



US007730633B2

(12) **United States Patent**
Jurkovich et al.

(10) **Patent No.:** **US 7,730,633 B2**
(45) **Date of Patent:** **Jun. 8, 2010**

(54) **AGRICULTURAL-PRODUCT PRODUCTION
WITH HEAT AND MOISTURE RECOVERY
AND CONTROL**

(75) Inventors: **John C. Jurkovich**, Edina, MN (US);
Mark R. Oliver, Eagan, MN (US)

(73) Assignee: **Pesco Inc.**, Minnetonka, MN (US)

(*) Notice: Subject to any disclaimer, the term of this
patent is extended or adjusted under 35
U.S.C. 154(b) by 1451 days.

(21) Appl. No.: **10/963,954**

(22) Filed: **Oct. 12, 2004**

(65) **Prior Publication Data**

US 2006/0093718 A1 May 4, 2006

(51) **Int. Cl.**
F26B 7/00 (2006.01)

(52) **U.S. Cl.** **34/381; 59/316; 422/307;**
99/468

(58) **Field of Classification Search** 34/380,
34/381, 138; 422/307; 99/468; 59/316
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

1,759,702 A *	5/1930	Koon	34/361
2,054,441 A *	9/1936	Peebles	159/4.07
2,062,025 A *	11/1936	Harrington	110/228
2,142,984 A *	1/1939	Thurman	159/2.1
2,295,918 A *	9/1942	Thomas	34/136
2,316,670 A *	4/1943	Dwaine et al.	562/33
2,411,152 A *	11/1946	Folsom	34/295
2,413,420 A *	12/1946	Stephanoff	34/364
2,515,098 A *	7/1950	Smith, Jr.	34/290
2,561,256 A *	7/1951	Wilson et al.	528/485
2,619,425 A *	11/1952	Levin	424/543
2,664,389 A *	12/1953	Rex et al.	201/33
2,689,823 A *	9/1954	Hardy et al.	208/103
2,695,459 A *	11/1954	Hutchins	34/418

2,701,786 A *	2/1955	Evans	208/300
2,708,654 A *	5/1955	Lykken	202/131
2,751,687 A *	6/1956	Colton	264/28
2,772,642 A *	12/1956	Lindl	425/308
2,903,400 A *	9/1959	Poindexter et al.	202/109

(Continued)

OTHER PUBLICATIONS

Badger State Ethanol, "Dry Mill Process", web address: <http://www.badgerstateethanol.com/downloads/drymillprocess.pdf>, downloaded Aug. 17, 2004), (1 page).

(Continued)

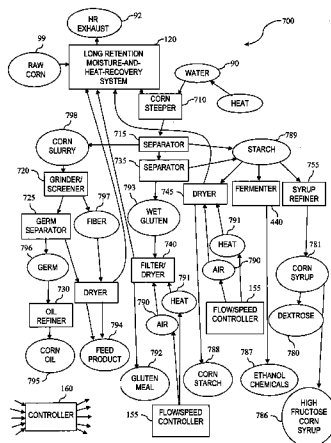
Primary Examiner—Stephen M. Gravini

(74) *Attorney, Agent, or Firm*—Charles A. Lemaire; Jonathan M. Rixen; Lemaire Patent Law Firm, P.L.L.C.

(57) **ABSTRACT**

A method and apparatus for agricultural product production with heat and moisture recovery and control. Some embodiments transfer heat and moisture from a warm, moist exhaust air stream to incoming agricultural material, steam condition the material, pelletize the material into warm pellets, cool the warm pellets with make-up air to produce the warm, moist exhaust air used to transfer heat to the incoming material and to produce cooled pellets, wherein the cooled pellets are at a temperature lower than the warm moist air. In some embodiments, the system includes counter-flow devices to transfer heat and moisture. In some embodiments, a controller is used to adjust system devices and overall system flow. In some embodiments a water sprayer, to moisten agricultural product when the product is over dry, and an air flow controller, to slow air flow through the pellet dryer/cooler when ambient temperatures are dryer/cooler, are provided.

41 Claims, 9 Drawing Sheets



U.S. PATENT DOCUMENTS

2,933,822 A *	4/1960	Nathan	34/364	7,140,122 B1 *	11/2006	Adams et al.	34/361
3,007,254 A *	11/1961	Schuster	34/391	7,487,601 B2 *	2/2009	Carin et al.	34/381
3,047,473 A *	7/1962	Schmidt	201/4	2003/0000100 A1 *	1/2003	Ludwig et al.	34/62
3,085,012 A *	4/1963	Wayne	34/287	2003/0019229 A1 *	1/2003	Dodo et al.	62/238.3
3,086,008 A *	4/1963	Opila et al.	536/102	2003/0033820 A1 *	2/2003	Lu et al.	62/78
3,101,040 A *	8/1963	Lanz	99/471	2004/0200091 A1 *	10/2004	Strand et al.	34/360
3,131,035 A *	4/1964	Erickson	34/77	2005/0120715 A1 *	6/2005	Labrador	60/618
3,150,005 A *	9/1964	Oleson et al.	127/28	2006/0010714 A1 *	1/2006	Carin et al.	34/514
3,212,197 A *	10/1965	Crawford	34/371	2006/0101665 A1 *	5/2006	Carin et al.	34/513
3,254,881 A *	6/1966	Rusk	432/51	2006/0112588 A1 *	6/2006	Ness et al.	34/513
3,266,169 A *	8/1966	Smith, Jr.	34/58	2006/0201024 A1 *	9/2006	Carin et al.	34/576
3,295,221 A *	1/1967	Joy	34/364	2006/0254081 A1 *	11/2006	Carin et al.	34/576
3,392,455 A *	7/1968	Kingsbaker, Jr. et al.	34/405	2008/0104858 A1 *	5/2008	Carin et al.	34/282
3,411,465 A *	11/1968	Shirai	110/227	2008/0110043 A1 *	5/2008	Carin et al.	34/487
3,438,780 A *	4/1969	Singer		2008/0189979 A1 *	8/2008	Carin et al.	34/576
3,440,135 A *	4/1969	Chung	162/157.6	2008/0214749 A1 *	9/2008	Weismantel et al.	526/73
3,466,021 A *	9/1969	Van Weert et al.	432/4	2008/0222913 A1 *	9/2008	Ronning et al.	34/467
3,598,131 A *	8/1971	Weihe, Jr.	134/107	2009/0199425 A1 *	8/2009	Taylor	34/241
3,795,987 A *	3/1974	Kemmetmueller	34/168				
3,861,058 A *	1/1975	Whelan					
4,016,657 A *	4/1977	Passey	34/92				
4,035,925 A *	7/1977	Brown et al.	34/323				
4,163,469 A *	8/1979	English					
4,183,675 A *	1/1980	Zarow	366/144				
4,211,071 A *	7/1980	Wyatt					
4,226,844 A *	10/1980	Reh et al.	423/625				
4,285,773 A *	8/1981	Taciuk	202/100				
4,310,973 A *	1/1982	King	34/368				
4,357,358 A *	11/1982	Schanze					
4,447,965 A *	5/1984	Bray					
4,449,483 A *	5/1984	Strohmeyer, Jr.	122/4 D				
4,583,468 A *	4/1986	Reed et al.	110/246				
4,659,299 A *	4/1987	Pierik	425/72.1				
4,674,418 A *	6/1987	Schafer					
4,676,152 A *	6/1987	Tsuji et al.	99/468				
4,699,210 A *	10/1987	Brannstrom	165/120				
4,724,620 A *	2/1988	Hsu	34/174				
4,894,117 A *	1/1990	Bianchi et al.	159/49				
4,929,163 A *	5/1990	Volk					
4,935,874 A *	6/1990	Volk, Jr.					
5,069,801 A *	12/1991	Girovich	210/770				
5,100,510 A *	3/1992	Bianchi et al.	159/6.3				
5,220,733 A *	6/1993	Bothe et al.	34/426				
5,263,817 A *	11/1993	States	425/331				
5,335,425 A *	8/1994	Tomizawa et al.	34/265				
5,373,648 A *	12/1994	Wolf	34/578				
5,393,501 A *	2/1995	Clawson et al.	422/187				
5,402,352 A *	3/1995	Kniepmann et al.	700/117				
5,445,329 A *	8/1995	Anderson	241/65				
5,455,005 A *	10/1995	Clawson et al.	422/1				
5,486,102 A *	1/1996	Ettie et al.					
5,540,391 A *	7/1996	Anderson	241/17				
5,570,517 A *	11/1996	Luker					
5,596,815 A *	1/1997	Rice et al.	34/346				
5,744,186 A *	4/1998	Harrison					
5,871,802 A *	2/1999	Gao et al.					
5,915,815 A *	6/1999	Moore et al.	34/305				
5,992,048 A *	11/1999	DeVore et al.	34/522				
6,039,774 A *	3/2000	McMullen et al.	48/102 A				
6,146,600 A *	11/2000	Williamson	422/307				
6,330,982 B1	12/2001	Yu et al.					
6,449,872 B1 *	9/2002	Olkku et al.	34/380				
6,470,597 B1 *	10/2002	Stipp	34/422				
6,536,133 B1 *	3/2003	Snaper	34/265				
7,017,277 B1 *	3/2006	Adams et al.	34/92				
7,020,980 B1 *	4/2006	Adams et al.	34/361				
7,024,800 B2 *	4/2006	Gorbell et al.	34/576				

