydrogen gases in the resultant syngas produced. These are the two constituents of the syngas which are required for the catalytic synthesis production of the methanol. These processing conditions also minimize the formation of methane gas and other hydrocarbons in the syngas, see previous reference, "Chemistry of Coal Utilization, pages 895 through 899, and especially Figure 3, page 897". Hydrocarbon gases would be detrimental in subsequent processing, since the cleaned syngas is used for the production of methanol or ammonia. Mineral constituents of the ash of many coals and lignites have been found to have beneficial catalytic effects which increase the hydrogen content of syngas produced from coal or lignite in low-pressure high-temperature gasification processes. This was discovered and confirmed by researchers at the Energy and Environmental Research Center, University of North Dakota, during experimental work in their "Mild Gasification Program" for producing hydrogen and high hydrogen-content syngas from coals and lignites.

The injection of mixtures of superheated reactant steam and oxygen (thoroughly pre-mixed as is required) into the gasifying furnace, to mix and react therein with the reactive particulate carbon fuel and the fragmented solid waste materials, causes complex inter-related gasification reactions, which produce much of the hydrogen required to provide the two-to-one mole ratio of hydrogen-to-carbon monoxide, which must be provided in the cleaned syngas for its use as feedstock for methanol production. Introducing additional superheated steam, not pre-mixing with oxygen, in areas of the furnace outside the initial gasification reaction zone, can produce additional hydrogen by the reaction of such steam with carbon monoxide to produce hydrogen and carbon dioxide. There are some materials in the coal or lignite ash, in the solid waste materials, and in the mineral additives used, which will inherently serve as catalysts for this autogenous carbon monoxide shift reaction, which produces hydrogen and carbon dioxide.

Saturated steam from the cogeneration electric power plant, or from the syngas-cooling steam generator, is admitted as a reactant in a conventional catalytic carbon monoxide shift reactor, using a side-stream of relatively cool syngas, which has passed through the syngas-cooling steam generator, to produce a high-hydrogen syngas, to provide additional hydrogen needed in the syngas to be used for methanol production. The additional hydrogen required in the syngas is thus provided by the carbon monoxide shift reaction, sometimes referred to as the "watershift reaction". See previous reference, "Chemistry of Coal Utilization, pages 893 and 894". In this reaction, some of the carbon monoxide of the syngas is oxidized by water, as steam, to carbon dioxide, thereby taking oxygen from the steam and releasing hydrogen therefrom.

The present invention provides the processing capability for making adjustments in the ratio of the two feedstock materials, in order to compensate for the high degree of inherent variability in chemical and physical composition of the solid waste materials, and for the short-term and long-term variabilities in the rates of accumulation and delivery of the solid waste materials for any project area. Many difficulties would be encountered in storing the large quantities of solid waste materials which would be required to compensate for the inherent variabilities in both the fuel value and the quantity of solid waste materials, in order to provide reasonably constant feed rates, and to avoid serious and perhaps frequent turndowns in operating capacity and consequent reductions in productivity and profitability. The present invention also makes possible and profitable the mining of many existing landfills for the recovery and utilization of buried solid waste resource materials, where there has not been too much degradation of the fuel value of the materials from natural conversion to the pollutants, methane and/or carbon dioxide. This can allow avoiding the high costs of mining, transporting and reburying solid waste materials in new approved landfills, where that would otherwise be required.

The variabilities in quantity and quality of solid waste are accommodated by the processes and means of the invention, while maintaining continuity of operations and reasonably constant production capacity, which are both critical to the economics of most chemical processing operations. This is made possible by co-utilizing the fragmented solid waste materials and particulate carbon fuel as gasification feedstocks, thereby providing the capability for varying the percentages of the two feedstock materials, within acceptable limits, for example throughout the range from forty percent PCF to sixty percent PCF, on a fuel value basis, these being examples, not limits. The storage of large amounts of the PCF may be readily and inexpensively provided, while the storage of large amounts of solid waste materials would present serious problems and environmental hazards, and is most undesirable.

The particulate carbon fuels (PCF), used as gasifier feedstock, are produced from pulverized coal, or from Methacoal fuels in a Methacoal fuel separation plant, at the gasification project site, and are stored as dry particulate material in PCF storage silos, in adequate quantities to accommodate the variability in fuel values and rates of delivery of the solid waste materials. The PCF is moved to and from storage, and to the gasifying furnace, as fluidized solids in conventional equipment available for such purposes, and which use inert gas as the transport medium, for safety purposes and to protect the quality of the reactive PCF. In the preferred embodiment, the two feedstock materials are fed separately to the gasification furnace, as described hereinbelow, but in other embodiments could be fed by first blending PCF with the fragmented solid waste.

The ratio of PCF to fragmented solid waste, on a fuel value basis, may be varied within reasonably broad limits. The minimum percentage of PCF, which must be provided at any time, to prevent experiencing seriously detrimental effects on performance of the gasification process and equipment, will depend primarily on the moisture content and fuel value of the solid waste materials being used as feedstock, and these may be expected to vary greatly. The facilities could perhaps be operated with PCF feedstock only, however, this would defeat principal purposes of the invention, which are to provide practical and economical means for utilizing the solid waste resource materials, while eliminating the need for landfills, waste incineration, various fuel uses of waste, and those waste materials recycling activities which are not profitable or which present health hazards. Biomass materials produced as waste from farm crops, and biomass materials produced specifically for gasification, can also be used as feedstock materials for the gasifying furnace of the present invention.

There must always be sufficient percentages of the highly reactive PCF to allow achieving the very high gasification reaction rates and high initial gas temperatures required for simultaneous gasification, slagging, melting and vaporizing of the feedstock materials. The initial gas temperatures, developed by reactions of the pre-mixed oxygen and superheated steam with the particulate carbon fuel, will be in the range of three-thousand to four-thousand degrees Fahrenheit, and are controlled at the levels within that range, proven during actual operations to be required for maintaining acceptably low viscosities of the fluid slags produced and good percentages of carbon conversion. Slag viscosities should be in the range of about twenty to sixty centipoise for ease of tapping and utilizing most slags, for gravity separation of the molten slag and the heavier metals in the furnace, and for achieving good quality of the slag products. Gas temperatures throughout the reaction zone and the bottom of the gasifying furnace, though lower than the initial reaction temperatures, must also be sufficiently high to insure the rapid slagging, melting, or vaporizing of essentially all of the non-combustible solids in the fragmented solid waste, in the coal or lignite-derived particulate carbon fuels, and in the mineral additives used for control of the slagging process, before the product syngas reaches the syngas outlets from the gasifying furnace.

The high-quality syngas exiting the gasifying furnace is produced with maximum combined carbon monoxide and hydrogen content and with minimum amounts of hydrocarbons and carbon dioxide. A mixture of reactant oxygen and superheated reactant steam, adequately pre-mixed as required, is used for achieving the very rapid gasification reactions with the PCF, and the very high initial gas temperatures produced thereby, to facilitate producing syngas from the combustible portions of all the feedstock materials, and for maintaining the gas temperatures sufficiently high to either liquefy or vaporize essentially all of the non-combustible solids in the feedstock materials. This will generally require oxygen-to-steam mole ratios of about forty to fifty percent oxygen in the oxygen-steam mixture. See previous reference, "Chemistry of Coal Utilization, pages 954 and 955.

The low-viscosity fluid slag, with rock-like chemical/mineral composition, is produced primarily from the non-metallic non-combustible components of the feedstock materials. The chemical composition of the fluid slag is controlled by using the necessary mineral additives, in the required amounts, to provide low eutectic points (or low melting temperatures) for the mixtures of materials which form the low-viscosity fluid slags. This facilitates achieving complete liquefaction of the slag-producing materials, low fluid slag viscosities, and ease of removal by tapping of the low-viscosity fluid slag from near the bottom of the gasifying furnace. See previous reference, "Chemistry of Coal Utilization, pages 955 through 957", and additional references cited therein.

The chemical composition of the fluid slag is also controlled, to some extent, within desirable limits which are determined during actual operations, to facilitate obtaining the desired physical characteristics of the important coproduct, light-weight aggregates. The practical limits of fluid slag composition may be determined experimentally, and slag composition may then be monitored and controlled by using periodic chemical analyses of the materials produced from the fluid slag, and making necessary adjustments in slag composition by using the appropriate mineral additives.

The "silica ratio", which is defined as the ratio of silicon dioxide to the combination of silicon dioxide, ferritic iron oxide, magnesium oxide and calcium oxide, is an important parameter in studying and controlling the characteristics of slags, as reported in the above references. However, there will usually be very little ferritic iron oxide in these slags, because of the highly reducing conditions provided by the principal products of gasification, hydrogen and carbon monoxide. Most of the iron present as iron oxides and iron sulfides should be reduced to the metallic form and recovered with other metals as marketable product. Frequent adjustments in slag composition may be necessary, because of the high degree of variability which may be expected in the non-combustible solids portion of the feedstock materials, and because of the variations necessitated in the proportions of solid waste materials and particulate carbon fuel.

Very hot syngas, exiting from the top of the gasifying furnace, will be passed first through water-heating and nucleate-boiling sections (not shown) of the syngas-cooling steam generator shown in Figure 1. The tubing of the water-heating and nucleate-boiling sections of the syngas-cooling steam generator is capable of tolerating the high temperatures of the syngas from the furnace, and are used to substantially and quickly reduce those temperatures. If necessary, in some circumstances, the gases may be slightly precooled in the furnace by adding low temperature saturated steam or a mixture of low-temperture saturated steam and hot water (not shown), as discussed hereinbelow, in order to protect the tubing in the syngas cooling steam generator.

The somewhat lower temperature syngas, after passing through the initial feedwater heating and/or saturated steam generating tubing, then passes through the steam superheater tubing (not shown) in the syngas-cooling steam generator, where the syngas temperatures are further reduced as the steam is superheated to the desired temperatues. The steam superheating tubing could not tolerate the very high gas temperatures of the initial syngas exiting the gasifying furnace. Additional saturated steam generation tubing is also provided after the superheater tubing, to further reduce the syngas temperatures. The final syngas cooling is completed in the feedwater heating section of the syngas-cooling steam generator, as shown in Figure 1. If additional syngas cooling is required, beyond the capability of the feedwater heaters to remove and utilize such heat, combustion air or feedwater may be pre-heated for the cogeneration electric power plant. It may be necessary to waste some low temperature heat through air-cooled or water-cooled heat exchangers, in some cases.

