

INJECTOR SYSTEM FOR EXTRUDER EQUIPMENT**CROSS-REFERENCE**

[0001] This application claims the benefit of U.S. Provisional Application No. 63/087,077, filed on October 2, 2020, U.S. Provisional Application No. 63/146,608, filed on February 6, 2021, and U.S. Provisional Application No. 63/153,740, filed on February 25, 2021, each of which is incorporated herein by reference in its entirety.

BACKGROUND

[0002] Pretreatment of lignocellulosic biomass is an essential step to obtain sugars and lignin from such biomasses, aimed at breaking the recalcitrant structure of lignocellulose and facilitating the access of enzymatic hydrolytic agents to carbohydrates. Among the variety of pretreatment technologies that have been investigated in the past years, extrusion is a promising thermo-mechanical pretreatment. It can be a continuous process, highly versatile, having good mixing and heat transfer capabilities and is able to operate at high solids loadings. However, its design still needs to be refined before it can unlock its potential for biomass processing. For example, the continuous deconstruction of tons of biomass not only necessitates scaling up the size of extruders, but increasing input of large amounts of liquids and steam to maintain the required pressures, temperatures, and chemicals.

[0003] In biomass processing, extruders can be configured with screws designed to produce one or more reaction zones and permit the addition of steam to increase pressure and temperature in these zones during pretreatment. As the barrel diameter or the length of the extruder is increased for commercial use however, additional steam input is required to maintain the high pressure and temperature in the barrel to process material. If too little pressure is exerted upon the materials being processed or too low a temperature attained, the final products may be undercooked and yields of preferred products lost. Other liquids may also be required, such as water, acids or bases at various times in the processing. Given the volume and speed of biomass material sent through commercially-viable extrusion systems, conventional injector assemblies become inadequate and are susceptible to plugging or blowback.

[0004] Various approaches have been used in the past to achieve and maintain appropriate levels of pressure, control of processing and liquids within extruder barrels. For example, it has been known to install one or more shear lock devices along the length of extruder screws. These devices are not adjustable, however. Variable restriction devices have also been proposed in the past, in order to permit on the go variation in flow restriction. For example, U.S. Pat. No. 4,136,968 describes a flow restriction device specifically adapted for use with twin screw

extruders but it cannot be used on other extruder types and is limited in the degree of restriction it can produce.

[0005] There is accordingly a need in the art for improved extruder injector assemblies that can operate efficiently on high-output, biomass extruder systems without the design and plugging problems of conventional systems.

SUMMARY

[0006] Provided herein is a system for introducing one or more additives into materials, the system comprising: an assembly of injectors, wherein the injectors comprises internal bores of a diameter ranging from 2 to 6 mm; a manifold for controlling flows of substances in said assembly of injectors; valves incorporated into the manifold for each injector to independently control the flows of substances in the injector; and a supply of an additive. In some examples, the additive is a liquid or a steam. In some examples, the additive is water. In some examples, the additive is an acid. In some examples, the additive is a steam and wherein the steam is at a pressure of about 80-600 psi. In some examples, the additive is a steam and wherein the steam is at a pressure of about 150 psi. In some examples, the additive is a steam and wherein the steam is at a pressure of about 200 psi. In some examples, the additive is a steam and wherein the steam is at a pressure of about 250 psi. In some examples, the additive is a steam and wherein the steam is at a pressure of about 300 psi.

[0006a] In one aspect, the present disclosure refers to an extruder comprising: (1) a barrel, wherein the barrel comprises an inner chamber comprising a feeder zone and a reaction zone, wherein the extruder is constructed and arranged such that a steam impervious plug is formed by compacting biomass in a high pressure zone separating the feeder zone and the reaction zone; (2) a discharge valve body at a discharge end of the barrel, wherein the discharge valve body comprises a plurality of injection ports that penetrate an outer wall of the discharge valve body; and (3) a system for introducing one or more additives into materials, the system comprising: an assembly of injectors, wherein the injectors comprises internal bores of a diameter ranging from 2 to 6 mm; a manifold for controlling flows of substances in said assembly of injectors; valves incorporated into the manifold for each injector to independently control the flows of substances in the injector; and a supply of an additive, wherein the injectors are placed into the plurality of injection ports in the outer wall of the discharge valve body.

[0007] In some examples, the materials comprise a biomass. In some examples, the materials comprise a biomass, and wherein the materials are within a conduit. In some examples, the conduit comprises an extruder. In some examples, the conduit further comprises a discharge valve. In some examples, the internal bores of the injectors have a diameter of about 2 mm. In

some examples, the internal bores of the injectors have a diameter of about 2.5 mm. In some examples, the internal bores of the injectors have a diameter of about 3 mm. In some examples, the internal bores of the injectors have a diameter of about 3.5 mm. In some examples, the internal bores of the injectors have a diameter of about 4 mm. In some examples, the internal bores of the injectors have a diameter of about 4.5 mm. In some examples, the internal bores of the injectors have a diameter of about 5 mm. In some examples, the internal bores of the injectors have a diameter of about 5.5 mm. In some examples, the internal bores of the injectors have a diameter of about 6 mm.

[0008] In some examples, the assembly of injectors comprises 2 or more injectors. In some examples, the assembly of injectors comprises 4 or more injectors. In some

examples, the assembly of injectors comprises 6 or more injectors. In some examples, the assembly of injectors comprises 8 or more injectors. In some examples, the assembly of injectors comprises 10 or more injectors. In some examples, the assembly of injectors comprises 12 or more injectors. In some examples, the assembly of injectors comprises 14 or more injectors. In some examples, the assembly of injectors comprises 16 or more injectors. In some examples, the materials consist of biomass within a reaction zone.

[0009] In another aspect, the present disclosure refers to a method of injecting liquid and steam into an extruder having an extruder barrel and a discharge valve body, wherein the extruder barrel comprises an inner chamber comprising a feeder zone and a reaction zone, wherein the extruder is constructed and arranged such that a steam impervious plug is formed by compacting biomass in a high pressure zone separating the feeder zone and the reaction zone, the method comprising: providing a plurality of injection ports, wherein the injection ports penetrate an outer wall of the extruder barrel and an outer wall of the discharge valve body; introducing injectors into the plurality of injection ports; injecting steam into said extruder barrel or said discharge valve body to maintain a pressure between 150 to 800 psi in said extruder barrel or said discharge valve body; and injecting liquid into said discharge valve body.

[00010] The present disclosure also refers to a method of injecting liquid and steam into an extruder barrel or a valve body comprising: providing a plurality of injection ports, wherein the injection ports penetrate the extruder barrel or the valve body; introducing injectors into the plurality of injection ports; and injecting liquid and steam into said extruder barrel or said valve body to maintain a pressure between 150 to 800 psi in said extruder barrel or said valve body.

[00011] In some examples, the injector comprises a nozzle bore with a diameter between 2-6 mm. In some examples, the injector comprises a nozzle bore with a diameter between 2-4 mm. In some examples, the injector comprises a nozzle bore with a diameter between 2-3 mm. In some examples, the injector comprises a nozzle bore with a diameter of about 2 mm. In some examples, for pretreating at least one dry ton of biomass per day, the method further comprising: feeding the biomass at a rate of at least one dry metric ton (MT) of biomass per day into an extrusion system comprising a barrel, wherein the barrel comprises an inner chamber comprising a feeder zone and a reaction zone, wherein the extrusion system is constructed and arranged such that: a steam impervious plug is formed by compacting the biomass in a high pressure zone separating the feeder zone and the reaction zone, and an assembly of steam injectors having an internal nozzle bore diameter of 6 mm or less provide pressure and high temperatures to the reaction zone.