OTHER PUBLICATIONS

Badger State Ethanol, "Ethanol Production Process", web address: <http://www.badgerstateethanol.com/process.htm>, (Copyright 2001), (2 pages).

Barr-Rosen Ltd, "Swirl Fluidizer", web address: <http://www.barr-rosin.com/english/products/b12.html>, (downloaded Aug. 6, 2004), (2 pages).

Barr-Rosen Ltd., "Column Dryer", web address: <http://www.barr-rosin.com/english/products/b6.html>, (downloaded Aug. 6, 2004), (2 pages).

Barr-Rosen Ltd., "Ring Dryer", web address: <http://www.barr-rosin.com/english/products/b2.html>, (downloaded Aug. 6, 2004), (5 pages).

Barr-Rosin Ltd., "Flash Dryer", web address: <http://www.barr-rosin.com/english/products/b1.html>, (downloaded Aug. 6, 2004), (3 pages).

Barr-Rosin Ltd., "Fluid Bed Dryer", web address: <http://www.barr-rosin.com/english/products/b5.html>, (downloaded Aug. 6, 2004), (3 pages).

Bliss Industries, Inc., "Eliminator Combo Rotary Feeders & Magnet Adapters", web address: <http://www.bliss-industries.com/pdfs/rotaryfd.pdf>, (downloaded Aug. 17, 2004), (4 pages).

Bliss Industries, Inc., "OP-FLO-Coolers The circular solution to counterflow cooling", web address: <http://www.bliss-industries.com/pdfs/cooler.pdf>, (downloaded Aug. 17, 2004), (6 pages).

Bliss Industries, Inc., "Pioneer Pellet Mill", web address: <http://www.bliss-industries.com/pdfs/peltpmill.pdf>, (downloaded Aug. 17, 2004), (6 pages).

Corn Products International, Inc., "Corn Wet Milling Process Diagram", web address: <http://www.cornproducts.com/WetMillingProcess.shtml> <http://www.cornproducts.com/images/Fermentation.gif>, (downloaded Aug. 17, 2004), (1 page).

Natural Corn-To-Ethanol Research, "Flow Diagram", web address: <http://www.siu.edu/ETHANOL/flow.html>, (downloaded Aug. 18, 2004), (1 page).

Pioneer, "Corn Wet Milling Information", web address: http://www.pioneer.com/media/industryselect/about_industryselect/wet_milling_brochure.pdf, (2003/2004), (2 pages).