The cooled syngas, exiting the feedwater heater, is thus reduced in temperature sufficiently to facilitate the removal, in a particulate removal plant, of entrained particulate materials, which are expected to be primarily metallic dust or muds, in most cases. In the event that substantial unburned carbon is found in the particulate materials, it may be separated therefrom and returned to the PCF storage for return to the gasifying furnace. The cooled syngas, after removal of the particulate materials, is compressed as required in the syngas cleaning plant, preferably using steam turbine-driven centrifugal compressors (not shown), to the pressures required for the particular conventional syngas cleaning methods and equipment selected and used.

Standard syngas cleaning methods and equipment have been developed and commercially demonstrated in the United States in recent years by both Government and Industry. Good examples are the gas-cleaning processes demonstrated at the Coolwater Integrated Gasification Combined Cycle Power Plant project, at

Doggett, California, and those used for the very large Great Plains Coal Gasification Project, in North Dakota, both previously referred to herein. Those methods and equipment may be used satisfactorily for the syngas cleaning for the present invention. After removal of carbon dioxide, nitrogen, nitrogen oxides, sulfur compounds, and other contaminants and diluents, the cleaned syngas is compressed in the syngas compression plant, to the synthesis reaction pressure required for methanol production. The specific pressure required depends on which of the conventional methanol synthesis processes and catalysts are selected. The pressurized clean syngas is then delivered to the methanol plant for synthesis conversion to methanol. The methanol may be produced as fuel-grade product, as chemical-grade product, or as mixed alcohols which are primarily methanol. In other embodiments, some or all of the pressurized clean syngas may be used for producing mixtures of methanol and higher alcohols, or for producing ammonia.

Various materials removed from the syngas during syngas cleaning, are recovered as byproducts for marketing, or to provide feedstock materials for product manufacturing. These include the particulate materials, unreacted carbon from the particulate materials, elemental sulfur 56, carbon dioxide 57 in gaseous or solid form, and nitrogen 58 in gaseous or liquid form. The particulate solids, removed from the cooled syngas, may be processed for recovery of metals and other useful materials, and the remaining materials may be returned (recycled) to the feedstock for the gasifying furnace. Other coproducts of value (not shown) are also produced, including excess-capacity liquid or gaseous oxygen, liquid or gaseous nitrogen, and other air-reduction gases, from the air reduction plant, if the preferred cryogenic oxygen process is used. Surplus hydrogen in the syngas may be produced by carbon monoxide shift reaction and later recovered from the purge-loop gases exiting the condensers of the methanol plant. This hydrogen could be recovered and prepared for marketing as either gaseous hydrogen or liquid hydrogen, when sufficient markets develop.

The solid waste materials are thus completely restructured and made useful by their conversion to marketable products, coproducts, byproducts and inert gases. Fragmented metals such as automobiles, home appliances, metal food containers, sheet metal roofing, and various other forms of light metals, may be added to the solid waste feedstock for the gasifying furnace. Even lead storage batteries, may be added to the feedstock, and the lead compounds of the battery should all be converted to metallic lead and other recoverable materials. It is also probable that shredded vehicle tires and some iron ores, especially pyrites and marcasites, may be useful as additional feedstock materials. Both would produce significant amounts of byproduct elemental sulfur. High-sulfur coals will be preferred for PCF production or Methacoal fuels production, since both the iron and the sulfur from the coals will be recovered and marketed.

Sewage plant solids could be accepted as feedstock, either in the dried form or as concentrated sludge, to provide a practical, beneficial and environmentally acceptable means of disposal thereof. Waste oils, lubricants and solvents, though not solids, will be desirable as additions to the feedstock materials. Hydrocarbon contaminated soils or clays could be used as mineral additives to provide a means of disposal which is less costly than currently required incineration, and without the environmentally questionable residues of incineration, which require disposal.

Medical wastes and many other materials classified as toxic wastes or hazardous wastes may be accommodated as feedstock additions without concern, and with great savings and environmental benefits. Because of the very high temperatures and reducing conditions achieved, there cannot be any dioxins or bacteria remaining in any of the product, coproduct or byproduct materials. There will be no remaining solids which must be disposed of by landfill burial or by other means of temporary or permanent storage for undesirable or unsanitary waste materials. Only minimal amounts of inert gaseous effluents, which are primarily carbon dioxide and nitrogen, will be discharged to the atmosphere. In many areas, most or all of the carbon dioxide recovered may be marketed for tertiary oil recovery and for other uses.

The methanol produced may be beneficial to the environment in various ways, such as providing neat methanol (methanol only) as low-pollution oxygenated automotive fuel, blended auto fuels made with the use of gasolines, blended methanol-ethanol-additive automotive fuels (called Trinary Fuels), superior-quality higher-efficiency gas turbine fuels, diesel fuel replacement using Avocet additive, and fuels for new types of very high efficiency methanol-fueled combined cycle power plants. The invention may be applied primarily for the purposes of eliminating "unsanitary landfills", sometimes inappropriately called "sanitary landfills"; costly and environmentally undesirable incineration, often used for solid waste volume reduction; and environmentally undesirable use of solid waste as refuse-derived fuels for steam or electric power generation, which exacerbates other serious environmental problems.

Conventional sorting and recycling of various materials, from the solid waste materials collected, may be accommodated to the extent that it is desirable and profitable. Where it is unprofitable or impractical, sorting and recycling may be entirely eliminated, and all the waste materials may be accepted as feedstock for the gasifying furnace of the invention. It may be beneficial and desirable to remove heavy metal objects before fragmentation, to protect the fragmenting equipment. It may be profitable to remove aluminum, either before or after fragmentation, depending on how much aluminum is oxidized in the gasifying furnace and lost to the slag.

Most municipal solid waste problems, and many other solid waste problems, can therefore be profitably eliminated, wherever such improvements are considered sufficiently valuable so that the "status quo" may somehow be altered, for profits, for conservation of valuable materials, for the benefit of mankind, and for the preservation and improvement of the human habitat, the Global Environment.

The principal integrated facilities required are the fragmented solid waste and particulate carbon fuel gasification facilites and facilities for the production of fuel methanol, building materials, and byproducts; at or near the source of the solid waste materials, integrated with a cogeneration (steam-electric) power plant, and indluding a large air reduction or other type of oxygen plant.

In other embodiments, a fuel ethanol plant and a TMR feeds plant may be integrated with, and located adjacent to, the solid waste gasification and methanol production facilities. Both principal facilities are then preferably integrated with either a new cogeneration electric power plant, or with a modified existing steam-electric power plant; which can provide all of the steam requirements not provided by the gasification project facilities; and which can also provide all the electric energy requirements for the processing facilities, while producing additional electric energy for the participating electric utility, or for sale to utility companies.

Figure 2 and Figure 3, present schematic illustrations of the gasifying furnace of the preferred embodiment, in order that one skilled in the art may understand this unique, cylindrical, vertical axis, low pressure, high temperature, slag-bed gasifier; and to make clear the means whereby it is capable of gasifying all the combustible components of the feedstock materials, slagging all the non-metallic non-combustible solids of the feedstock materials and the additives, liquefying or vaporizing all the metallic components of the feedstock materials, and reducing many compounds of the feedstock materials to their elements, or to other, often simpler, compounds. For example, reducing the iron in the iron sulfides to metallic iron, which is recovered as metal, and the sulfur therein to gaseous sulfur compounds, from which elemental sulfur is recovered in the syngas cleaning operations.

Figure 2 is a cross-sectional elevation view taken through the center of the solid waste gasifying furnace, a cylindrical, vertical axis, low pressure, high temperature, slag-bed gasifier. The outer furnace shell 59 is a water-cooled steel double wall, or may contain steam generating tubing, to allow recovery of the heat passing through the graphitized carbon furnace lining 60, and the insulating refractory materials 60 between the furnace lining and the outer furnace shell, and to facilitate maintaining uniform temperature gradients through the materials of the cylindrical furnace walls. The furnace lining is made of graphitized carbon blocks or cast in place graphitized carbon lining materials, and is backed by the insulating refractory materials to reduce the rate of flow of heat from the furnace.

Such furnaces must be relatively large in diameter, in order to provide a large slag surface area for -protecting the graphitized carbon lining 62, of the furnace bottom 63 and the graphitized carbon lining of the furnace shell, from damage by significant concentrations of unreacted oxygen, which might otherwise come in contact with the graphitized carbon. The diameter of the furnace is approximately the same dimension as the height thereof, and these dimensions, per unit of gasification capacity, will be relatively large, compared to high-pressure gasifiers of the same capacity. However, the costs for these very low pressure gasifying furnaces should be modest by comparison, since the high-pressure gasifiers typically require metal-walled pressure vessels, with walls several inches thick, and complicated high-pressure feed lock-hoppers, or slurry feeding systems, and high-pressure quenching and removal means for the partially-slagged ash.

Slag tap openings 64, are provided at various points around the periphery of the lower furnace walls for removing fluid slag by tapping, either intermittently or continuously, as is done in the case of removing slags and metals from electric furnaces, which also operate at very low (near-atmospheric) pressures. The position of the slag runners is shown in Figure 1, and they were described hereinbefore. Metal tap openings 65 are provided at various points around the periphery of the furnace walls, lower than the slag tap openings, and very near the bottom of the furnace. The molten metals may be removed therefrom by periodic tapping. The position of the metal runners is shown in Figure 1, and they were described hereinbefore.