[00012] Disclosed herein is an extruder system comprising an assembly of one or more injectors, wherein the injectors comprise a nozzle bore with a diameter of 6 mm or less. In some

examples, the injectors provide steam at a pressure of 150-800 psi to the extruder bore. In some examples, the injectors have an internal bore diameter of 4 mm or less. In some examples, the injectors have an internal bore diameter of 2 mm or less. In some examples, the extruder system comprises at least 2 assemblies of injectors, at least 3

assemblies of injectors, or at least 4 assemblies of injectors. In some examples, internal bores of the injectors have a diameter of about 2 mm. In some examples, internal bores of the injectors have a diameter of about 2.5 mm. In some examples, internal bores of the injectors have a diameter of about 3 mm. In some examples, internal bores of the injectors have a diameter of about 3.5 mm. In some examples, internal bores of the injectors have a diameter of about 4 mm. In some examples, internal bores of the injectors have a diameter of about 4.5 mm. In some examples, internal bores of the injectors have a diameter of about 5 mm. In some examples, internal bores of the injectors have a diameter of about 5.5 mm. In some examples, internal bores of the injectors have a diameter of about 6 mm. In some examples, the assembly of one or more injectors comprises 2 or more injectors. In some examples, the assembly of one or more injectors comprises 4 or more injectors. In some examples, the assembly of one or more injectors comprises 6 or more injectors. In some examples, the assembly of one or more injectors comprises 8 or more injectors. In some examples, the assembly of one or more injectors comprises 10 or more injectors. In some examples, the assembly of one or more injectors comprises 12 or more injectors. In some examples, the assembly of one or more injectors comprises 14 or more injectors. In some examples, the assembly of one or more injectors comprises 16 or more injectors.

[00013] Disclosed herein is an extruder system comprising a barrel section having spiral or concentric ports for an assembly of injector nozzles. In some examples, the barrel section comprises at least 4 ports. In some examples, the barrel section comprises at least 6 ports. In some examples, the barrel section comprises at least 8 ports. In some examples, the barrel section comprises at least 10 ports. In some examples, the barrel section comprises at least 12 ports. In some examples, the barrel section comprises at least 14 ports. In some examples, the barrel section comprises at least 16 ports. In some examples, the extruder system comprises two or more barrel sections. In some examples, the barrel section is interchangeable with other barrel sections. In some examples, the spiral or concentric ports are perpendicular to the barrel section. In some examples, the injectors are predisposed to inject 30-50% steam per dry weight of material.

[00014] Disclosed herein is a system for introducing one or more additives into materials, the system comprising: at least one assembly of injectors with internal bores of a diameter ranging from 2 to 6 mm; a manifold for controlling the flow of substances in said assembly; valves incorporated into the manifold for each injector to independently control the flow of substances in the injector; and a supply of at least one additive. In some examples, the additive is a liquid or steam. In another example, the additive is water or an acid. In other examples, the additive is steam at a pressure of 80-600 psi. In other examples, the additive is steam at

a pressure of 80-600 psi. In other examples, the additive is steam at a pressure of 150 psi. In other examples, the additive is steam at a pressure of 200 psi. In other examples, the additive is steam at a pressure of 250 psi. In other examples, the additive is steam at a pressure of 300 psi. In one example, the materials consist of biomass in a conduit. In another example, the conduit is an extruder. In another example, the conduit comprises an extruder and a discharge valve.

[00015] Also disclosed herein is the system described *supra* wherein the internal bores of the injectors have a diameter of 2 mm, or 2.5 mm, or 3 mm, or 3.5 mm, or 4 mm, or 4.5 mm or 5 mm, or 5.5 mm, or 6 mm. Some examples further comprise the assembly consisting of 2 or more injectors, 4 or more injectors, 6 or more injectors, 8 or more injectors, 10 or more injectors, 12 or more injectors, 14 or more injectors, or even 16 or more injectors. In another example, the materials consist of biomass within a reaction zone.

[00016] Also disclosed herein are methods of injecting liquid or steam into an extruder barrel or a valve body comprising: having a plurality of injection ports penetrate the outer wall of the extruder barrel or outer valve wall to its bore; including injectors into the injection ports; injecting steam into said extruder barrel or valve to maintain the pressure between 150 to 800 psi in the conduit; and injecting liquid into said extruder barrel or valve.

[00017] In a further example, methods are disclosed of injecting liquid and steam into an extruder barrel or a valve body comprising: having a plurality of injection ports penetrate the extruder barrel or valve body to its bore; including injectors into the injection ports; and injecting liquid and steam into said extruder barrel or valve to maintain the pressure between 150 to 800 psi inside said zone.

[00018] In some examples, the injector nozzle bore diameter is between 2-6 mm. In some examples the injector nozzle bore diameter is between 2-4 mm. In other examples, the injector nozzle bore diameter is between 2-3 mm. In another example, the injector nozzle bore diameter is 2 mm.

[00019] Also disclosed are methods for pretreating at least one dry ton of biomass per day, the method comprising: feeding the biomass at a rate of at least one dry metric ton (MT) of biomass per day into an extrusion system comprising a barrel defining an inner chamber comprising a feeder zone and a reaction zone, wherein the extrusion system is constructed and arranged such that: a steam impervious plug is formed by compacting the biomass in a high pressure zone separating the feeder zone and the reaction zone, and at least one assembly of steam injectors

having an internal nozzle bore diameter of 6 mm or less provide pressure and high temperatures to the reaction zone.

[00020] Also disclosed is an extruder system having at least one assembly of one or more injectors having an internal nozzle bore diameter of 6 mm or less. In some examples, the injectors provide steam at a pressure of 150-800 psi to the extruder bore. In some examples, the injectors have an internal bore diameter of 4 mm or less. In other examples, the injectors have an internal bore diameter of 2 mm or less.

[00021] In some examples, the system consists of at least 2 assemblies of injectors, at least 3 assemblies of injectors, or at least 4 assemblies of injectors. In another example, the internal bores of the injectors have a diameter of 2 mm. In another example the internal bores of the injectors have a diameter of 2.5 mm, or 3 mm, or 3.5 mm, or 4 mm, or 4.5 mm, or 5 mm, or 6mm.

[00022] In some examples the assembly consists of 2 or more injectors. In some examples, the assembly consists of 4 or more injectors. In some examples, the assembly consists of 6 or more injectors. In some examples, the assembly consists of 8 or more injectors. In some examples, the assembly consists of 10 or more injectors. In some examples, the assembly consists of 12 or more injectors. In some examples, the assembly consists of 14 or more injectors. In some examples, the assembly consists of 16 or more injectors.

[00023] Also disclosed herein is an extruder system comprising at least one barrel section having spiral or concentric ports for an assembly of injector nozzles. In some examples, the barrel section has at least 4 ports. In other examples, the barrel section has at least 6 ports. In some examples, the barrel section has at least 8 ports. In some examples, the barrel section has at least 10 ports. In further examples, the barrel section has at least 12 ports. In another example, the barrel section has at least 14 ports. In some examples, the barrel section has at least 16 ports.

[00024] In some examples, the extruder system comprises at least two barrel sections. In some examples, the barrel section is interchangeable with other barrel sections. In some examples, the spiral or concentric ports are perpendicular to the barrel section.

[00025] Also disclosed herein is an extruder system wherein the injectors are predisposed to inject 30-50% steam per dry weight of material.

INCORPORATION BY REFERENCE

[00026] All publications, patents, and patent applications mentioned in this specification are herein incorporated by reference to the same extent as if each individual publication, patent, or patent application was specifically and individually indicated to be incorporated by reference.