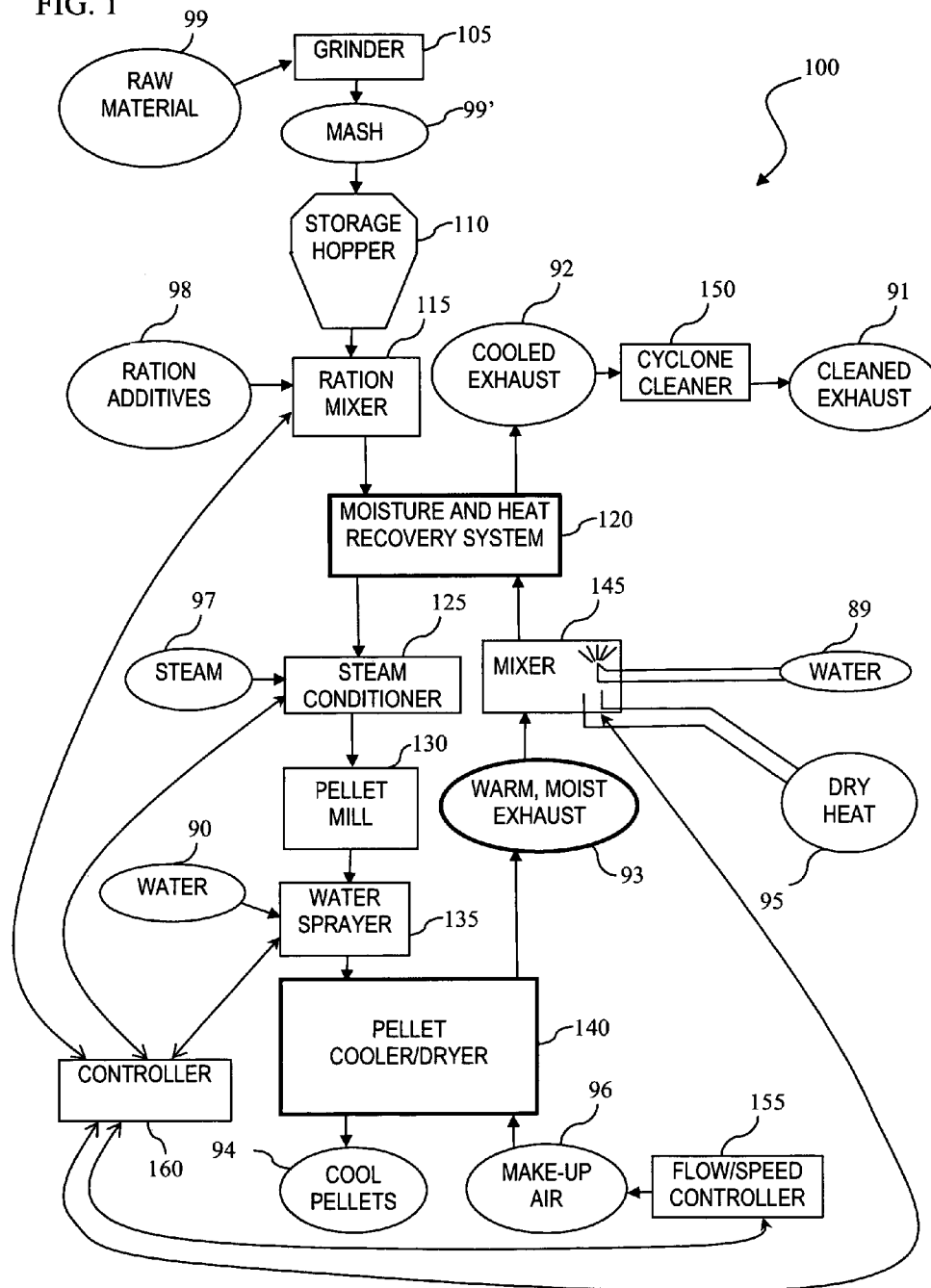
Renewable Fuels Association, "How Ethanol is Made", web address: http://www.ethanolrfa.org/prod_process.html, (Copyright 2000), (3 pages).

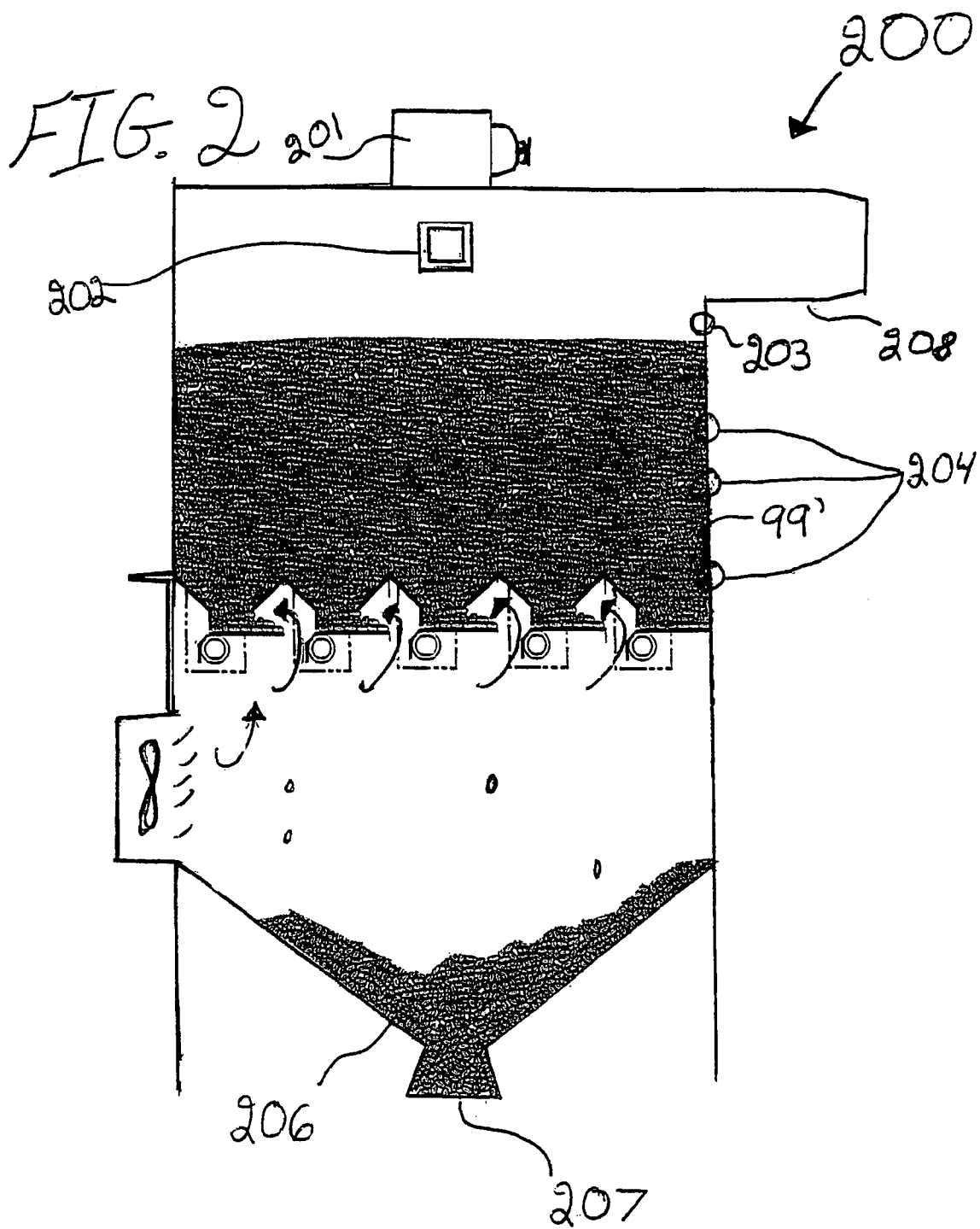
Scott Equipment Company, "A.S.T. Drying System", web address: <http://www.scottequipment.com/drying/ast.dryer/pdf/scotteco.astdryer.ebrochure.pdf>, (downloaded Aug. 17, 2004), (6 pages).

Stillspirits, "FAQ's Yeast & Fermentation", web address: <http://www.stillspirits.com/wawcs016220/6220.html>, (downloaded Aug. 18, 2004), (4 pages).