Relatively large syngas exit ports 66 are provided around the periphery of the gasifying furnace, near the top of the furnace walls, and are connected to refractory-lined syngas ducts 67. The syngas ducts have double metal walls with inert gas therebetween for safety, as described in U. S. Patent No. 4,097,217, titled "Method for Converting Combustors from Hydro-Carbonaceous Fuels to Carbonaceous Fuels", issued to one of the co-inventors hereof. The ducts are also insulated on the outer surfaces. These ducts will transport the hot syngas to the syngas-cooling steam generators. Two or more sets of syngas ducts and two or more syngas-cooling steam generators are used, in order to facilitate uniform flow of syngas from the gasifying furnace into the ducts, and to minimize the lengths of the ducts required. The syngas-cooling steam generators and carbon monoxide shift reactors, shown in Figure 1, should be located at sufficient distances from the furnace to allow adequate access for slag tapping and metal tapping operations, which are located at positions around the furnace, and near the furnace bottom.

For the preferred embodiment, a dome-shaped furnace top 68 is shown, since this provides good self-supporting mechanical characteristics for the structure, and facilitates holding the refractory furnace top lining 69 thereunder. It also assists in supporting the various gasifying furnace feedstock and reactant feed equipment above and at the central areas of the dome-shaped furnace top. In other embodiments, a cone frustrum-shaped furnace top may be used. A conical feed hopper 70 serves as a surge chamber for the two lock hoppers 71, which alternately feed fragmented solid waste 72 into the conical feed hopper, in such a manner that there is no escape of syngas from the furnace through the conical feed hopper.

The lock hoppers are purged by steam or inert gas after emptying and some of the purge steam or gas is passed through the conical hopper and into the gasifying furnace. The empty lock hoppers are vented to a fume collection system during filling. Conveyor chutes 73, from conveyors (not shown) above the lock hoppers, alternately feed fragmented solid waste into one lock hopper then the other, as required. Various conventional conveyor arrangements and equipment are available to deliver the fragmented solid waste into the lock hoppers. In other embodiments, only one lock-hopper may be used, or a plurality of lock-hoppers may be used.

Referring to Figures 2, 3, 4 and 5, the fragmented solid waste material is fed from the conical feed hopper to the gasifying furnace in such a manner that the material is dropped continuously, falling uniformly from all points around the entire periphery of the rotating feeder table 74, of the feeder-distributor 75, at the center of and underneath the conical feed hopper. For reference regarding the feeder-distributor see U. S. Patent No. 3,306,501, titled "Feeder Apparatus", granted to one of the co-inventors hereof and assigned to Monsanto Company in 1967. This is truly a mass-flow feeder, in that all the material in the hopper remains continuously in motion, though moving very slowly, so long as the feeder table is turning. The mass flow rate is a function of the rotating speed of the feeder table only, the flow rate is very uniform at any fixed speed, and is approximately proportional to that rotating speed, with no other flow rate controls required. Figure 4 and Figure 5 show details of the feeder-distributor for clarification.

For the preferred embodiment, the rotating feeder table is refractory coated on the underneath side and is water-cooled or gas-cooled to provide protection from the extreme radiant heat it is exposed to from below. The other feeder parts and the hopper are protected from the heat by injecting ambient temperature inert carbon dioxide gas or low temperature steam, under slight positive pressure, inside the conical hopper, so it is forced to flow downward through the conical hopper and the feeder-distributor, and then into the gasifying furnace. The rotating feeder table is supported from above by a hollow rotatable center shaft 76, mounted in radial and thrust bearings 77 at the top of the conical feed hopper. The rotatable feeder table is rotated by the hollow rotatable center shaft, which is driven by a variable-speed drive mechanism 78, above the center of the conical feed hopper.

The diameter of the flat rotatable feeder table is considerably larger than the outer extremities of the feeder's spiral elements 79, which begin at the throat of the conical feed hopper, extend vertially downward therefrom, and spiral (extend) uniformly outward therefrom as they orient in the direction of rotation of the feeder table (the spiral plates remaining vertical), to a terminal point some distance outside the diameter of the throat of the conical feed hopper, and displaced radially in the direction of rotation of the feeder table, to a point on a radius thereof whereupon the next successive spiral element begins at the throat of the conical feed hopper. Three or more spiral elements are preferred for this type of application, and several are considered for the preferred embodiment, as shown in Figure 5. This arrangement of the spiral elements allows moving the solids off the outer periphery of the rotating feeder table at uniform rates, at all points around its periphery, to form a cylindrical curtain 80 of falling and dispersing fragmented solid waste materials, to facilitate the rapid combustion, partial combustion and gasificiation reactions required. A smaller diameter surge control table 81, is located slightly above the throat of the conical feed hopper, and is mounted on and rotated by the same rotating center shaft as the rotating feeder table.

Heated oxygen 82, from an oxygen heater 83, both shown in Figure 1, at the optimum temperature for desired performance; which optimum temperature must be established by operating experience for the specific gasifying furnace, feedstock materials, and operating conditions; is passed through the rotating center shaft and discharged downward through oxygen nozzles 84, shown in Figure 2, positioned below the central portion of the rotating feeder table. This places the heated oxygen inside the cylindrical curtain of solid waste materials, thus exposing the solid waste materials to the highly reactive oxygen at the optimum initial ambient or preheated temperatures for process control purposes. This facilitates the very rapid partial oxidation and complete oxidation reactions, between the solid waste materials and oxygen, as the surrounding reaction gases, at very high temperatures, force the materials inward toward the center of the furnace and downward toward the bottom of the furnace.

Referring to Figure 2, the mixture of reactant oxygen and superheated reactant steam 85, adequately pre-mixed, is continuously fed downward through alternately positioned nozzles 86, in a larger diameter circle of nozzles, around the outside of the falling curtain of solid waste materials. The other alternately positioned nozzles 87, in or near the same circle, feed reactive particulate carbon fuel 88, as fluidized solids in inert gas or steam, at controlled feed rates, and directed downward between the alternate streams of the pre-mixed reactant oxygen and superheated reactant steam.

The resultant combined gasification reactions between the reactive particulate carbon fuel and the mixture of reactant oxygen and superheated reactant steam, encompass the solid waste materials inside a cylindrical envelope formed by the very rapidly reacting and very high temperature gases produced by the reactions. The temperatures of the product gases formed by the reactions of the particulate carbon fuel and the mixture of reactant oxygen and superheated reactant steam will generally be within the range of three-thousand to thirty-five hundred degrees Fahrenheit, with the temperature at any time depending primarily on the mole ratio of reactant oxygen to superheated reactant steam, in the mixture thereof, which is injected into the reaction zone, through alternate nozzels, with the reactive particulate carbon fuel. See previous reference, "Chemistry of Coal Utilization, pages 954 and 955".

Increasing the mole ratio of oxygen to steam in the mixture thereof, will increase the temperature of the reacting gases, but this also increases the amount of carbon dioxide which is produced in the syngas, and which must be removed later in syngas purification. Under equilibrium conditions, the maximum gasification efficiency results when the mole-basis oxygen concentration in the pre-mixed reactant oxygen and superheated reactant steam, fed to the gasifying furnace, is in the range of forty to forty-eight percent oxygen. These concentration levels correspond to maximum temperatures, in the reaction zone, in the range of fifteen hundred degrees Cenigrade (2,732 degrees Fahrenheit) to eighteen-hundred degrees Centigrade (3,272 degrees Fahrenheit). Increasing the mole ratio of oxygen in the reactant mixture could increase the temperatures to about four thousand degrees Fahrenheit. See previous reference, "Chemistry of Coal Utilization, pages 954 and 955".

The downward-moving mass of high temperature reacting gases will accelerate as they expand, move downward, and impinge upon the surface of the underlying molten slag layer 89, near the bottom of the furnace, and above the molten metals layer 90. The reacting gases will then turn horizontally outward in all directions, toward the outer cylindrical walls of the furnace, traveling along the molten slag surface 91, and diminishing in velocity as they travel outward. This carries the hottest gases over the surface of the molten slag, and also tends to move any particulate materials, which may remain in the gas stream, downward onto the slag surface, where particles may stick and remain while continuing to react and gasify, melt, or vaporize. By the time the gases reach the graphitized carbon lining of the furnace walls, essentially all of the oxygen will have been consumed by the reactions, and the remaining gases will be primarily reducing gases, carbon monoxide and hydrogen.

In order to obtain nearer optimum percentages of hydrogen in the gases within the gasifying furnace, additional steam 92, either saturated or superheated, is added through another even larger diameter circle of downward directed steam nozzles 93 outside the primary reaction zone 94, and about midway between the center of the furnace and the furnace lining of the outer peripheral walls. A water-steam mixture (not shown) may also be added in this area, as discussed hereinbelow. The nozzles of this outer circle are directed downward so the steam may encompass and react with the already reacting gases in the outer portion of the primary reaction zone, and may assist in preventing highly oxidizing gases from reaching the graphitized carbon lining of the furnace shell, by containing them and moving them downward toward the molten slag surface. This admission of steam will also produce some additional carbon monoxide shift reaction and carbon-steam reaction within the furnace, and surplus steam may also be used to lower the exiting syngas temperatures. The carbon monoxide shift reaction will provide additional hydrogen, thus minimizing the amount of hydrogen which must be produced afterward, in the catalytic carbon monoxide shift reactor, shown in Figure 1.

Figure 3 is a horizontal cross section taken through the upper central portion of the furnace, near the top of the primary reaction zone therein. It depicts the concentric circular arrangements of the feedstock and reactant materials, as they begin their downward flow into the primary reaction zone of the furnace. The streams of oxygen 95, which are admitted at optimum temperatues for process control purposes, as required by the nature of the solid waste materials being used, are shown near the center of the concentric circles, with the larger diameter cylindrical curtain of solid waste materials 96 encompassing them. The alternately positioned streams 97 of pre-mixed reactant oxygen and superheated reactant steam and the alternately positioned streams 98 of reactive particulate carbon fuel injected with inert gas or steam, are both shown in the second encompassing circle.

The alternately positioned streams are shown as small circles, alternately clear 97, and then dark 98, which form the large circle. The streams of additional steam 99 shown as small clear circles, are shown in the third encompassing large circle, with a few additional streams of reactive particulate carbon fuel 100 shown as small darkened circles, provided in or near the same circle. These additional streams of reactive particulate carbon fuel can provide more carbon-steam reactions, if this proves advantageous with some feedstock materials or under some particular operating conditions, and would tend to reduce the presence of unreacted oxygen in the outer areas of the gasifying furnace, when this is found to be beneficial.