BRIEF DESCRIPTION OF THE DRAWINGS

[00027] The novel features of the invention are set forth with particularity in the appended claims. A better understanding of the features and advantages of the present invention will be obtained by reference to the following detailed description that sets forth illustrative embodiments, in which the principles of the invention are utilized, and the accompanying drawings of which:

[00028] **Figure 1** is a diagram depicting a longitudinal section of a twin screw extruder with valve assemblies.

[00029] **Figure 2** is a diagram showing a longitudinal view of an extruder barrel section and bores for injectors.

[00030] **Figures 3A, 3B, 3C, 3D, 3E, and 3F** are diagrams depicting longitudinal views (**3A, 3C, 3E**) and cross sections (**3B, 3D, 3F**) of the bores for different injectors in barrel sections.

[00031] **Figure 4** is a longitudinal drawing of the valve body depicting the placement of injectors.

[00032] **Figures 5A and 5B** are longitudinal drawings of injectors.

[00033] **Figure 6** is a diagram depicting the extruder and discharge valve with the injector assemblies attached to the manifolds.

DETAILED DESCRIPTION OF THE INVENTION

[00034] As used in the specification and the appended claims, the singular forms "a," "an" and "the" include plural referents unless the context clearly dictates otherwise. Thus, for example, reference to "a purified monomer" includes mixtures of two or more purified monomers. The term "comprising" as used herein is synonymous with "including," "containing," or "characterized by," and is inclusive or open-ended and does not exclude additional, unrecited elements or method steps.

[00035] "About" means a referenced numeric indication plus or minus 10% of that referenced numeric indication. For example, the term about 4 would include a range of 3.6 to 4.4. All numbers expressing quantities of ingredients, reaction conditions, and so forth used in the specification are to be understood as being modified in all instances by the term "about." Accordingly, unless indicated to the contrary, the numerical parameters set forth herein are approximations that can vary depending upon the desired properties sought to be obtained. At the very least, and not as an attempt to limit the application of the doctrine of equivalents to the scope of any claims in any application claiming priority to the present

application, each numerical parameter should be construed in light of the number of significant digits and ordinary rounding approaches.

[00036] Wherever the phrase "for example," "such as," "including," "comprising," "containing" and the like are used herein, the phrase "and without limitation" is understood to follow unless explicitly stated otherwise. Therefore, "for example lignin production" means "for example and without limitation lignin production."

[00037] In this specification and in the claims that follow, reference will be made to a number of terms which shall be defined to have the following meanings.

[00038] "Optional" or "optionally" means that the subsequently described event or circumstance may or may not occur, and that the description includes instances where said event or circumstance occurs and instances where it does not. For example, the phrase "the medium can optionally contain glucose" means that the medium may or may not contain glucose as an ingredient and that the description includes both media containing glucose and media not containing glucose.

[00039] Unless characterized otherwise, technical and scientific terms used herein have the same meaning as commonly understood by one of ordinary skill in the art.

[00040] Definitions

[00041] The term "biomass" as used herein has its ordinary meaning as known to those skilled in the art and can include one or more carbonaceous biological materials that can be converted into a biofuel, chemical or other product. Biomass as used herein is synonymous with the term "feedstock" and includes silage, agricultural residues (corn stalks, grass, straw, grain hulls, bagasse, etc.), nuts, nut shells, coconut shells, animal waste (manure from cattle, poultry, and hogs), Distillers Dried Solubles, Distillers Dried Grains, Condensed Distillers Solubles, Distillers Wet Grains, Distillers Dried Grains with Solubles, woody materials (wood or bark, sawdust, wood chips, wood pellets, timber slash, and mill scrap), municipal waste (waste paper, recycled toilet papers, yard clippings, etc.), and energy crops (poplars, willows, switchgrass, alfalfa, prairie bluestem, algae, including macroalgae such as members of the Chlorophyta, Phaeophyta, Rhodophyta, etc.). One exemplary source of biomass is plant matter. Plant matter can be, for example, woody plant matter, non-woody plant matter, cellulosic material, lignocellulosic material, hemicellulosic material, sugar cane, grasses, switchgrass, sorghum, high biomass sorghum, bamboo, algae and material derived from these. Plants can be in their natural state or genetically modified, *e.g.*, to increase the cellulosic or hemicellulosic portion of the cell wall, or to produce additional exogenous or endogenous enzymes to increase the separation of cell wall components. Plant matter can be further described by reference to the chemical species present, such as

proteins, polysaccharides and oils. Polysaccharides include polymers of various monosaccharides and derivatives of monosaccharides including glucose, fructose, lactose, galacturonic acid, rhamnose, etc. Plant matter also includes agricultural waste byproducts or side streams such as pomace, corn steep liquor, corncobs, corn fiber, corn steep solids, distillers' grains, peels, pits, fermentation waste, straw, lumber, sewage, garbage and food leftovers. Peels can be citrus which include, but are not limited to, tangerine peel, grapefruit peel, orange peel, tangerine peel, lime peel and lemon peel. These materials can come from farms, forestry, industrial sources, households, etc. Another non-limiting example of biomass is animal matter, including, for example milk, bones, meat, fat, animal processing waste, and animal waste. "Feedstock" is frequently used to refer to biomass being used for a process, such as those described herein.

[00042] "Pretreatment" or "pretreated" is used herein to refer to any mechanical, chemical, thermal, biochemical process or combination of these processes whether in a combined step or performed sequentially, that achieves disruption or expansion of the biomass so as to render the biomass more susceptible to attack by enzymes and/or microbes, and can include the enzymatic hydrolysis of released carbohydrate polymers or oligomers to monomers. In one embodiment, pretreatment includes removal or disruption of lignin so as to make the cellulose and hemicellulose polymers in the plant biomass more available to cellulolytic enzymes and/or microbes, for example, by treatment with acid or base. In one embodiment, pretreatment includes disruption or expansion of cellulosic and/or hemicellulosic material. In another embodiment, it can refer to starch release and/or enzymatic hydrolysis to glucose. Steam explosion, and ammonia fiber expansion (or explosion) (AFEX) are well known thermal/chemical techniques. Hydrolysis, including methods that utilize acids, bases, and/or enzymes can be used. Other thermal, chemical, biochemical, enzymatic techniques can also be used.

[00043] "Steam explosion" as used herein is a physicochemical method that uses high-pressure steam to disrupt bonding between polymeric components and decompression to break the lignocellulose structure. In this method, the lignocellulose slurry is treated with high-pressure steam for some time and then rapidly depressurized to atmospheric pressure.

[00044] As intended herein, a "liquid" composition may contain solids and a "solids" composition may contain liquids. A liquid composition refers to a composition in which the material is primarily liquid, and a solids composition is one in which the material is primarily solid. A "slurry" refers to solids dissolved or undissolved in a liquid.

[00045] Description

[00046] The following description and examples illustrate some exemplary embodiments of the disclosure in detail. Those of skill in the art will recognize that there are numerous variations and modifications of this disclosure that are encompassed by its scope.

Accordingly, the description of a certain exemplary embodiment should not be deemed to limit the scope of the present disclosure.

[00047] Although the history of food extrusion processing goes back to the late 1800s, the control of this process and the design of new extruded products are still mostly based on limited empirical knowledge. With regard to the pretreatment of biomass, extrusion is still a relatively novel pretreatment, in which the material is submitted to mixing, heating and shearing, resulting in physical and chemical modifications. Even in batch mode, results can be inconsistent and, instead of providing high sugar and clean lignin yields, byproducts and low yields are brought about by fluctuating pressures, chemicals, and inconsistent sizing of materials.