* cited by examiner

FIG. 1





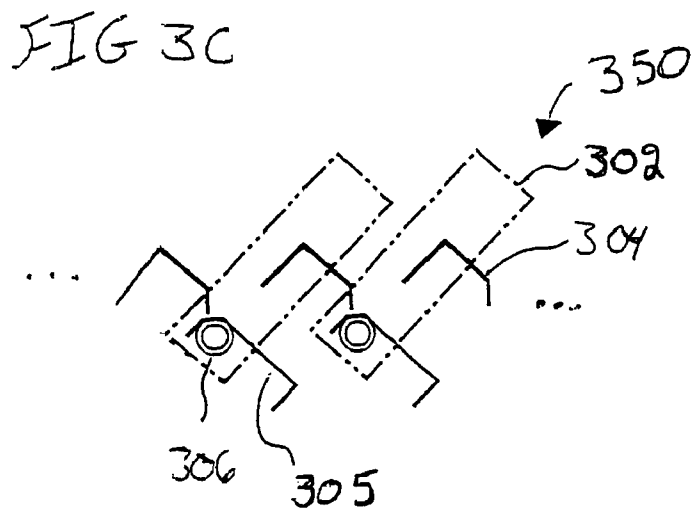
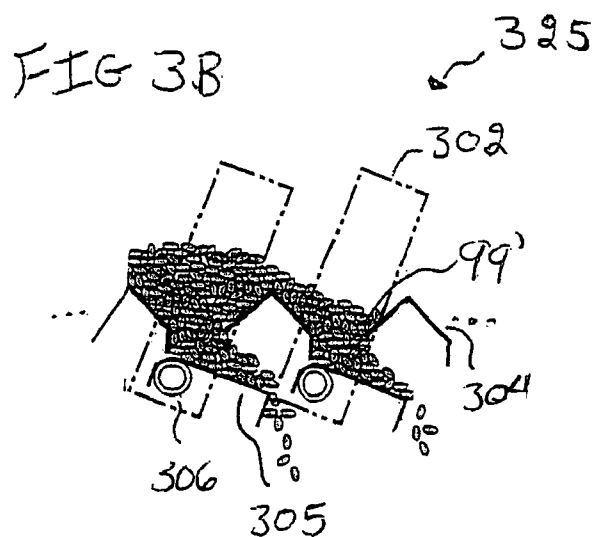
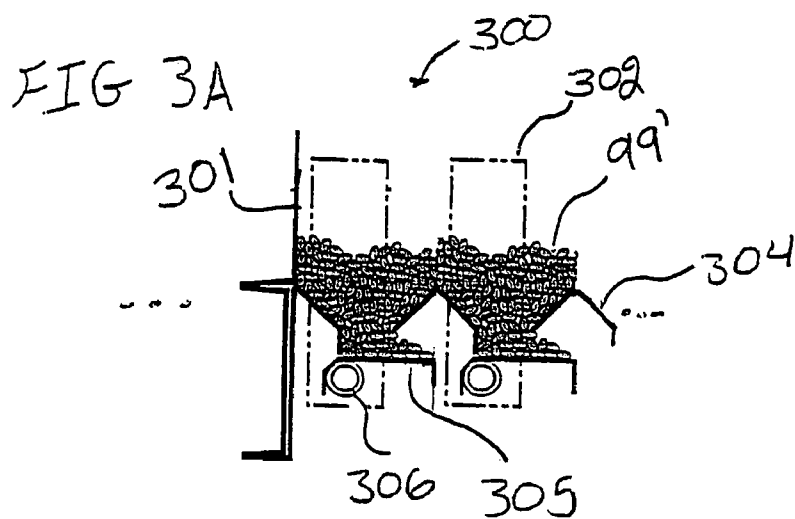