In the preferred embodiment, the waterheating, steam generation and steam superheating functions (not shown) of the syngas-cooling steam generator shown in Figure 1, are arranged in a unique manner for optimum performance and economy. The feedwater is first heated by the cooling of syngas in the feedwater heater to reduce syngas temperatures to the lowest practical levels before cleaning and compression of the syngas. Following additional heating in the furnace shell, or with parallel heating therein and in the feedwater heater; low-quality saturated steam (a mixture of vapor and tiny water droplets) is generated in the syngas cooling steam generator, at the design pressure. The design pressure must be established during design and engineering for a specific gasification project, since this pressure also inherently establishes the pressure of the superheated steam generated. Steam pressures must be sufficiently high to minimize the volumetric requirements of steam headers, steam generator tubing, superheater tubing, etc. Optimum steam pressures will generally be in the ranges of a few hundred pounds per square inch (psi) gage pressure.

The saturated steam must be produced with controlled quality, having more than sufficient liquid droplets remaining therein to contain all of the soluble and insoluble contaminants from the untreated or minimally treated feedwater used. This low-quality saturated steam generation is accomplished in the syngas-cooling steam generator, with the pressure of the saturated steam controlled, which also controls the pressure of the superheated steam produced from the saturated steam. This low-quality saturated steam is then passed through a conventional vapor-liquid phase separator (not shown), similar to the steam drums of conventional boiler plants, to produce clean saturated steam for subsequent superheating in the same syngas-cooling steam generator. The phase separator also produces controlled amounts of hot water, at the same temperature as the steam, which will contain all the dissolved and suspended contaminants of the initial feedwater.

The clean saturated steam, from the phase separator and its demister, is then superheated in the syngas-cooling steam generator, to the temperature level required for gasification process control. The reactant oxygen and superheated reactant steam are pre-mixed, as required, and as described in the previous references, for admission to the gasification zone of the furnace to sustain the gasification reactions. The hot water from the phase separator is taken by pipeline to the top of the furnace, where it is mixed with superheated steam at temperatures in the range of five-hundred to one-thousand degrees Fahrenheit, preferably in dynamic venturis, thereby forming mineral-bearing and mineral salt-bearing superheated steam at the resultant temperature, which is somewhat lower than the original superheated steam temperature. This contaminant-bearing superheated steam must be maintained at near-critical velocities, after mixing with the contaminant-bearing water, while being immediately fed into the gasifying furnace as streams of additional steam as shown in Figure 3. The high steam velocities and the substantial turbulence induced by the dynamic venturis are sufficient to prevent salting out and buildup of the mineral materials and mineral salts in the feed pipes or nozzles carrying the steam into the furnace.

The entrained solids and mineral salts in the lower temperature superheated steam will have no detrimental effect on the gasification reactions, and may therefore be tolerated in the process. They are relatively clean materials compared to the other feedstock materials, and some may serve as beneficial catalysts for the gasification process, as noted in the previous references. Most important, this provides means for avoiding the very high costs and difficulties of physically and chemically treating feedwater for the entire gasification process, in order that the saturated steam may be superheated in the conventional manner. If difficulties are encountered in this process, for any project or set of circumstances encountered, then the dirty hot water may be admitted directly into the gasification zone of the furnace, by being blown therein as streams of fine mist formed in venturis, with minimum quantities of either saturated or superheated steam required, to accomplish the same purpose.

Although this invention has been described with a certain degree of particularity, it is understood that the present disclosure is made only by way of example, as a preferred embodiment, and that numerous changes in the details of construction and the combination and arrangement of parts may be resorted to without departing from the spirit and the scope of the invention, reference being had for the latter purpose to the appended claims.

CLAIMS

What is claimed is:

1. A process for effecting virtually complete physical and chemical restructuring of municipal solid waste, other solid wastes, and other waste materials, hereinafter referred to as "solid waste materials", by high-temperature thermo-chemical conversion of said solid waste materials, in combination with particulate carbon fuel which is highly reactive, and using oxygen and steam as gasification reactants, thereby producing marketable products, coproducts and byproducts, and leaving no waste solids which must be disposed of by burying in landfills or by other means of solid waste containment and storage, and releasing only minor amounts of clean inert gases to the atmosphere, said process comprising;

preparing of gasification feedstock materials for storage, handling and feeding into a gasifying furnace, said gasification feedstock materials comprising said solid waste materials, with the particle sizes of said solid waste materials being reduced by conventional means of fragmentation to maximum dimensions in the range of two inches to three inches, as a first said gasification feedstock material, and comprising particulate carbon fuel, which is highly reactive and which is produced from coal or lignite, as a second said gasification feedstock material;

feeding said gasification feedstock materials simultaneously into said gasifying furnace, wherein simultaneous gasification, slagging, melting, and vaporizing of said gasification feedstock materials, and of mineral additives used to control the slagging process and the fluid characteristics of the molten slag, are all effected, said gasifying furnace facilitating the operation of a gasification process, utilizing the conventional and well-known gasification reactions to provide a low-pressure, high-temperature, totally-slagging gasification process;

providing storage means for large quantities of said particulate carbon fuel, thus making possible substantial adjustments in the proportions of said solid waste materials and said particulate carbon fuel being fed into said gasifying furnace, thereby allowing for the accommodation of inherent day-to-day variations, seasonal variations, and year-to-year variations, in the quantities and the fuel values, of said solid waste materials which are collected, processed and used as one of the said gasification feedstock materials, while maintaining ratios of the two said gasification feedstock materials within effective limits which allow adequately controlling and continually operating said gasification process at reasonable capacity levels for effective process control and profitable operation of the processing facilities;

gasifying, slagging, melting and vaporizing said gasification feedstock materials, simultaneously, and at very high gasification reaction temperatures and near-atmospheric pressures in said gasifying furnace, wherein pre-mixed reactant oxygen and superheated reactant steam are used as a gasification reactant mixture, while said reactant oxygen and said superheated reactant steam are also used separately, as said gasification reactants, said gasification reactions producing syngas (synthesis gas) which is typical for such conditions, having a high hydrogen content, high carbon monoxide content, near-zero methane content, and variable, but low, carbon dioxide content, said carbon dioxide content depending in amount on the feedstock characteristics and operating conditions;

converting most non-combustible solids contained in said solid waste materials, in said particulate carbon fuel, and in said mineral additives used to control the composition and fluid characteristics of said molten slag, or fluid slag, by the very high temperatures of said gasification reactions, in the range of three thousand to four thousand degrees Fahrenheit, and by the very strong reducing nature of the products of said gasification reactions, to said molten slag of low viscosity, to molten metals, and to metal vapors, collecting said molten slag in a molten slag layer near the bottom of said gasifying furnace and overlying a molten metals layer, collecting said molten metals in said molten metals layer, at the bottom of said gasifying furnace, removing said fluid slag and said molten metals separately by conventional tapping of said gasifying furnace, and recovering said fluid slag and said molten metals as valuable coproducts of said gasification process, said metal vapors being carried out of said gasifying furnace with the flow of said syngas exiting said gasifying furnace, and being condensed to powder-like metallic dust in a syngas cooling steam generator, as the temperatures of said syngas are reduced therein, and are then recovered as metallic dust in the cleaning of said syngas;

controlling the mineral-chemical composition of said fluid slag by the use of appropriate said mineral additives such as silica, iron oxides, limestone, and alumina, as needed, thus maintaining low eutectic points (low melting temperatures) of said fluid slag and facilitating gravity separation of the heavier said molten metals from the lower-density, low-viscosity said fluid slag, separately removing said fluid slag and said molten metals by said tapping through conventional tap-holes at different elevations, from near the bottom of said gasifying furnace, using said mineral additives to provide some control of the quality of foamed light-weight aggregates and rock-wool insulating materials, which are produced from said fluid slag as valuable coproducts;

removing said fluid slag from said molten slag layer, through said tap-holes of said gasifying furnace, and transferring said fluid slag by slag-runners to the desired location, where most of said fluid slag is poured, as controlled-diameter small streams of said fluid slag, into pools of water of controlled depths, forming rounded particles, or granules, of said light-weight aggregate, which are removed and classified as sized coproducts for subsequent use in concrete products manufacturing, for light-weight concrete construction, for roadbuilding, and for various other purposes, using some of said fluid slag for producing dense rock-like aggregate, called dense slag-rock, for crushing and screening for use as heavy aggregate for concrete construction and for railroad ballast or fill materials, and using some of said fluid slag for producing said rock-wool insulation materials by conventional blowing methods used for this purpose, thus conserving the energy generally required for melting of various mineral materials, to form molten mineral slags generally used in the blowing processes for manufacture of such useful inert insulating materials;

removing said molten metals through said tap-holes from said molten metals layer near the bottom of said gasifying furnace and beneath said molten slag layer, and transferring said molten metals by metal runners to casting machines, casting in molds and cooling to form metal ingots to facilitate handling, said metal ingots being usable for producing metals and alloys, or marketed as raw materials for the metal refining industries, precious metals being recovered in the metal refining operations and from metals removed from the bottom of said gasifying furnaces during outages;

removing heat energy of the high temperature said syngas exiting said gasifying furnace, by heating feedwater, generating saturated steam, and superheating steam in a syngas cooling steam generator and its feedwater heater, passing a side-stream of cool syngas from said syngas cooling steam generator through a carbon monoxide shift reactor, and reacting said syngas with saturated process steam, the carbon monoxide shift reaction providing additional hydrogen in a stream of high-hydrogen syngas which is re-mixed with said syngas from said gasifying furnace, in the amounts necessary for adjusting the mole ratio of said hydrogen to said carbon monoxide, of the product said syngas, to a two-to-one mole ratio of said hydrogen to said carbon monoxide, some of the heat generated in said carbon monoxide shift reactor being removed by generating saturated steam therein, said saturated steam being subsequently superheated in said syngas cooling steam generator, thus utilizing said heat energy for the purposes of preheating said feedwater, generating saturated steam from said feedwater, and superheating said saturated steam to produce superheated reactant steam for use in said gasifying furnace, the removal of said heat energy thus effecting the cooling of said syngas to the required temperatures for removal therefrom of particulate materials including said metallic dust, said syngas cooling being supplemented as required by air-cooled or water-cooled heat exchangers recovering heat energy for other purposes, or for wasting surplus said heat energy to cooling water or to the atmosphere;