[00048] Extrusion processing of foodstuffs, animal feeds, and plastic materials has been practiced for many years. Although biomass processing using extruders has also been tried, until recently, it was not very successful due to the difficulty of working with such recalcitrant heterogeneous materials and varying moisture content. Biomass is usually comprised of plant cells walls, a cross-linked matrix of primarily lignin, cellulose and hemicellulose. The ratio and composition of these materials can vary from species to species of plants, and even with environmental variables.

[00049] More recently, however, the extruder process was improved to handle such materials to where mass pretreatment is economical. See, *e.g.*, U.S. patent No. 10,844,413. Unlike present methods, which retain biomass materials in a chamber for a long period of time, it has been discovered that processing of these materials can avoid long retention times under thermal and chemical treatment, thereby avoiding the degradation of C5 sugars, proteins and lignins into undesirable products such as hydroxymethyl furfural (HMF) and furfurals, while allowing the separation of carbohydrate materials, both monomeric and polymeric sugars, from other biomass components. The inhibitors usually formed during pretreatment include acetic acid (formed during the release of C5 sugars) and also formic acid, furfural and HMF. Formation of the latter three compounds is largely dependent on the temperature, pressure and biomass residence time during pretreatment.

[00050] To successfully process biomass materials, input of steam or liquids is required at precise times in the process and in accurate amounts. In one aspect, however, understanding the importance of uniform treatment throughout the process as shown in U.S. Patent No. 10,844,413 can lead to very high yields of desired products without the levels of inhibitors found in other

pretreatment means. This is especially true of the pressure, temperature and pretreatment time to which the biomass is submitted.

[00051] When scaling up this process, however, the problem of plugging of the injector nozzles becomes more prominent and can interfere with continuous or batch pretreatment. Conventional injectors are manufactured with large bores, over 12 mm, and often contain restriction elements. Examples of such nozzles that are used on extruders are described in US patent Nos. 7,521,076; 7,988,884, 9,931,603; 8,858,065, and 8,967,849. The processes described that incorporate these injectors typically teach the use of less steam and fewer chemicals than those required to successfully process biomass. To process biomass quickly and efficiently, pretreatment times must be reduced and the materials subject to higher than normal steam and chemicals uniformly over the reaction time period. However, larger bores are easily plugged under these conditions. Further, a small number of injectors is not adequate to quickly reach materials moving rapidly through an extruder barrel section.

[00052] In one aspect, the injector assemblies described herein overcome the problems outlined above, and permit economical, high-capacity production of biomass, including elevated quantities of plant and fibrous materials above 20% by weight in either batch or continuous mode.

[00053] Further, it has been discovered that the solubilization of crystalline cellulose is not impeded by short exposure times. The methods provided herein also allow biomass to be heated and pressurized uniformly for improved access of treatment reactants to the biomass. During this process, concentrated masses (plugs) can be produced that can shear the biomass into smaller particles and can further increase access of reactants to hydrolyze and release the C5 polymers while also releasing and solubilizing the C6 polymers. In one embodiment, the biomass is moved through a reaction zone wherein steam and pressure are applied, followed by the addition of acid, and finally release of the material to atmospheric pressure by a rapidly opening and closing an end valve. The whole process can happen within seconds, resulting in a thermo-mechanically and/or chemically-hydrolyzed biomass with lower or reduced levels of inhibitors as compared to pretreatment methods known in the art.

[00054] In some embodiments, the biomass is treated for less than 60, 55, 50, 45, 40, 35, 30, 25, 20, 19, 18, 17, 16, 15, 14, 13, 12, 10, 9, 8, 7, 6, 5, 4, 3, 2, or 1 seconds in the reaction zone. In some embodiments, the biomass is treated for about 5 to 15 seconds in the reaction zone; in larger systems, the biomass is treated for 30 seconds or less, or is treated for 60 seconds or less. In another embodiment, biomass can be pretreated at an elevated temperature and/or pressure. In one embodiment biomass is pretreated at a temperature range of 20°C to 400°C. In another embodiment biomass is pretreated at a temperature of about 20°C, 25°C, 30°C,

35°C, 40°C, 45°C, 50°C, 55°C, 60°C, 65°C, 80°C, 90°C, 100°C, 120°C, 150°C, 200°C, 250°C, 300°C, 350°C, 400°C or higher. In another embodiment, elevated temperatures are provided by the use of steam, hot water, or hot gases. In one embodiment steam can be injected into a biomass containing vessel. In another embodiment the steam, hot water, or hot gas can be injected into a vessel jacket such that it heats, but does not directly contact the biomass.

[00055] In general, extruders in accordance with the invention comprise an elongated barrel having an inlet adjacent to one end thereof and an opening for materials to flow into a valve assembly attached to the opposite end. Extruders for this purpose can be single screw, twin screw, or even triple screw extruders, meaning that the screw elements are assembled on one to three axially rotatable shafts, respectively, between the inlet and the outlet of the extruder barrel.

[00056] The screw elements within the extruder comprises a plurality of screw components in end-to-end alignment including an entrance component and an exit component, with each screw component including an elongated shaft, and outwardly extending helical flighting along the length of the shaft presenting a flighting diameter, an inlet section, and a discharge section. The screw components are moreover arranged end-to-end with the discharge section of the entrance screw component proximal to the inlet section of the exit screw component.

[00057] In order to provide flow restrictions and greater shear in sections of the extruder, flow restricting elements and/or kneading elements are provided between the discharge sections and inlet sections of the screw assembly components. These elements can comprise the means to form plugs from the materials to form zones within the extruder. In preferred aspects, a steam-impervious plug is formed by compacting the biomass in a high pressure zone separating the feeder zone from the reaction zone. These are one or more steam-permeable plugs formed by compacting biomass so that the biomass, not the screw elements, form a barrier to steam and/or acid piped into the reaction zone.

[00058] The pressures achieved within this zone emanate from the direct injection of steam, combined with a flow-restriction valve at the outlet, and aid in directional flow, and facilitate turbulence and intimate mixing within the system while the plug keeps the steam from backflowing (flowing upstream) to the extruder feed, thereby maintaining elevated pressure and temperature in the reaction zone in coordination with the end valve. A dilute acid (or possibly base, or possibly an ionic liquid) is also added in the reaction zone to speed up the conversion process. Further, the high pressure zone that is formed keeps the reactive material and liquids in the reaction zone, allowing for a less expensive, more durable metal to be used for the manufacture of the barrel liners and screw elements in the conveying zone.

[00059] Tying the formation of the high pressure zone with the discharge (end) valve described *infra* closes the loop on the actual formation of a high pressure reactive zone within the extruder. High pressures in the reaction zone have been attained from 1 psi to 800psi, and even over 1000 psi without backflow of the steam through the high pressure zone. In one aspect, the steam reaches and maintains a pressure of at least about 500 psi, at least about 600 psi, at least about 700 psi, at least about 800 psi, at least about 900 psi, or at least about 1000 psi. This pressure is maintained for at least about 1 hr, at least about 2 hrs, at least about 4 hrs, at least about 5 hrs, at least about 6 hrs, at least about 8 hrs, at least about 10 hrs, at least about 12 hrs, at least about 13 hrs, at least about 14 hrs, at least about 15 hrs, at least about 16 hrs, at least about 17 hrs, or at least about 18 hrs or more. In these instances, the biomass feeding rate is in a range from about 60 to about 350 dry kg/hr.

[00060] The direct steam injection through injection ports permits a very rapid and uniform heating of the biomass, especially if the biomass particle size is small. The combination of high temperature, intimate mixing, small particle size, and even distribution of reactive solutions (dilute acid, ionic liquid, etc.) brings about a very rapid pretreatment process that produces low inhibitors.