FIG. 4

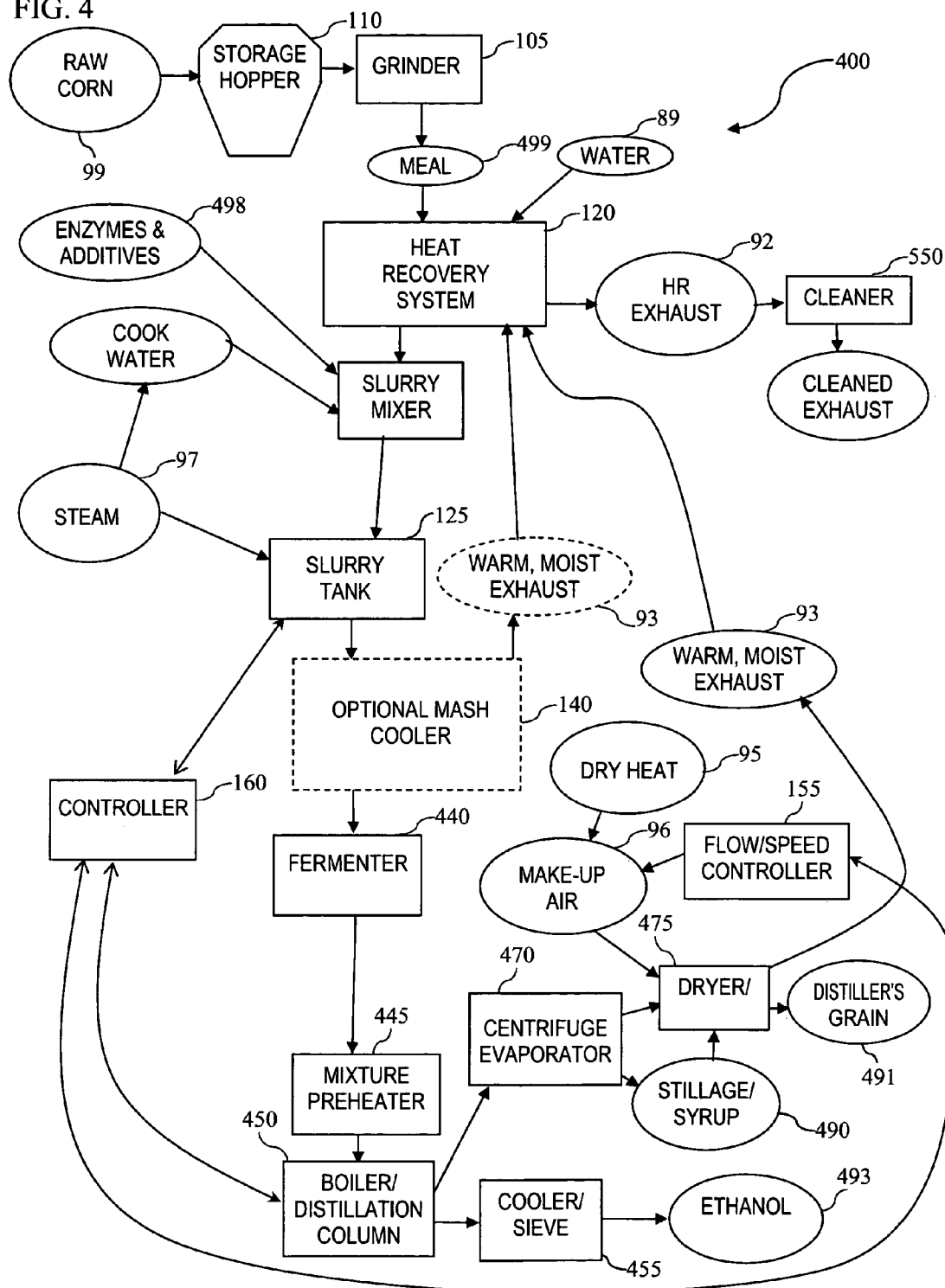
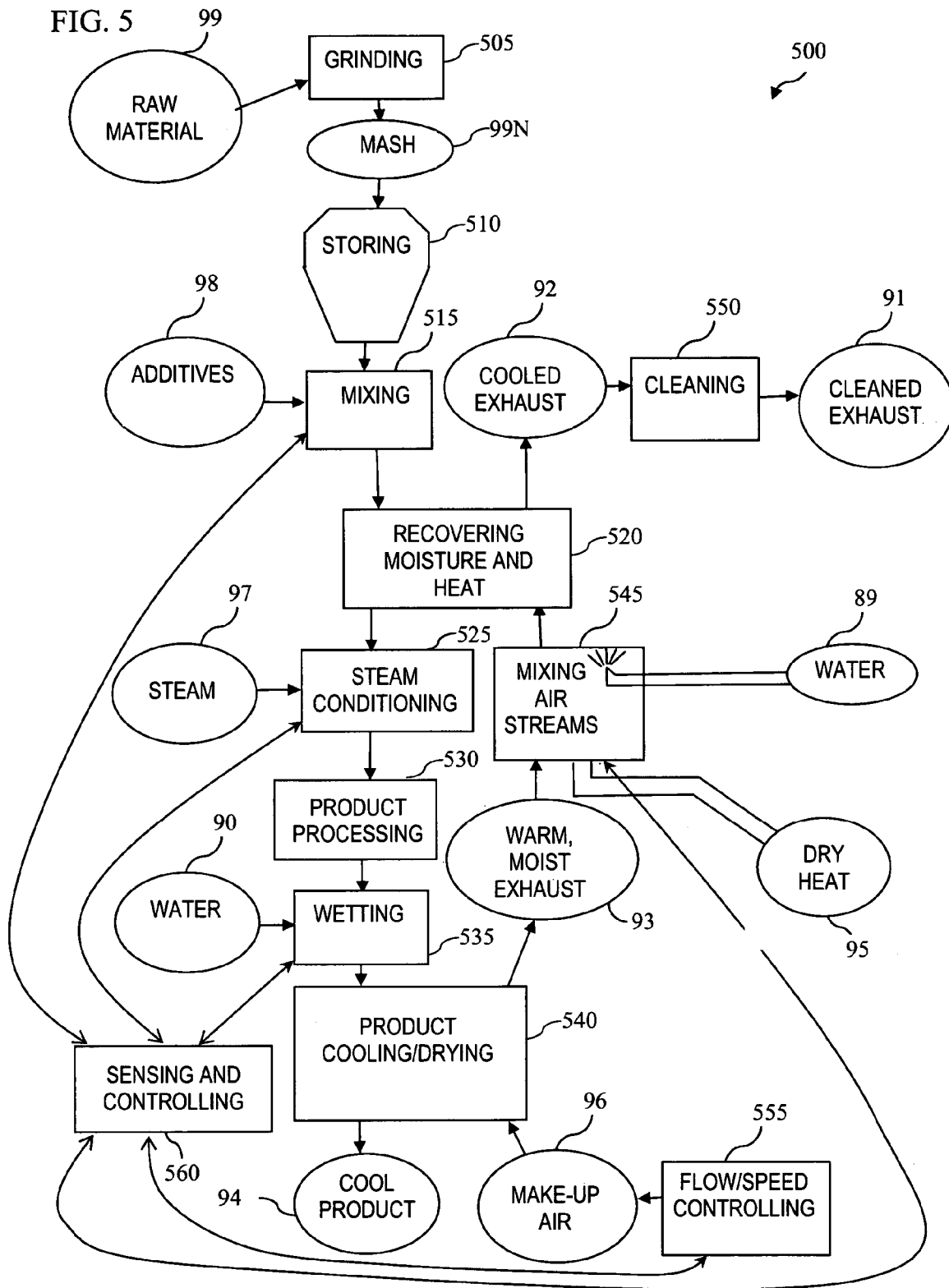