providing additional saturated steam, required for supplementing said saturated steam generated in said syngas cooling steam generator, and similarly used for subsequent said superheating in the same said syngas cooling steam generator, from a cogeneration electric power plant, which is made an integral part of the facilities provided, said cogeneration electric power plant providing the electric energy required for said integrated facilities, and also electric energy for other uses, said additional saturated steam being provided by turbine exhaust extraction steam, used in condensing-boiling steam generators for producing said additional saturated steam, with condensate from said condensing-boiling steam generator being returned to said cogeneration electric power plant to conserve boiler feedwater for said cogeneration electric power plant, and to reduce treatment requirements and costs for said boiler feedwater, and providing additional superheated steam, directly from superheated steam headers in said cogeneration electric power plant, said additional superheated steam being used for powering steam turbines driving air compressors of a cryogenic air-reduction oxygen plant, providing reactant oxygen for said gasification reactions, said additional superheated steam also being provided to power other steam turbines driving syngas compressors of a syngas cleaning plant and syngas compressors of a syngas compression plant, with exhaust condensate from said steam turbines being returned to said cogeneration power plant to conserve said boiler feedwater, and to reduce treatment requirements and costs for said boiler feedwater, thus improving energy utilization efficiencies and reducing operating costs for all the integrated facilities provided;

cleaning and purifying hot said syngas exiting said gasifying furnace, said syngas having been cooled in said syngas-cooling steam generator and said feedwater heater, supplemented as required by said heat exchangers for cooling said syngas, by removing said particulate materials including said metallic dust, chemical impurities, and undesirable diluents therefrom, which, if not removed, would adversely affect subsequent synthesis reactions, said syngas being cleaned and purified by using the best available standard dust removal methods and equipment and gas cleaning methods and equipment, and the purified gaseous product, cleaned syngas, is then further compressed in said syngas compression plant for providing pressurized clean syngas;

converting said pressurized clean syngas by synthesis reaction to methanol, using a standard methanol plant, surplus heat energy being recovered from said methanol plant, and said surplus heat energy therefrom being used for generating steam for superheating in said syngas-cooling steam generators; in another embodiment, part or all of said pressurized clean syngas may be converted by a similar synthesis reaction, using conventional facilities and catalysts, to mixtures of methanol and higher alcohols, in yet another embodiment, part or all of said pressurized clean syngas may be converted by yet another synthesis reaction, using conventional facilities and catalysts, to ammonia.

recovering said byproducts from said syngas cleaning plant by proven, conventional means, in forms which are marketable as byproduct materials, sulfur present in chemical compounds is converted to elemental sulfur for marketing as such, metallic dust recovered from syngas cleaning is marketed to metal refiners, carbon dioxide gas from syngas cleaning is used as inert gas and marketed for tertiary oil recovery and for other conventional uses, and nitrogen gas from syngas cleaning is used as inert gas and marketed to the cryogenics industries to the extent possible, the surplus carbon dioxide and nitrogen are discharged to the atmosphere, adequate provisions are made and proper precautions are taken in all designs, processes and operations to minimize environmental impacts, the escape of undesirable effluents of any kind, or production of any solid remnants of processing which would require burying in said landfills, or disposal by said other means of waste containment and storage.

2. The process of Claim 1, wherein said cogeneration electric power plant is a new facility, designed for use as an integral part of the gasification project facilities, said electric energy is provided therefrom for said integrated facilities, and surplus said electric energy may be produced for other uses.

3. The process of Claim 1, wherein said cogeneration electric power plant is provided by the modification of a previously existing steam-electric power plant, with the modified said steam-electric power plant being used as the cogeneration steam electric power plant described therein.

4. The process of Claim 1, wherein said cogeneration electric power plant is provided as a Methacoal Integrated Combined Cycle Power Plant, (MICC) power plant, and Methacoal fuel provided for thermal separation thereof, to provide the required condensate liquid fuel and said particulate carbon fuel for the operation of said MICC power plant, and to also provide said Methacoal fuel for a thermal separation plant providing said particulate carbon fuel for said gasification project facilities, is produced from low-cost said coal or low-cost said lignite at the remote sources thereof, and said methanol, used as a component of said Methacoal fuel is produced from low-cost natural gas from remote sources, or alternatively said methanol is produced, by coal gasification, from the same said coal or said lignite used for the production of said Methacoal fuel, and said Methacoal fuel is delivered by Methacoal fuel pipelines or by combinations of said Methacoal fuel pipelines and marine tankers or barges, to the site of said gasification project facilites, and condensate liquid fuels and said pulverulent carbonaceous fuels, produced from said Methacoal fuel, are consumed by said MICC power plant, thus making said methanol, which is produced by said methanol plant of said gasification project facilities, and also said methanol which is recovered from said Methacoal fuel by thermal separation in producing said particulate carbon fuel for said gasifiers of said gasification project facilites, both available for local or regional marketing as said methanol, or for use in the production of Trinary Fuels, said Trinary Fuels being blended alcohol fuels containing approximately sixty percent said methanol, thirty percent ethanol, eight to nine percent unleaded gasoline, and one to two percent of selected ethers and other additives.

5. means for effecting essentially complete physical and chemical restructuring of solid waste materials, including municipal solid waste, and various other solid wastes, by the high temperature thermo-chemical conversion of said solid waste materials, in combination with particulate carbon fuel, to marketable products, coproducts and byproducts, thereby leaving no waste solids which must be disposed of by burying in landfills or by other means of solid waste containment and storage, and releasing only minor amounts of clean inert gases to the atmosphere, said means comprising;

a gasifying, slagging and metals recovery furnace, hereinafter referred to as a gasifying furnace, said gasifying furnace being a cylindrical bodied, vertical axis, low pressure, high temperature, slag bed type of said gasifying furnace, having a furnace shell which is made of metal, and which is double-walled metal and is water-cooled, said furnace shell containing an inner furnace lining made of graphitized carbon materials, said furnace lining being able to resist damage from the very high temperatures of reacting gases and product gases formed by gasification reactions therein, and from the molten slag and molten metals produced and accumulated therein, said furnace lining being backed with refractory materials, between said graphitized carbon materials of said inner furnace lining and said furnace shell, to minimize the heat losses through said furnace lining and to the cooling water of said furnace shell, and to maintain uniform temperature profiles through said graphitized carbon materials, furnace tap-holes being provided at two or more elevations around the periphery of said gasifying furnace, near the bottom thereof, for separately removing said molten slag and said molten metals from said gasifying furnace, said gasifying furnace having a dome-shaped furnace top, containing a refractory lining thereunder for protection from the very high temperatures of said reacting gases and said product gases thereunder, and having a double-walled outer shell which is water cooled;

said furnace top supporting, at and near its center, equipment for feeding gasification feedstock materials into said gasifying furnace, and for feeding gasification reactants into said gasifying furnace, with said gasification feedstock materials consisting of fragmented said solid waste materials and highly reactive said particulate carbon fuel, and with said gasification reactants consisting of a mixture of reactant oxygen and superheated reactant steam, and said oxygen used as such and introduced either at ambient temperatures or at elevated temperatures, said superheated reactant steam introduced as such, saturated reactant steam, and mixtures of steam and hot water, all fed downward at or near the top of and in central areas of said dome-shaped furnace top of said gasifying furnace;

said gasifying furnace comprising an interior chamber located inside of said inner furnace lining, said interior chamber being bounded by said furnace top, side walls of said furnace shell, and a slag surface of a slag bed containing molten slag produced by the high temperatures of said gasification reactions, said side walls extending between said furnace top and the bottom of said furnace, said interior chamber comprising a central area and a peripheral area, said central area extending from said equipment for feeding said gasification feedstock materials and said gasification reactants downward through said central area of said furnace top and onto said slag surface, said slag surface extending radially outward from a lower portion of said central area to said side walls, said peripheral area being located around said central area so as to be interposed between said central area and said side walls, said central area, said slag surface and said peripheral area forming a flow path, wherein said gasification feedstock materials and said gasification reactants are introduced into the top of said central area by said equipment for feeding said gasification feedstock materials and said gasification reactants, and wherein they react to form a mixture of reacting gases and product gases, said reacting gases and said product gases flowing downward through said central area to said slag surface where they are forced radially outwardly into said peripheral area, said gases then flowing upward through said peripheral area;

said gasifying furnace having exit ports in said side walls, near said furnace top, said exit ports communicating with said peripheral area, said exit ports being used for withdrawing said product gases, called syngas, from said gasifying furnace, refractory lined ducts are connected to said exit ports, said ducts transporting said syngas to a syngas-cooling steam generator, said ducts having double metal walls, with an opening therebetween for circulating inert cooling gas, wherein said circulating cooling gas also serves as a monitoring medium for detection of poisonous gas leakage, thus providing safe containment and transmission therethrough of said syngas.