[00061] In some cases, the pretreatment methods provided herein permit the release and depolymerization of sugars in a very rapid time frame. This process occurs in less than 20 seconds and up to a few minutes depending on the size of the extruder. Generally, the time in the reaction zone can range from a second to less than 20 seconds, preferably less than 10 seconds. In a larger scale system, pretreatment can take place over several minutes. This reduced pretreatment period amounts to continuously moving biomass through the tube and end valve zone, resulting in a rapidly-pretreated biomass containing few, no, or substantially no inhibitors.

[00062] Described herein are improved, low cost, energy-efficient pretreatment devices and methods for the rapid processing of lignocellulose, cellulose, hemicellulose, and the like biomass materials prior to enzymatic hydrolysis, which includes a thermo-mechanical treatment with or without chemicals and a reaction extrusion controlled by high pressure zone and a pressure-driven variable end valve. The methods disclosed herein can include the use of a device that comprises a cylindrical chamber divided into tubular zones, wherein biomass can be moved either continuously or in batches through the cylindrical chamber; be reduced in size; and treated with pressure, heat, chemicals, or a combination thereof in the different tubular zones prior to being subjected to a rapid difference in temperature and pressure (*e.g.*, explosive decompression). The biomass can be moved by screw-type mechanism, such as a single, twin, or even triple screw as found in an extruder. Alternatively, the biomass can be moved by a mechanism such as a block or other mechanical pressure, differential hydrostatic pressure

managed by air, oil, piston, vacuum, or gravity. These mechanisms can also have a function for pushing or driving forward or separating the biomass into chambers or zones for particular treatment or addition of materials.

[00063] In general, an extruder for use in this system includes an elongated barrel presenting a material inlet and a material outlet adjacent opposed ends thereof, with one or more elongated, axially rotatable screw(s) within the barrel which serves to advance the material from the inlet end to the outlet end thereof. The screw is designed to smooth the flow of material while reducing it in size and various screw elements are arranged to increase or decrease the flow, or to form plugs of the biomass within the barrel. The screw(s) coupled with an end valve under pressure at the outlet, control the speed, pressure, and partly the temperature applied to the biomass as it moves through and out of the barrel.

[00064] The systems and methods disclosed herein can be used for industrial scale pretreatment of biomass at a high rate of throughput. For example, it is estimated that biomass can move through and be processed in accordance with the following Table 1 by continuous operation of a twin screw extruder in accordance with some of the methods disclosed herein.

Table 1

Screw Diameter	Dry Matter Throughput
	Dry Tons/Day
30mm	3.3
52mm	17.0
92mm	94.4
124mm	231.1

[00065] The barrel screw reactor can comprise a metal cylindrical barrel (which can be lined with specialty materials such as ceramic, glass, aluminum, hastelloy, titanium and the like) having a size that can range from, *e.g.*, 30 mm to 220 mm diameter or larger equipped with one or more screws, oriented horizontally or vertically. The barrel can be divided into separate sections (barrel sections) and can be equipped with multiple use ports along the top, side, and/or bottom surfaces. Such multiple use ports can be sealable ports. The multiple use ports can allow the injection of water, steam, acid or other chemicals. The multiple use ports can allow the insertion of thermocouples and/or pressure gauges for measurement of temperature and pressure inside the barrel. Additional ports can be added as required. The reactor barrel can be equipped with electric heating elements or a steam jacket for even heating of the barrel. Heating can alternatively or additionally be supplied by the injection of steam. The reactor barrel can be attached to a pipe that discharges into a flash tank or other container. The flash tank can be

constructed using stainless steel. The barrel can be isolated from the flash tank by a pipe with a seat end having a pressure actuated discharge valve arrangement capable of continuously adjusting position depending upon the back pressure on the valve and the pressure within the system. The discharge valve arrangement can comprise a metal or ceramic sealing seat in between to allow for an explosive discharge of biomass. The pressure-actuated valve arrangement can comprise a conical nozzle connected to a shaft. The diameter of the end valve can vary with the size of the machine, and typically ranges from 30 mm to 220 mm or larger. The conical nozzle can be connected to a shaft that is attached to an actuator in a backpressure generator. The actuator can provide the pneumatic pressure that is regulated by the backpressure generator, which monitors the pressure. The pressure can be a high pressure such that no backflow occurs and there is a restricted flow of material out of the tube. The backpressure on the conical nozzle and seat can be adjustable. For example, operations can be performed using 50 psi to 600 psi (gauge pressure) or higher of backpressure onto the shaft connected to the conical nozzle of the end shear valve. The cone of the end shearing valve can travel between a fully closed and a fully open position, and any intermediate position. A pipe at the outlet of the end shear valve can direct the treated solids down into the bottom of the flash tank, where the solids and vapor can be separated and easily removed.

[00066] The complete extruder, comprised of barrel sections, is normally equipped with a plurality of ports for injection of steam and/or acid into the confines of the barrel, with the ports located adjacent the inlet sections of at least certain of the screw components. In preferred forms, the injection ports are located at a 90° angle relative to the longitudinal axis of the barrel, and are equipped with steam injection assemblies having nozzles the ends of which are flush or barely intruding on the inner wall of the barrel. There can be 16 or more injection assemblies in a barrel section. This is unlike other systems in the art that utilize 2-4 nozzles per barrel section. The increased number allows large amounts of steam, chemicals or water to be injected in an amount needed precisely where it is required. The barrel sections are interchangeable so that the introduction of substances can be modified as required by the nature of the biomass to be processed. In one embodiment, the number of nozzles in a barrel section is at least 2, at least 4, at least 6, at least 8, at least 10, at least 12, at least 14, at least 16, or more in a barrel section. They are also arranged in a circular pattern around the end valve cylinder section to ensure a uniform distribution of liquid.

[00067] In the injection zone just beyond the outlet of the extruder and prior to the needle of the end valve, the nozzles can extend further into the opening of the end valve body. A feature of this invention is that the extrusion equipment is designed to process biomass materials using relatively high levels of specific thermal energy derived steam/water injection and acid, to reach

required levels of pressure within the barrel without any blowback or plugging of the nozzle assembly, as compared with conventional equipment. To this end, the extrusion screw assembly within the extruder barrel is designed to alternately convey, form plug(s) and work the biomass materials while permitting injection of significant amounts of steam into the barrel. Thus, the extruder provides zones of steam injection with zones of high friction and shear so that the material is uniformly hydrated and treated. At the same time, operation of the extruder does not require very high horsepower and does not result in undue wear on the extruder parts.

[00068] The end valve assembly has at least a two-fold purpose. The first is to maintain the pressure within the extruder barrel by restricting the outflow of steam and materials. In this manner, materials released from the valve assembly experience a sudden drop in pressure from a higher than atmospheric pressure to atmospheric pressure. The object of the sudden release is to subject materials to a steam explosion which further deconstructs the extruder-processed biomass. The second purpose is to direct the steam-exploded materials into a connected flash tank.

[00069] There are nozzles and valve assemblies to add water or another chemical to the materials coming downstream into the end valve assembly to enable a smooth flow through the end valve. These inputs can range in number from 4 to 16 or more in a barrel or valve section, depending on the size of the barrel, the speed of the flow, and the density of the materials. In one embodiment, the number of nozzles in the input section is at least 2, at least 4, at least 6, at least 8, at least 10, at least 12, at least 14, at least 16, or more in the end valve section. They are also arranged in a circular pattern around the end valve cylinder section to ensure a uniform distribution of liquid.