FIG. 5



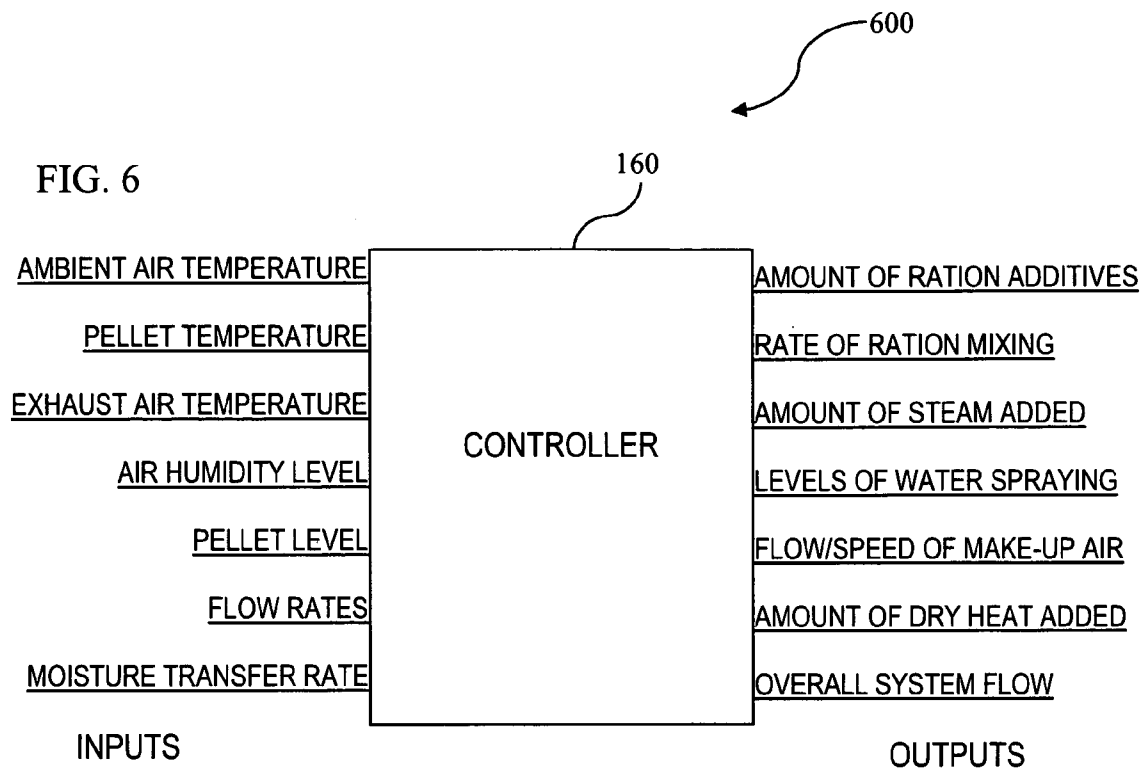


FIG. 7

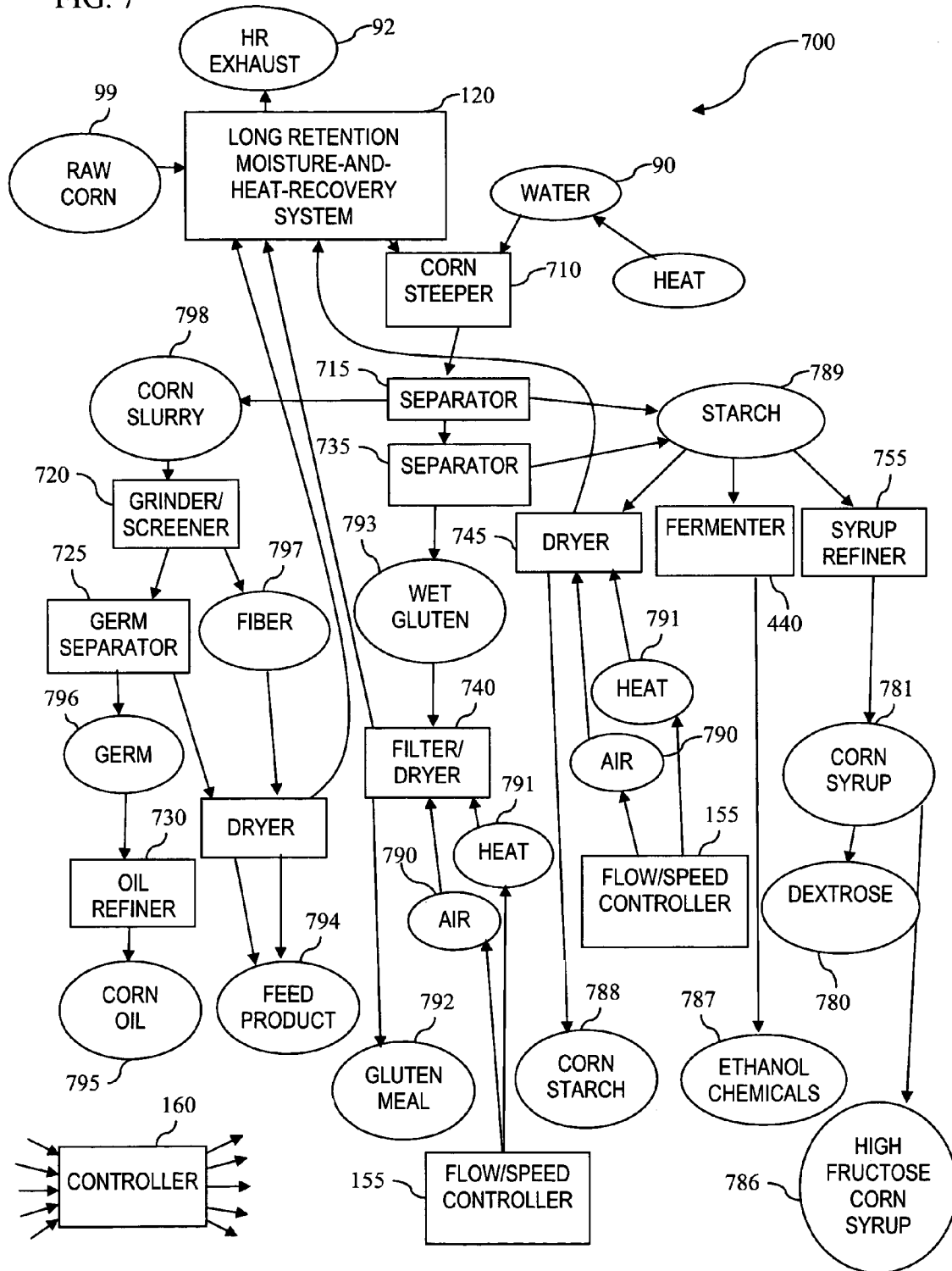


FIG. 8

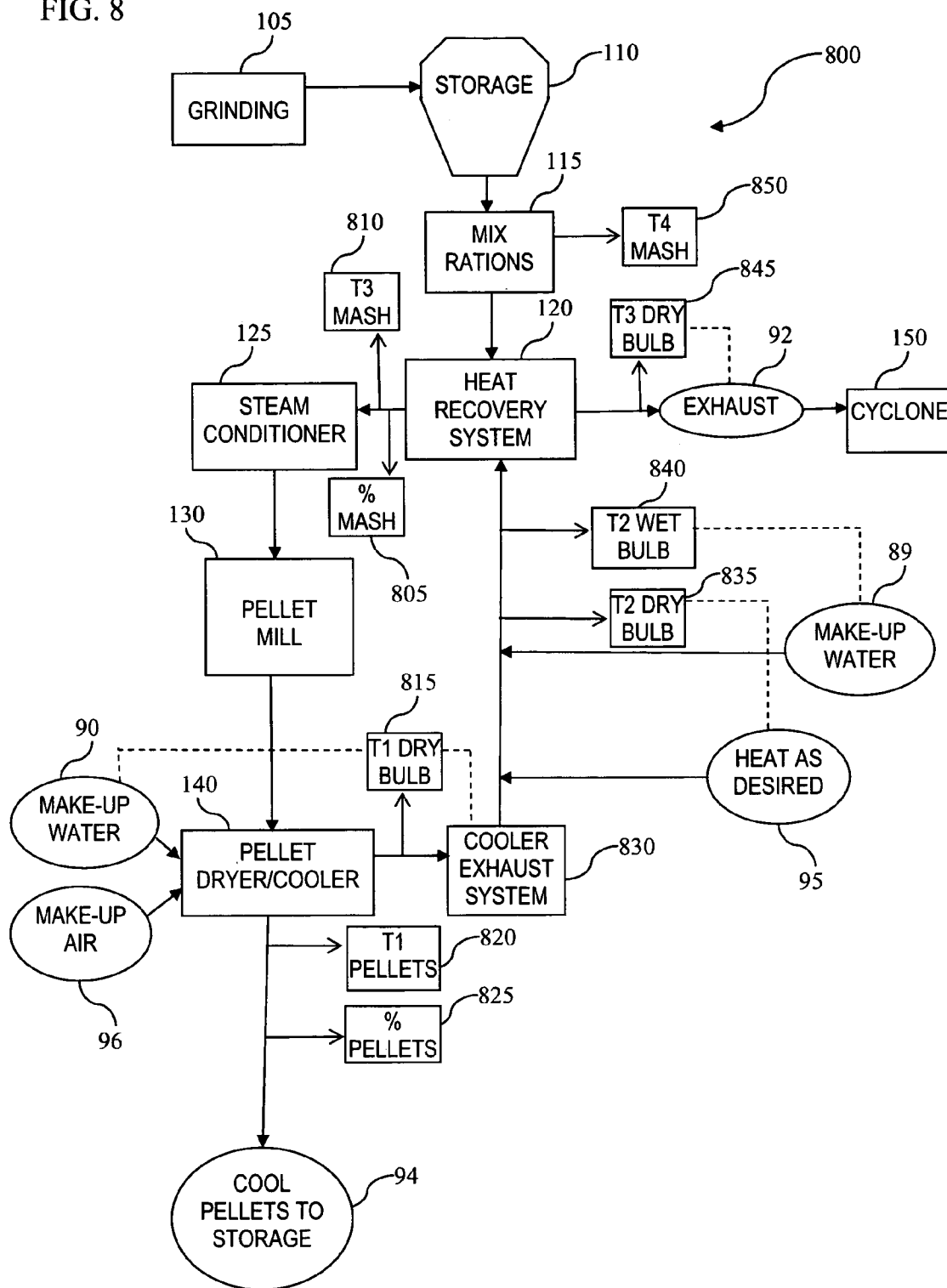
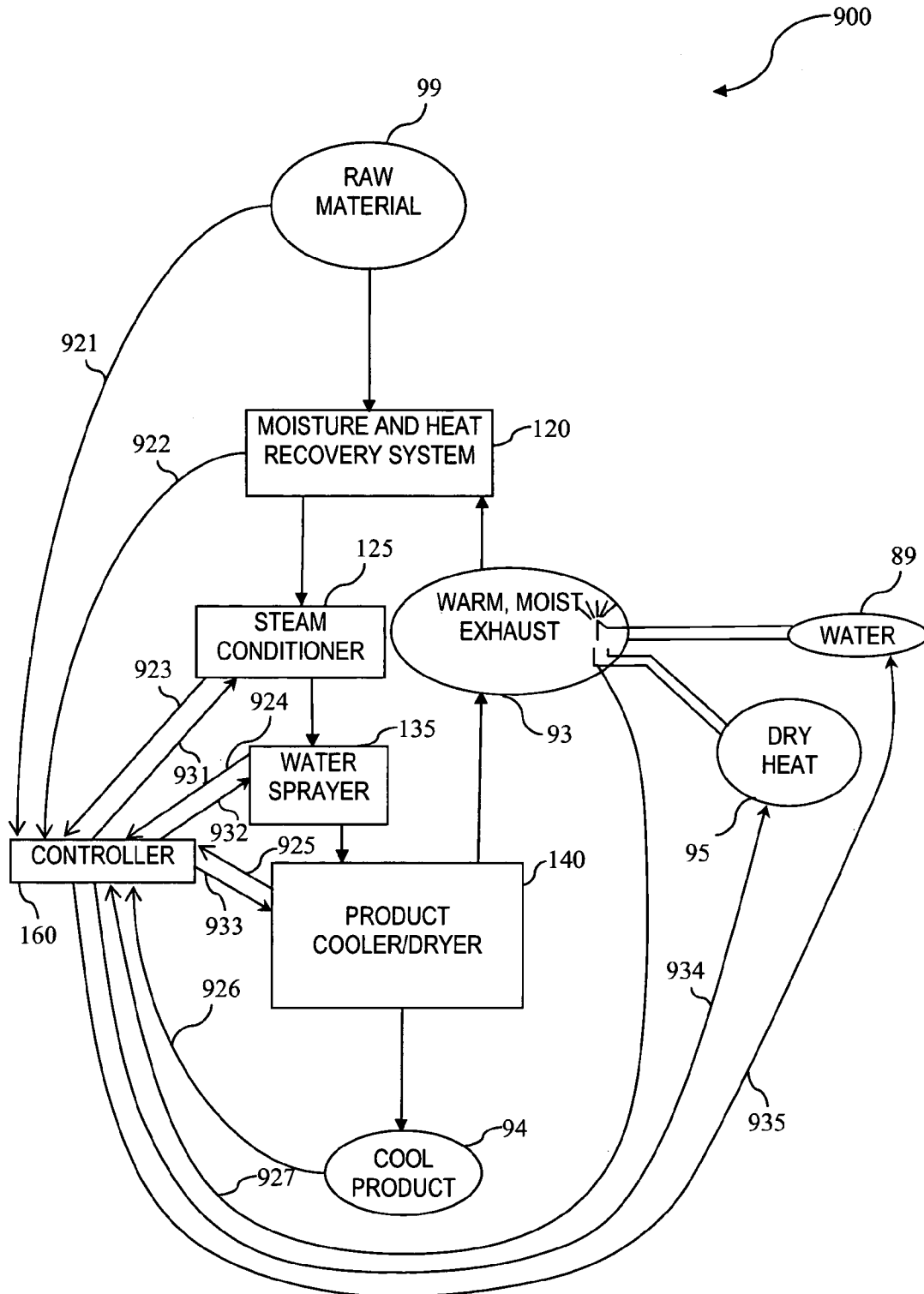


FIG. 9



1

AGRICULTURAL-PRODUCT PRODUCTION WITH HEAT AND MOISTURE RECOVERY AND CONTROL

FIELD OF THE INVENTION

This invention relates generally to agricultural-product processing and more particularly to heat and moisture recovery, reuse, and control of heat and moisture in a continuous, quasi-continuous, batch, or other process. The systems and methods presented by this invention may be used in pelletizing materials such as grain, corn, wheat, wood, and other such agricultural products; ethanol production from corn or other materials; wet corn milling; steam-flaking of feedstuffs; sugar processing; etc.

BACKGROUND OF THE INVENTION

Basic methods for processing agricultural products using heat are generally known. Agricultural-product processing, for instance making pelleted feed for livestock, can typically include grinding raw material, storing material, mixing ration additives to create mash, steam conditioning, pelletizing, and pellet cooling and drying. It is sometimes desirable to dry and cool pellets output from this system to within about six degrees Celsius (about ten degrees Fahrenheit) of ambient-air temperature in order to control product moisture in storage bins, and thus prevent growth of mold.

Before entering a pellet mill, mash has generally been steam conditioned by injecting, for example, five points of steam into the mash. One point of steam means adding an amount of steam equal to one percent of the weight of the product mash being heated. Steam conditioning is also useful in the agricultural-production process in that it may sterilize the agricultural product, cook the product to make nutrients more available, and/or gelatinize starch in the product so the product is better capable of sticking together.