6. The means of Claim 5, wherein the feeding system for feeding said fragmented solid waste materials into said gasification furnace comprises conveyor feed chute(s) for feeding

said solid waste materials into one or more conventional lock-hoppers, said lock-hoppers providing gas-tight seals, while accumulating batches of said solid waste materials and while feeding said batches of said solid waste materials into a conical feed hopper therebelow, said conical feed hopper being positioned above and at the center of said dome-shaped furnace top of said gasifying furnace, said conical feed hopper providing a surge bin and collecting hopper for said solid waste materials coming from said lock-hopper(s) above, and delivering said solid waste materials, by gravity flow, into a feeder-distributor provided therebelow;

said feeder-distributor feeds said solid waste materials from said conical feed hopper, said feeder-distributor being a mass-flow table feeder, using a horizontal, circular feeder table which is rotatable, said mass-flow feeder being provided with multiple spiral elements, said spiral elements being stationary, curved, vertical, metal bands, each said spiral element starting at the circumference of the throat at the bottom of said conical feed hopper (the smallest diameter thereof), and each spiralling uniformly outward in the direction of rotation of said feeder table of said feeder-distributor, to an optimum point at a larger radius from the center of said feeder table, each said spiral element reaching only to a terminal point on a radius extended from the circumference of the throat of said conical feed hopper, which said terminal point is outside the beginning end of the next said spiral element, said spiral elements being positioned just fractions of an inch above, but not touching, the rotatable said feeder table, and being firmly attached at their upper edges to the bottom side of a horizontal annular-shaped mounting plate, said mounting plate being attached to the throat of and to the inside lower walls of said conical feed hopper, said feeder table being sufficiently larger in diameter than the outer extremities of said feeder-distributor's said spiral elements, to allow the outer vertical faces, or sides, of said spiral elements to effect the uniform distribution of said fragmented solid waste materials on the surface areas of said feeder table, which are outside said spiral bands, as said feeder table rotates;

said feeder-distributor thus effects a uniform flow of said fragmented solid waste materials over the periphery of said rotatable feeder table, while said feeder table is rotating, flowing at all points around its circumference, and at discharge rates of said solid waste materials which are direct functions of the rotating speed of said rotatable feeder table, the hollow center shaft which supports and rotates said feeder table being supported in radial and thrust bearings mounted at the top of said conical feed hopper, and being rotated by a variable-speed driving mechanism to allow accurate control of the feed rate of said fragmented solid waste materials into said primary reaction zone of said gasifying furnace, for process control purposes, thus effecting the downward movement of said fragmented solid waste materials as a thin, falling, cylindrical-shaped curtain of said fragmented solid waste materials, with pure said oxygen, admitted either at near-ambient temperatures or after being heated to elevated temperatures, said oxygen being transported downward through a tube or tubes, passing through said hollow center shaft, and being discharged at controlled feed rates through oxygen nozzles pointed downward and mounted underneath said feeder table, thus providing direct contact of highly reactive said oxygen with said fragmented solid waste materials, to cause complete oxidation reactions and partial oxidation reactions to take place very rapidly, followed by the other gasification reactions, thus oxidizing, partially oxidizing, and gasifying combustible components of said fragmented solid waste materials and producing carbon monoxide gas, carbon dioxide gas, hydrogen gas and superheated water vapor;

and wherein the means provided for simultaneously feeding said gasification reactants and said highly reactive particulate carbon fuel into said gasifying furnace, comprise one set of alternately positioned nozzles, in or near a first circle of such said nozzles, positioned just outside said cylindrical curtain of said fragmented solid waste materials, said nozzles passing through said dome-shaped furnace top of said gasifying furnace, are used to feed a pre-mixed mixture of reactant oxygen and superheated reactant steam, downward into said primary reaction zone of said gasifying furnace, while another set of alternately positioned said nozzles, in or near said first circle of said nozzles, and passing through said dome-shaped furnace top of said gasifying furnace, feeds reactive said particulate carbon fuel, as fluidized solids carried by steam or inert gas, downward into said primary reaction zone, between the alternately positioned streams of pre-mixed said reactant oxygen and superheated reactant steam, to achieve the very rapid gasification reactions between reactive said particulate carbon fuel and the pre-mixed mixture of said reactant oxygen and superheated reactant steam, producing said gasification reactions, said gasification reactions having been shown to take place, almost to completion, in about ten milliseconds, thus the falling said cylindrical-shaped curtain of said fragmented solid waste materials, while being oxidized, is surrounded by very high temperature said reacting gases and product gases of said gasification reactions, at controlled initial temperatures in the range of three thousand to four thousand degrees Fahrenheit;

a second circle, or set of circles, of said nozzles, said circle or circles being even larger in diameter, and with said nozzles passing through said dome-shaped furnace top, and being positioned about midway between the center of said gasification furnace and the cylindrical said furnace walls, and outside the alternatively positioned said nozzles in said first circle of said nozzles described above, is used to feed mixtures of said saturated steam and hot water, or mixtures of said superheated steam and hot water, as best effects optimum process and operating controls, to effect additional reactions of steam with said carbon monoxide, by effecting said carbon monoxide shift reaction, thus producing some additional said hydrogen, and to react with unreacted carbon in the said reacting gases to produce said carbon monoxide, said carbon dioxide, and said hydrogen, with additional nozzles also being provided for feeding reactive said particulate carbon fuel, as said fluidized solids carried by other said steam or said inert gases, through other said nozzles in these outer said second circles of nozzles, in event this is required or proves to be advantageous during operation of said gasifying furnace in some situations or circumstances.

7. A process for simultaneously gasifying the combustible components of gasification feedstock materials; converting most non-combustible components of said gasification feedstock materials to molten slag, molten metals and metal vapors;

thermochemically reducing some metal-bearing compounds of said gasification feedstock materials to elemental metals and gaseous compounds; and thermochemically reducing many components of said feedstock materials to chemically simpler molecular forms, said process comprising;

gasifying, slagging, melting, vaporizing and thermochemically converting, simultaneously, said gasification feedstock materials in a unique, cylindrical bodied, vertical axis, low pressure, very high temperature, slag-bed protected gasifying furnace, said gasifying furnace having a furnace shell made of metal, said furnace shell being double-walled and cooled by circulating water therebetween, and containing a furnace lining of graphitized carbon materials, said furnace lining being capable of resisting damage from the very high temperatures of synthesis gas (syngas) produced therein by the gasification reactions, and from the molten slag and molten metals produced in said gasifying furnace and accumulated in separate layers therein, said molten metals being in a layer at the bottom of said gasifying furnace and below the layer of said molten slag, said furnace lining being backed with insulating refractory materials, between said graphitized carbon materials of said furnace lining and the inner wall of said furnace shell, to minimize heat losses through said furnace lining and said furnace shell, and to maintain uniform temperature profiles through said graphitized carbon materials of said furnace lining;

conventional tap-holes are provided at two or more elevations around the periphery of said gasifying furnace, near the bottom thereof, for separately removing said molten slag and said molten metals from said gasifying furnace, said gasifying furnace having a dome-shaped furnace top, the outer shell thereof being of double-walled metal construction, and containing a refractory lining thereunder for protection of said outer shell from the very high temperatures of the reacting gases and of the product gases thereunder, said outer shell of said dome-shaped furnace top being water-cooled, said dome-shaped furnace top supporting or assisting in supporting, the equipment providing said gasification feedstock materials and gasification reactants for said gasifying furnace;

said gasification feedstock materials for said gasifying furnace being of two classes: 1) particulate carbon fuel, and 2) fragmented materials, wastes and fuels; said particulate carbon fuel comprising coal or lignite-derived particulate carbon fuel, finely pulverized coal or lignite, or methanol activated pulverulent carbonaceous fuel; and said fragmented materials, wastes and fuels comprising a wide variety of materials which may be combustible, partially combustible or non-combustible, and may include municipal solid waste, biomass waste, biomass fuels, industrial waste, sewage plant solids or sludges, medical waste, biological waste, agricultural waste, food processing waste, contaminated soils, shales with high carbon content, shales with high hydrocarbon content, vehicle tires, scrap rubber, lead storage batteries, refinery waste materials, waste solvents and solvent sludges, chemical wastes, many hazardous waste materials, sulfur-bearing iron ores, other metal ores, and mineral additives used to control the slagging process and the viscosity of said molten slag;

said fragmented materials, wastes and fuels being prepared by conventional means of particle size reduction, to sizes smaller than about one to two inches, and mixed or blended sufficiently to minimize variability to acceptable levels for handling and for feeding to said gasifying furnace, and to sustain reasonably uniform gasification, slagging, melting and vaporization of the components of said fragmented materials, wastes and fuels, another requirement being that the combined feedstock materials contain sufficient combustible materials to sustain the rapid gasification reactions required, to provide sufficiently high resultant temperatures of initial said gasification reactions, said reacting gases, and of slagging solids, and to maintain temperatures of said molten slag in the ranges effecting low viscosities of fluid slag, to facilitate tapping of said fluid slag from said gasifying furnace, and the production from said fluid slag of light-weight foamed aggregate, dense slag-rock aggregate and rock wool insulation materials;

gasification reactants provided to sustain and complete said gasification reactions which provide the heat energy for said slagging, melting, vaporizing and thermochemical conversions comprise mixtures of pre-mixed reactant oxygen and superheated reactant steam, ambient temperature reactant oxygen, heated reactant oxygen, superheated reactant steam, saturated reactant steam, and mixtures of steam and water;

mixed or blended said fragmented materials, wastes and fuels, hereinafter referred to as "materials" are fed to said gasifying furnace, the feeding system for said materials comprising conveyor feed chute(s) receiving said materials and feeding said materials into one or more lock-hoppers which form gas-tight seals while feeding said materials into a conical feed hopper therebelow and positioned above the center of said gasifying furnace, said conical feed hopper acting as a surge bin and collecting said materials from said lock-hopper(s) above and delivering them by gravity flow into the feeder-distributor, said feeder-distributor being a mass-flow table feeder, using a horizontal, circular, feeder table which is rotatable, and using spiral elements, which are stationary, vertical, curved, metal bands, starting at the circumference of the throat at the bottom of said conical feed hopper (the smallest diameter thereof), and spiralling uniformly outward in the direction of rotation of said feeder table of said feeder-distributor, to an optimum larger radius, each said spiral element reaching only to a point on a radius extended outward from the circumference of the throat of said conical feed hopper, which point is outside the beginning end of the next said spiral element, with said spiral elements being positioned just fractions of an inch above, but not touching, the rotatable said feeder table, and being firmly attached to the bottom of said conical feed hopper by a circular horizontal mounting plate, said feeder table being sufficiently larger in diameter than the outer extremities of said feeder-distributor's said spiral elements, allowing the outer vertical faces, or sides, of said spiral elements to effect uniform distribution of said materials on the surface areas of the rotating said feeder table which are outside the outer ends of said spiral elements;

said feeder-distributor thus effecting the uniform flow of said materials over the periphery of said rotatable feeder table, while it is rotating, at all points around its circumference, and at discharge rates which are direct functions of the rotating speed of said rotatable feeder table, with the hollow center shaft which supports and rotates said feeder table being supported in radial and thrust bearings mounted at the top of said conical feed hopper, said feeder table and said hollow center shaft being rotated by a variable-speed driving mechanism to allow accurate control of the feed rate of said materials into the primary reaction zone of said gasifying furnace, said materials are fed over the edges of said feeder table to fall downward as a cylindrical-shaped curtain of said materials, with pure said oxygen, admitted either at near-ambient temperatures or after being heated to elevated temperatures, said oxygen being transported downward through a tube or tubes, through said hollow center shaft, and exiting through oxygen nozzles mounted underneath said feeder table, thus providing direct contact of said oxygen with said materials, to cause complete oxidation reactions and partial oxidation reactions, with the combustible portions thereof, to take place very rapidly, thus oxidizing and gasifying the combustible components of said materials, producing carbon monoxide gas, carbon dioxide gas, hydrogen gas and superheated water vapor;