[00070] **Fig. 1** shows an embodiment of one type of a design of a reactor provided in longitudinal section. The reactor can be a commercial scale reactor. It comprises a horizontal cylindrical barrel **45** with twin screws fitted with screw elements **51, 52** assembled on shafts **38**, and a discharge valve body **10** and needle **11** partially shown. The extruder and the discharge valve comprise the conduit through which biomass moves to a discharge unit (not shown).

[00071] The barrel can be insulated and can have impermeable walls. Support **7** for the extruder is shown in **Fig. 6**. A motor **24** or other means for moving the screws can be attached near the first end. The motor can be, *e.g.*, an electrically-driven motor and gearbox combination, with or without pulleys and V-belts or any other mechanism to turn the screws. The motor can also be, for example and without being limiting, a synchronous torque motor. A hopper (not shown) can be attached to the inlet of the barrel **45**. Biomass can be added through the opening of the hopper. The biomass can be any biomass as described *supra*. There can be a feeder for non-compacting or compacting flow generation (not shown) such as a crammer to control

biomass addition from the hopper to the barrel **45**. The compacting and/or non-compacting feeder can be any compacting and/or non-compacting loader known in the art. For example, a non-compacting flow inducing feeder can be a non-compacting feeder or various types of live-bottom bin flow inducers followed by flow metering conveyors such as various types of drag chains, bucket elevators, or rotating helixes. In its simplest form a non-compacting feeder can refer to loading biomass by hand into an open first end of the cylindrical barrel. Compacting feeders can comprise mechanical compaction. Mechanical compaction can be achieved by provision of a mechanical compaction device such as a reciprocating plunger or screw feeder.

[00072] An important embodiment of this invention is the internal bore size of the input injectors. Normally, they are larger; however, due to high pressure and small particle size of the materials in the barrel that can cause plugging, they are built with a much smaller bore than in conventional designs. For water or acid injection, this bore will range from 2-3 mm in diameter, while the steam injectors will have bores of 2 mm ranging to 4.5 or 5 mm for extruder barrels of 113 mm or larger. The angle of the injectors to the barrel are generally perpendicular to the barrel although they could be angled towards upstream or downstream flows. Also, conventional extruders with steam or liquid inputs are generally designed for steam injections of 3 to 15% steam per dry weight of material. In the embodiments of this invention, the steam injectors are predisposed to inject 30-50% steam per dry weight of material and to process greater than 100 dry Mtons per day. The pressures generated in the extruder barrel are conducive to plugging of the nozzles and therefore they cannot be of conventional design with larger bores. Instead, to generate additional steam or liquids, additional injectors must be added to the system or the flow increased.

[00073] In one embodiment, as depicted in **Fig. 1**, the extruder barrel **45** comprises an array of injectors **29, 32, 34, 36** in a plurality of ports **55** (**Fig. 2**) organized in spiral or circular patterns about the extruder barrel **45** and valve body **10** for a flowpath designed to process biomass. In **Fig. 1**, the injectors are grouped in four sets, more clearly shown in **Fig. 6** as assemblages **S1, S2, S3, S4**. The first set **S1** consists of injectors **29** and occurs prior to plug formation initiated by kneading elements **52**. These injectors provide the addition of water upstream of the plug, to maintain a certain minimum moisture (max solids) in the plug (not shown) for control of torque, throughput and heat.

[00074] This upstream portion of the extruder barrel **45**, is equipped with a series of ports **55** (**Figs. 3A and 3B**, longitudinal and cross sections, respectively) for water injection to hydrate incoming materials, wherein each of the barrel ports houses an elongated water injector **29**. The series of ports **55** are located so as to penetrate the outer wall of the extruder and communicate

with the bore **30** of the barrel. The ports can be disposed about the flowpath and along the conduit in a spiral pattern, as depicted in **Figs. 2, 3, and 4**.

[00075] A second set **S2** of injectors **32** occurs downstream of the kneading elements **52** and within the reaction zone **R**. This set **S2** can be arranged in the barrel sections so as to input steam immediately after the plug formation, evenly throughout most of the reaction zone, or at the end of the reaction zone, depending on the extent of processing and magnitude of pressure/temperature required. In another embodiment, combinations of these arrangements can be used. **Fig. 3C** (longitudinal section) and **Fig. 3D** (cross-section) depict an embodiment of a barrel section with ports **55** designed to accommodate injectors arranged to provide steam just after plug formation.

[00076] A third set **S3** of injectors **34** also occurs downstream of the kneading elements **52** and within the reaction zone **R**. This set **S3** can be arranged in the barrel sections so as to input acid evenly after plug formation and throughout most of the reaction zone to the end of the extruder barrel **45**, depending on the extent of processing required. In other embodiments, different combinations of these injectors **34** can be used. **Fig. 3E** (longitudinal section) and **Fig. 3F** (cross-section) show an embodiment of a barrel section with ports **55** designed to accommodate injectors arranged to provide acid just after plug formation and prior to materials moving into the valve body.

[00077] The fourth set **S4** of injectors **36** are organized just beyond the extruder barrel **45** but prior to the needle **11** within the valve body **10** (**Figs. 1 and 4**). They are used to inject water as the biomass material emerges from the extruder and are disposed beyond the end of the screw elements **51** although any shaft caps **39** may protrude into this space **21**. The water is used to thin the material, improve rheology through steam explosion and therefore reduce torque on the extruder to push through the valve. With processing, materials, especially slurries, do not often flow, but surge a bit as they are processed through a pipe or barrel. The flow at exit is turbulent and, as it mixes with the water, it smooths into a laminar flow traveling downstream in the space of the valve **21**. Any liquid can be added just prior to output from the tube to facilitate the flow of materials through the valve system and/or to further process materials. In one embodiment, liquids such as water, acid, bases, alcohols, solvents, aldehydes, ketones, and the like can be used for this purpose.

[00078] The injectors are connected to ports **55** so that the injector assemblies are disposed at a desired angle relative to the flowpath of the materials or screw elements. Thus, as shown in **Fig. 1**, an injector **29** (which is in the first set of injector combinations) can be connected to a port **55** (**Figs. 2 and 3B**) so that it is disposed at an angle of about 90° relative to the extruder barrel and the flowpath. Also, an injector **32** (which is in the second set of injector assemblies)

can be connected to a port **55** (**Figs. 2 and 3D**) so that it is disposed at an angle of about 90° relative to the extruder barrel **45** and the flowpath of the materials.

[00079] While the system depicted in **Fig. 1** with the injector assemblies set at particular angles, the angles employed can be varied so long as the injector assemblies do not physically interfere with each other or the movement of the screw elements. Thus, the angle between the injector assemblies can be, for example, decreased as the physical dimensions of the injector assemblies decreases or can be, for example, increased as the physical dimensions of the injector assemblies increases. The ports are disposed at discrete locations about the flowpath of the materials and along the length of the extruder or valve body in a spiral or helical pattern to provide both angular and longitudinal separation between individual ports.

[00080] **Figs. 5A and 5B** depict an individual injector. The injector comprises a distal end where the bore **73** is open to the inner chamber of the extruder, a proximal end **70**, and a duct **71** connecting the distal and proximal ends of the injector. An adjustable valve (not shown) is housed in the manifold (**Fig. 6**) prior to attachment of the conduit that connects the injector to the manifold. The nozzle **72** of the injector tube can project into the flowpath of the extruder any suitable distance as long as it does not interfere with the movement of the screw elements or other moving parts. Thus, the nozzle **72** will be almost flush and barely protruding in the inner wall **45** of the extruder, but can extend further into the valve body **10** without hindering mechanical movement.

[00081] Each injector nozzle **72** is fed from its own unique manifold/header with attendant piping to the nozzles. So, if water is injected into the barrel, it is fed from its own pump into a manifold to which all of the nozzles in use are connected. The flow can be controlled by the setting on the pump. There is no restriction in the tube of the injector. The same is true for acid and other fluids; they each have their own pump and their own manifold/header. Steam is fed from the steam supply which is operated at a pressure of 69 barg at source, downgraded to 49 barg through a pressure reduction system at the extruder. The flow of steam is regulated by the opening of a flow control valve (not shown).

[00082] The valves emanating from the manifold, are individually adjustable for each line to an injector nozzle. Thus, flow to specific nozzles of each injector is adjustable as well. If fewer injectors are required in any particular set, the injector can be removed and the hole plugged after the valve is turned off so no materials flow from the manifold to that nozzle and no materials move out of the extruder through that bore.

[00083] The valve comprises at least one inlet for the supply of additive(s) to the valve and can comprise any suitable valve, such as a manually or automatically actuated two-way valve. Suitable valves include, but are not limited to, the valves described in U.S. Pat. No. 6,220,296

(Ragsdale et al.), U.S. Pat. No. 6,247,839 (Kochanowicz et al.), U.S. Pat. No. 6,316,053 (Ragsdale et al.), and U.S. Pat. No. 6,541,531 (Ragsdale), each of which are herein incorporated by reference.

[00084] The conduit of the manifold can be constructed from any suitable material. For example, the conduit can be constructed from a metal, such as aluminum, steel, stainless steel, corrosion-resistant alloys and the like, or from a plastic material (if using lower pressures), such as polyvinyl chloride (PVC), polycarbonate, and the like.

[00085] The manifold can be provided with any suitable means for fitting it to a suitable system, such as a system used in the manufacture of a polymer foam (*e.g.*, a polyurethane foam). For example, the ends of the conduit can be threaded to provide a means for coupling the manifold to a suitable system. Alternatively, the ends of the conduit can be provided with flanged fittings to provide a means for coupling the manifold to a system.

[00086] While preferred embodiments of the present invention have been shown and described herein, it will be obvious to those skilled in the art that such embodiments are provided by way of example only. Numerous variations, changes, and substitutions will now occur to those skilled in the art without departing from the invention. It should be understood that various alternatives to the embodiments of the invention described herein may be employed in practicing the invention. It is intended that the following claims define the scope of the invention and that methods and structures within the scope of these claims and their equivalents be covered thereby.

[00087] Exemplary Embodiments

[00088] Embodiment 1. A system for introducing one or more additives into materials, the system comprising:

- a. At least one assembly of injectors with internal bores of a diameter ranging from 2 to 6 mm;
- b. A manifold for controlling the flow of substances in said assembly;
- c. Valves incorporated into the manifold for each injector to independently control the flow of substances in the injector; and
- d. A supply of at least one additive.

[00089] Embodiment 2. The system of embodiment 1 wherein the additive is a liquid or steam.

[00090] Embodiment 3. The system of embodiment 1 wherein the additive is water.

[00091] Embodiment 4. The system of embodiment 1 wherein the additive is an acid.

[00092] Embodiment 5. The system of embodiment 1 wherein the additive is steam is at a pressure of 80-600 psi.

- [00093]** Embodiment 6. The system of embodiment 1 wherein the additive is steam is at a pressure of 150 psi.
- [00094]** Embodiment 7. The system of embodiment 1 wherein the additive is steam is at a pressure of 200 psi.
- [00095]** Embodiment 8. The system of embodiment 1 wherein the additive is steam is at a pressure of 250 psi.
- [00096]** Embodiment 9. The system of embodiment 1 wherein the additive is steam is at a pressure of 300 psi.
- [00097]** Embodiment 10. The system of embodiment 1 wherein the materials consist of biomass.
- [00098]** Embodiment 11. The system of embodiment 1 wherein the materials consist of biomass within a conduit.
- [00099]** Embodiment 12. The system of embodiment 11 wherein the conduit is an extruder.
- [00100]** Embodiment 13. The system of embodiment 12 wherein the conduit comprises an extruder and a discharge valve.
- [00101]** Embodiment 14. The system of embodiment 1 wherein the internal bores of the injectors have a diameter of 2 mm.
- [00102]** Embodiment 15. The system of embodiment 1 wherein the internal bores of the injectors have a diameter of 2.5 mm.
- [00103]** Embodiment 16. The system of embodiment 1 wherein the internal bores of the injectors have a diameter of 3 mm.
- [00104]** Embodiment 17. The system of embodiment 1 wherein the internal bores of the injectors have a diameter of 3.5 mm.
- [00105]** Embodiment 18. The system of embodiment 1 wherein the internal bores of the injectors have a diameter of 4 mm.
- [00106]** Embodiment 19. The system of embodiment 1 wherein the internal bores of the injectors have a diameter of 4.5 mm.
- [00107]** Embodiment 20. The system of embodiment 1 wherein the internal bores of the injectors have a diameter of 5 mm.
- [00108]** Embodiment 21. The system of embodiment 1 wherein the internal bores of the injectors have a diameter of 5.5 mm.
- [00109]** Embodiment 22. The system of embodiment 1 wherein the internal bores of the injectors have a diameter of 6 mm.

[000110] Embodiment 23. The system of embodiment 1 wherein the assembly consists of 2 or more injectors.

[000111] Embodiment 24. The system of embodiment 1 wherein the assembly consists of 4 or more injectors.

[000112] Embodiment 25. The system of embodiment 1 wherein the assembly consists of 6 or more injectors.

[000113] Embodiment 26. The system of embodiment 1 wherein the assembly consists of 8 or more injectors.

[000114] Embodiment 27. The system of embodiment 1 wherein the assembly consists of 10 or more injectors.

[000115] Embodiment 28. The system of embodiment 1 wherein the assembly consists of 12 or more injectors.

[000116] Embodiment 29. The system of embodiment 1 wherein the assembly consists of 14 or more injectors.

[000117] Embodiment 30. The system of embodiment 1 wherein the assembly consists of 16 or more injectors.

[000118] Embodiment 31. The system of embodiment 1 wherein the materials consist of biomass within a reaction zone.

[000119] Embodiment 32. A method of injecting liquid or steam into an extruder barrel or a valve body comprising:

- a. Having a plurality of injection ports penetrate the outer wall of the extruder barrel or outer valve wall to its bore;
- b. Including injectors into the injection ports;
- c. Injecting steam into said extruder barrel or valve to maintain the pressure between 150 to 800 psi in the conduit; and
- d. Injecting liquid into said extruder barrel or valve.

[000120] Embodiment 33. A method of injecting liquid and steam into an extruder barrel or a valve body comprising:

- a. Having a plurality of injection ports penetrate the extruder barrel or valve body to its bore;
- b. Including injectors into the injection ports; and
- c. Injecting liquid and steam into said extruder barrel or valve to maintain the pressure between 150 to 800 psi inside said zone.

[000121] Embodiment 34. The method of embodiment 32, wherein the injector nozzle bore diameter is between 2-6 mm.

[000122] Embodiment 35. The method of embodiment 32, wherein the injector nozzle bore diameter is between 2-4 mm.

[000123] Embodiment 36. The method of embodiment 32, wherein the injector nozzle bore diameter is between 2-3 mm.

[000124] Embodiment 37. The method of embodiment 32, wherein the injector nozzle bore diameter is 2 mm.