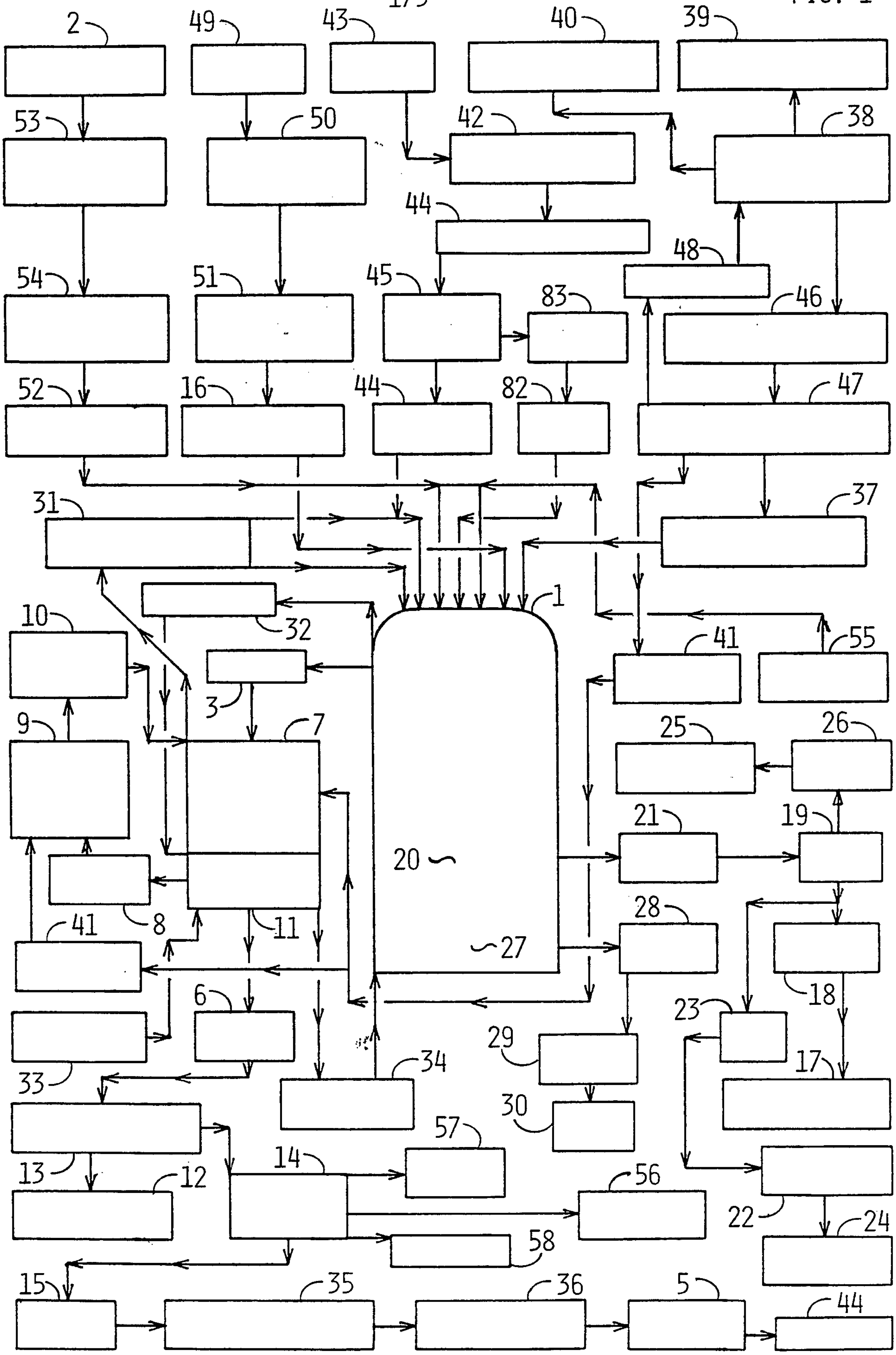
simultaneously, a first set of alternately positioned nozzles, in or near a first circle of such said nozzles, just outside said cylindrical curtain of said feedstock materials, and passing through said dome-shaped top of said gasifying furnace, feed pre-mixed reactant oxygen and superheated reactant steam, downward into said primary reaction zone of said gasifying furnace, a second set of alternately positioned said nozzles, in or near the same circle of said nozzles, and passing through said dome-shaped top of said gasifying furnace, feeds said reactive carbon fuel, as fluidized solids carried by steam or inert gas, downward into said primary reaction zone, between the alternately positioned streams of pre-mixed reactants, to achieve the very rapid gasification reactions between reactive said particulate carbon fuel and said pre-mixed reactant oxygen and superheated reactant steam, said gasification reactions have been shown to take place almost to completion in about ten milliseconds, thus surrounding the falling and oxidizing said materials with high temperature said reacting gases and reaction product gases, at controlled initial temperatures in the range of three thousand to four thousand degrees Fahrenheit;

a set of similar said nozzles is positioned in or near a second circle of said nozzles, said second circle of nozzles being of even larger diameter, said nozzles passing through said dome-shaped top of said gasifying furnace, and positioned about midway between the center of said gasifying furnace and said furnace walls, outside the alternately positioned said nozzles in or near said first circle of nozzles described hereinabove, are provided for injecting said saturated steam, or said superheated steam, or mixtures of said saturated steam and hot water, or mixtures of said superheated steam and said hot water, as best effects optimum process and operating controls, to react with said carbon monoxide by said carbon monoxide shift reaction, thus producing some additional said hydrogen, and to react with unreacted carbon in said reacting gases to produce said carbon dioxide, said carbon monoxide and said hydrogen, and with provision made for also feeding reactive said particulate carbon fuel, as said fluidized solids carried by said steam or said inert gases, through other said nozzles in these outer said second circles of said nozzles, in event this proves to be advantageous or necessary during operation of the gasifying furnace with some feedstock combinations and in some operating situations;

said process makes possible the conversion of said gasification feedstock materials, as described hereinabove, to useful and valuable products including said syngas, which can be used as feedstock for the catalytic synthesis of various chemicals such as methanol; mixtures of methanol and higher alcohols, and ammonia; fluid slag, which can be used to produce light-weight aggregates, dense aggregates and inert rock-wool insulating materials; metal ingots, for use in metal refining processes; metal vapors, which are condensed and recovered as metallic dust or muds, during syngas cooling and cleaning; sulfur compounds from the syngas, which are converted to elemental sulfur in the syngas purification processes; and carbon dioxide and nitrogen gases, recovered during syngas purification, which can be marketed to the extent possible, with the surplus gases being vented to the atmosphere;

the processes and means hereof provides unique opportunities for profitable utilization, as opposed to costly disposal, for many undesirable materials, waste materials and hazardous materials; for the utilization of high sulfur coal or lignite resources, with both the iron and sulfur from the iron sulfides being recovered in marketable forms; for the utilization of iron sulfide ores and other mineral ores, to economically recover their metals and sulfur; for the utilization of high fuel-value shales to produce syngas, sulfur and slag products; and for utilization of biomass waste materials and biomass produced for its fuel values; with all the combined feedstock materials being converted to valuable products, coproducts, byproducts and inert gases, eliminating the need for recycling, landfills, waste incineration, refuse-derived fuels projects, and waste to energy projects, and also providing new opportunities for utilizing high sulfur coals and lignites, some sulfur-bearing mineral ores, biomass waste materials and fuels, and high fuel value shales which are usually also high in sulfur content.