[000125] Embodiment 38. The method of embodiment 32, for pretreating at least one dry ton of biomass per day, the method comprising:

(a) feeding the biomass at a rate of at least one dry metric ton (MT) of biomass per day into an extrusion system comprising a barrel defining an inner chamber comprising a feeder zone and a reaction zone, wherein the extrusion system is constructed and arranged such that:

(i) a steam impervious plug is formed by compacting the biomass in a high pressure zone separating the feeder zone and the reaction zone, and

(ii) At least one assembly of steam injectors having an internal nozzle bore diameter of 6 mm or less provide pressure and high temperatures to the reaction zone.

[000126] Embodiment 39. An extruder system having at least one assembly of one or more injectors having an internal nozzle bore diameter of 6 mm or less.

[000127] Embodiment 40. The system of embodiment 38, wherein the injectors provide steam at a pressure of 150-800 psi to the extruder bore.

[000128] Embodiment 41. The system of embodiment 39, wherein the injectors have an internal bore diameter of 4 mm or less.

[000129] Embodiment 42. The system of embodiment 39, wherein the injectors have an internal bore diameter of 2 mm or less.

[000130] Embodiment 43. The system of embodiment 38, wherein the system consists of at least 2 assemblies of injectors, at least 3 assemblies of injectors, or at least 4 assemblies of injectors.

[000131] Embodiment 44. The system of embodiment 43, wherein the internal bores of the injectors have a diameter of 2 mm.

[000132] Embodiment 45. The system of embodiment 43, wherein the internal bores of the injectors have a diameter of 2.5 mm.

[000133] Embodiment 46. The system of embodiment 43, wherein the internal bores of the injectors have a diameter of 3 mm.

[000134] Embodiment 47. The system of embodiment 43, wherein the internal bores of the injectors have a diameter of 3.5 mm.

[000135] Embodiment 48. The system of embodiment 43, wherein the internal bores of the injectors have a diameter of 4 mm.

[000136] Embodiment 49. The system of embodiment 43, wherein the internal bores of the injectors have a diameter of 4.5 mm.

[000137] Embodiment 50. The system of embodiment 43, wherein the internal bores of the injectors have a diameter of 5 mm.

[000138] Embodiment 51. The system of embodiment 43, wherein the internal bores of the injectors have a diameter of 5.5 mm.

[000139] Embodiment 52. The system of embodiment 43, wherein the internal bores of the injectors have a diameter of 6 mm.

[000140] Embodiment 53. The system of embodiment 43, wherein the assembly consists of 2 or more injectors.

[000141] Embodiment 54. The system of embodiment 43, wherein the assembly consists of 4 or more injectors.

[000142] Embodiment 55. The system of embodiment 43, wherein the assembly consists of 6 or more injectors.

[000143] Embodiment 56. The system of embodiment 43, wherein the assembly consists of 8 or more injectors.

[000144] Embodiment 57. The system of embodiment 43, wherein the assembly consists of 10 or more injectors.

[000145] Embodiment 58. The system of embodiment 43, wherein the assembly consists of 12 or more injectors.

[000146] Embodiment 59. The system of embodiment 43, wherein the assembly consists of 14 or more injectors.

[000147] Embodiment 60. The system of embodiment 43, wherein the assembly consists of 16 or more injectors.

[000148] Embodiment 61. An extruder system comprising at least one barrel section having spiral or concentric ports for an assembly of injector nozzles.

[000149] Embodiment 62. The extruder system of Embodiment 61, wherein the barrel section has at least 4 ports.

[000150] Embodiment 63. The extruder system of Embodiment 61, wherein the barrel section has at least 6 ports.

[000151] Embodiment 64. The extruder system of Embodiment 61, wherein the barrel section has at least 8 ports.

[000152] Embodiment 65. The extruder system of Embodiment 61, wherein the barrel section has at least 10 ports.

[000153] Embodiment 66. The extruder system of Embodiment 61, wherein the barrel section has at least 12 ports.

[000154] Embodiment 67. The extruder system of Embodiment 61, wherein the barrel section has at least 14 ports.

[000155] Embodiment 68. The extruder system of Embodiment 61, wherein the barrel section has at least 16 ports.

[000156] Embodiment 69. The extruder system of Embodiment 61 comprising at least two barrel sections.

[000157] Embodiment 70. The extruder system of Embodiment 61, wherein the barrel section is interchangeable with other barrel sections.

[000158] Embodiment 71. The extruder system of Embodiment 61, wherein the spiral or concentric ports are perpendicular to the barrel section.

[000159] Embodiment 72. An extruder system of Embodiment 61, wherein the injectors are predisposed to inject 30-50% steam per dry weight of material.

CLAIMS

1. An extruder comprising:
 - (1) a barrel, wherein the barrel comprises an inner chamber comprising a feeder zone and a reaction zone, wherein the extruder is constructed and arranged such that a steam impervious plug is formed by compacting biomass in a high pressure zone separating the feeder zone and the reaction zone;
 - (2) a discharge valve body at a discharge end of the barrel, wherein the discharge valve body comprises a plurality of injection ports that penetrate an outer wall of the discharge valve body; and
 - (3) a system for introducing one or more additives into materials, the system comprising:
 - a. an assembly of injectors, wherein the injectors comprise internal bores of a diameter ranging from 2 to 6 mm;
 - b. a manifold for controlling flows of substances in said assembly of injectors;
 - c. valves incorporated into the manifold for each injector to independently control the flows of substances in the injector; and
 - d. a supply of an additive;wherein the injectors are placed into the plurality of injection ports in the outer wall of the discharge valve body.
2. The extruder of claim 1, wherein the additive is a liquid or a steam.
3. The extruder of claim 1, wherein the additive is water.
4. The extruder of claim 1, wherein the additive is an acid.
5. The extruder of claim 1, wherein the additive is a steam and wherein the steam is at a pressure of 80-600 psi.
6. The extruder of claim 1, wherein the additive is a steam and wherein the steam is at a pressure of 150 to 300 psi.
7. The extruder of claim 1, wherein the materials comprise a biomass.
8. The extruder of claim 1, wherein the internal bores of the injectors have a diameter of 2 to 4 mm.
9. The extruder of claim 1, wherein the internal bores of the injectors have a diameter of about 2 mm.

10. The extruder of claim 1, wherein the assembly of injectors comprises 2 or more injectors.
11. The extruder of claim 1, wherein the assembly of injectors comprises 16 or more injectors.
12. A method of injecting liquid and steam into an extruder having an extruder barrel and a discharge valve body, wherein the extruder barrel comprises an inner chamber comprising a feeder zone and a reaction zone, wherein the extruder is constructed and arranged such that a steam impervious plug is formed by compacting biomass in a high pressure zone separating the feeder zone and the reaction zone, the method comprising:
 - a. providing a plurality of injection ports, wherein the injection ports penetrate an outer wall of the extruder barrel and an outer wall of the discharge valve body;
 - b. introducing injectors into the plurality of injection ports;
 - c. injecting steam into said extruder barrel or said discharge valve body to maintain a pressure between 150 to 800 psi in said extruder barrel or said discharge valve body; and
 - d. injecting liquid into said discharge valve body.
13. The extruder of claim 1, wherein the barrel further comprises a plurality of injection ports that penetrate an outer wall of the barrel; and wherein the injectors are placed into the plurality of injection ports in the outer wall of the barrel.
14. The extruder of claim 13, wherein the barrel comprises the plurality of injectors organized in spiral or circular patterns about the barrel.
15. The extruder of claim 14, wherein the plurality of injectors are perpendicular to the barrel.
16. The extruder of claim 14, wherein one or more of the injectors are predisposed to inject 30-50% steam per dry weight of materials in the barrel.