FIG. 1



SUBSTITUTE SHEET

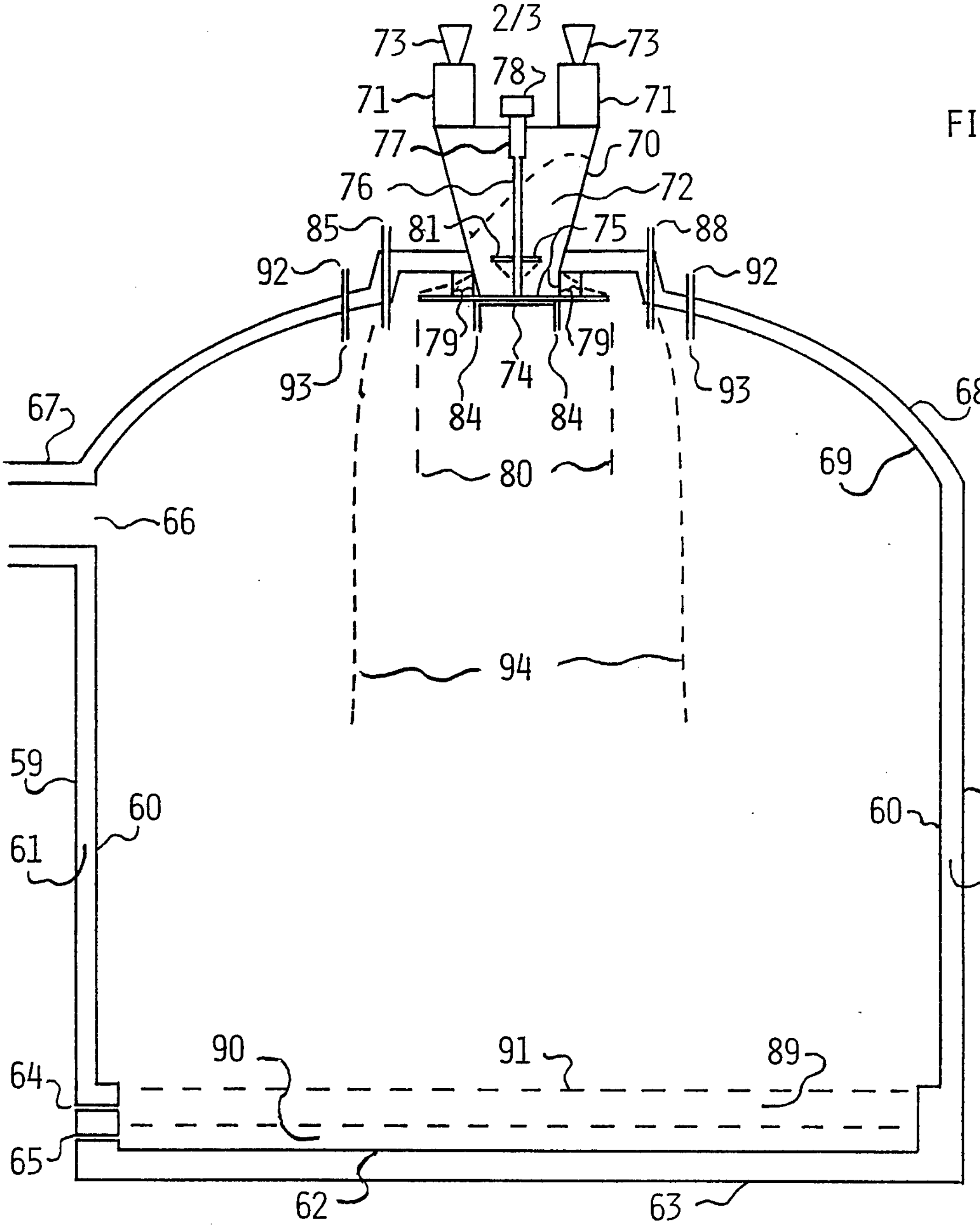

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FIG. 2

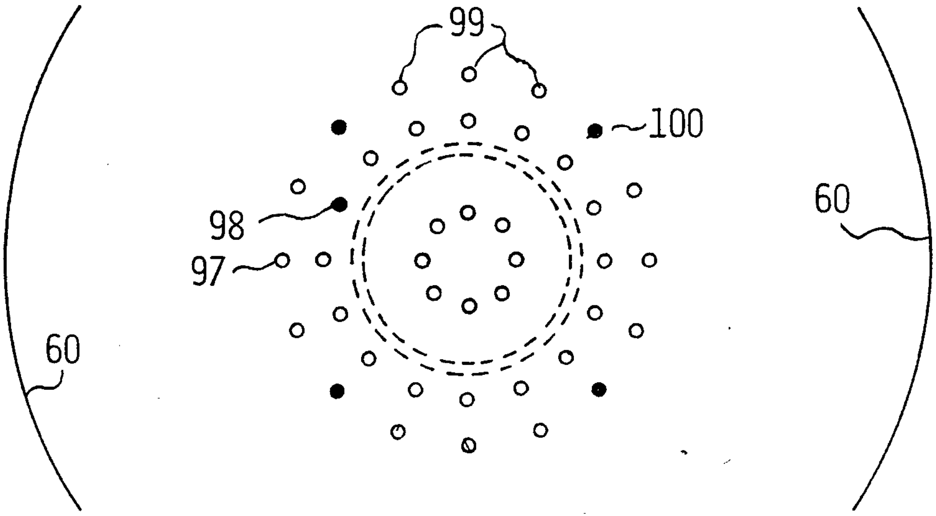
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FIG. 3

FIG. 4

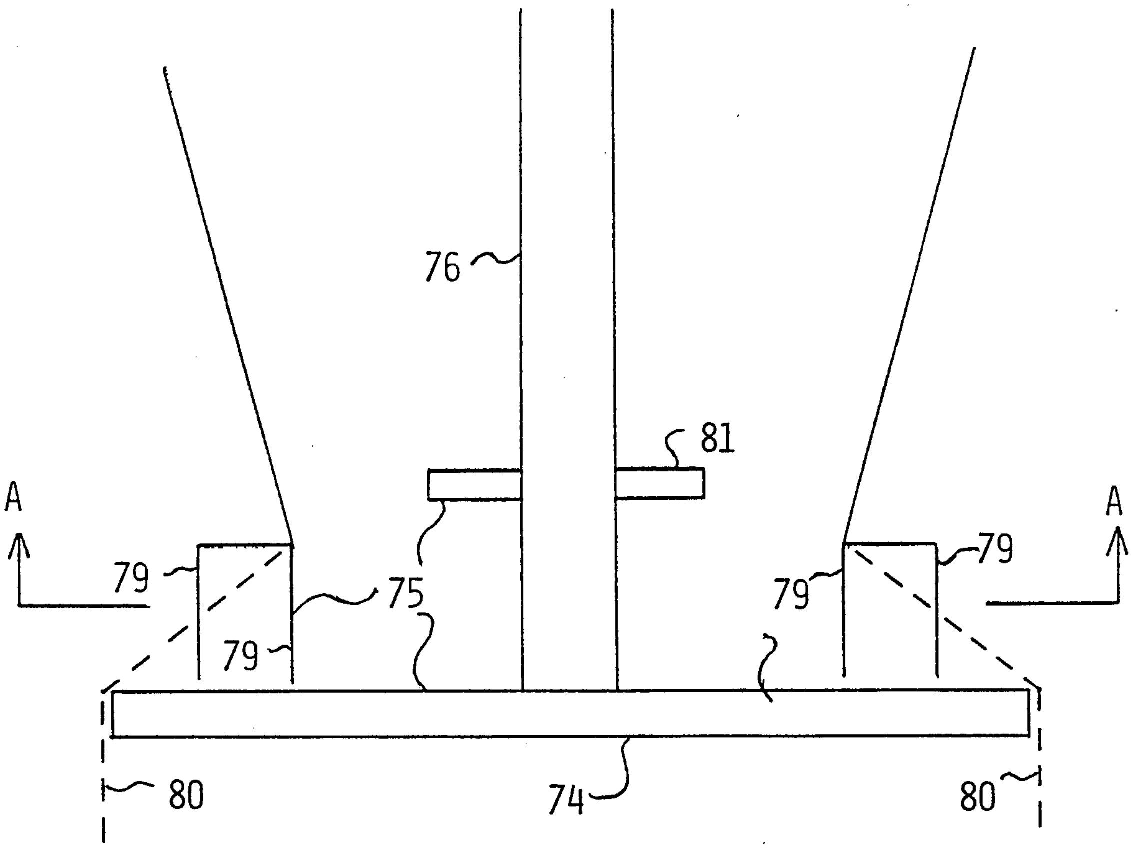
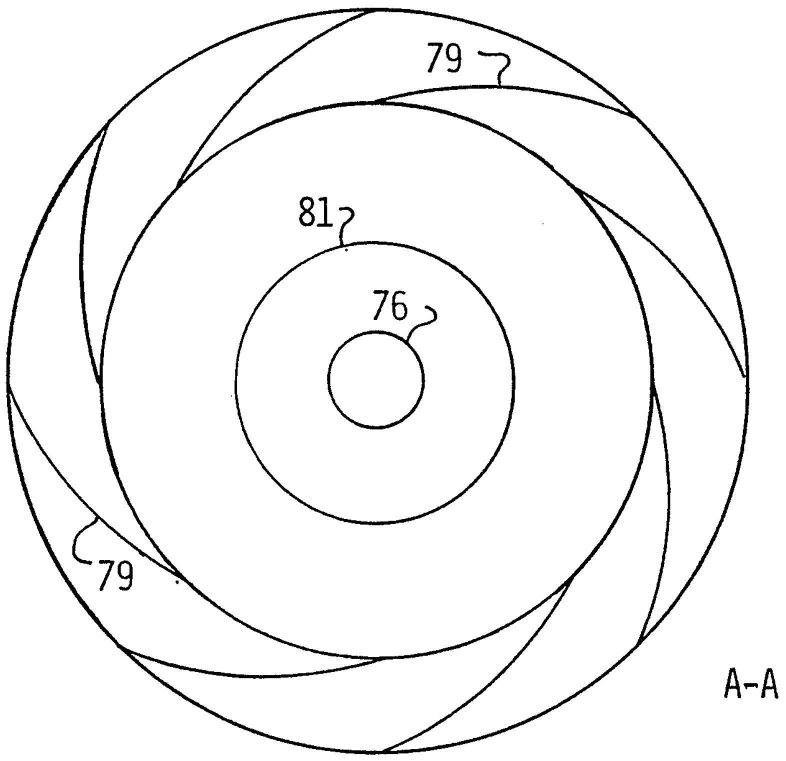


FIG. 5



INTERNATIONAL SEARCH REPORT

International application No.
PCT/US92/06495

A. CLASSIFICATION OF SUBJECT MATTER

IPC(5) :F23B 7/00
US CL :110/234
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 110/234 110/229,233,235,346, ; 122/1R,2; 48/111,209,DIG 2

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US,A, 4,960,056 (Pillsbury) 02 October 1990 See Col. 3, lines 43-50.	
A	US,A, 5,022,330 (Burgher et al.) 11 June 1991 See Col. 1, lines 45-53.	
A	US,A, 4,753,181 (Sosnowski) 28 June 1988 See Col. 2, lines 9-24.	

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

*	Special categories of cited documents:	"T"	later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"A"	document defining the general state of the art which is not considered to be part of particular relevance		
"E"	earlier document published on or after the international filing date	"X"	document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"L"	document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"Y"	document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"O"	document referring to an oral disclosure, use, exhibition or other means		
"P"	document published prior to the international filing date but later than the priority date claimed	"&"	document member of the same patent family

Date of the actual completion of the international search 23 SEPTEMBER 1992	Date of mailing of the international search report 30 OCT 1992
Name and mailing address of the ISA/ Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231	Authorized officer FAVORS, EDWARD G.
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