Climate changes affect the output from an agricultural-product processor. Industry trends have shown that, when ambient air temperatures are higher, production is increased and the production process is more cost efficient. The raw material and ambient air, used in the process, are already at a higher temperature when input into the system, thereby cutting down on energy costs because the product requires less additional heat than is necessary when raw material and ambient air temperatures are cooler, such as in winter months.

Similar processes involving grinding raw material, steam conditioning/heating, cooling and drying are also used in ethanol production, wet corn milling, sugar production, wood-pellet production (e.g., pellets for burning in home wood-pellet-burning stoves to generate residential heat), and other processing of agricultural products. These processes typically include at least some of the above functions, in particular steam moisturizing and conditioning/heating.

In U.S. Pat. No. 4,659,299 (incorporated herein by reference), a system is described in which "pre-heated mash is pelleted to thereby form warm pellets. Thereafter, the warm pellets are cooled by ambient air and the ambient air is heated by the heat from the warm pellets. The heated ambient air is used to pre heat the mash." "The airflow path is provided from the ambient air inlets through the dryer/cooler, through the belt conveyor to cool and remove moisture from the warm pellets and pick up heat, through the conveyor to pre-heat the mash and then exits the air dryer/cooler through the warm air conduit. The belt conveyor conveys the mash through the warm air in the air flow path to pre-heat the mash."

2

This U.S. Pat. No. 4,659,299 starts to address energy use and efficiency problems, but the belt conveyer mechanism used in this invention for cooling the pellets does not address inefficiencies related to a co-flow system or cross-flow system or an uneven dispersion of pellets. Because U.S. Pat. No. 4,659,299 describes a single cross-flow system using inefficient heat transfer (typically, a belt or tray requires high air flow and is prone to channeling, wherein most of the air goes through the spots with fewest pellets and least resistance), the system is typically unable to cool the agricultural product to a temperature below that of the intermediate moist exhaust air. The exhaust air is typically unable to reach a temperature higher than that of the pellet output. The dispersion of pellets created by the belt conveyor in this patent leaves the problem of an uneven spread of pellets. If the pellets are not spread uniformly in the cooling process, the air used to cool the product will travel through the path of least resistance, or where the fewest number of pellets are located. This will cause an inconsistent and inefficient cooling and drying of the pellets, and a lower quality product output. The belt-conveyor cooler is now usually considered obsolete technology that is generally being replaced in the industry by more efficient counterflow devices.

U.S. Pat. No. 4,929,163 (incorporated herein by reference) describes a system "which utilizes moisture in its liquid phase, i.e. water, and heat in the form of hot air, but no steam in converting the dry material into a mash suitable for pelletizing." This is done for purposes of "separating the temperature input from moisture input such that they may be individually adjusted independently of each other," thereby addressing the problems of using steam in which "an increase in the amount of steam increases both moisture and temperature and vice versa." While the device described addresses the inefficiency problems of steam, it does not provide a method for recovering moisture and heat from the agricultural product output, thereby necessitating a larger cost expenditure in the production of agricultural products since this unrecovered moisture and heat goes to waste. Further, the use of hot air for heating the product independent of any moisture addition during the heating will result in drying the product. Thus resulting in energy loss for evaporating water, which will need to be replaced with liquid water.

As described by C. B. Theurer et al. in *Invited Review: Summary of Steam-Flaking Corn or Sorghum Grain for Lactating Dairy Cows*, *Journal of Dairy Science* Vol. 82, No. 9, 1999: The net energy for lactation of steam-flaked corn or sorghum grain is about 20% greater than the net energy for lactation for dry-rolled corn or sorghum. Steam-flaking of corn or sorghum grain with careful quality control consistently improves most lactational measurements, especially milk and milk protein yields.

Theurer et al. further describe that steam-rolling is a common processing method for barley, corn, and wheat used in dairy concentrates. Grains are usually steamed for 15 minutes or less to increase grain moisture to about 15 percent and then crushed with various sizes of rollers to produce a thick flake without a specific flake density endpoint, usually about 438 to 540 g/L for corn and sorghum (34 to 42 lb./bu., in units as used in the industry). Quality is usually based on visual appraisal rather than steaming time, moisture content, flake density, or laboratory indices. Dry-rolling is a common form of processing barley, sorghum, and wheat; dry grain is passed through large rollers (46 to 76 cm or larger) to break the grain into several pieces (similar to coarsely ground), with a bulk density for sorghum of about 450 to 644 g/L (35 to 50 lb/bu).

Theurer et al. still further describe that steam flaking is a more extensive processing system (with careful quality con-

trol) than dry- or steam-rolling. In some embodiments, whole grain is steamed for 30 to 60 min in a vertical, stainless steel steam chamber (usually 3.1 to 9.2 m height and 91 to 183 cm diameter) to increase grain moisture to 18 to 20% and then flaked between preheated large rollers (e.g., 46 cm diameter by 76 to 91 cm length or 61 cm diameter by 122 cm length) to a specific desired flake density (usually 309 to 386 g/L or 24 to 30 lb/bu) (53). In most cited studies, the grain was steam flaked to a flake density (FD) of about 360 g/L and is referred to as SF 28 (reflecting the flake density in pounds per bushel after steam flaking). The rollers become hot as the steamed grain passes through, which is important in the flaking process. The extent of processing (flaking pressure) increases as flake density decreases (i.e., 309 g/L flake is more extensively processed than a 386 g/L flake). The quality of steam-flaked grain is routinely measured by flake density, and by laboratory methods (enzymatic starch hydrolysis or percent starch gelatinization).

U.S. Pat. No. 6,330,982 (incorporated herein by reference) describes a grinding system that allows for processing of both coarse and fine particles.

U.S. Pat. No. 5,486,102 (incorporated herein by reference) describes a pellet mill.

U.S. Pat. No. 4,674,418, (incorporated herein by reference) describes a cyclone cleaner.

What is needed is a system and method for processing an agricultural-product with improved heat and moisture recovery and control.

SUMMARY OF THE INVENTION

In contrast to systems that heat mash with dry air, expending considerable amounts of heat, drying the mash and requiring high production costs, and to systems that heat mash with uncontrolled steam and/or inefficiently recovered heat and moisture, the present invention extracts heat and moisture (in a highly efficient cooler or dryer) from cooling and/or drying agricultural product to a flow of air, and uses this warmed, moist air to preheat and premoisturize the mash. In doing so, some embodiments inject about two points of moisture (i.e., 2 pounds of water per 100 pounds of product, which equals 2 grams of water per 100 grams of product) and 970 BTUs of heat per pound (540 calories/gram) of water are transferred into the mash, reducing the amount of steam that is required later in the steam-conditioning part of the process. This reduces operating costs by the amount of steam and energy that would have otherwise been necessary. Conventional systems that add heat only (i.e., as contrasted to steam or moist air) are inefficient, since heat without moisture dries the product, using additional energy (i.e., the heat of vaporization for the moisture removed) and requiring additional liquid water be added.

In some embodiments, the system includes one or more counter-flow devices or other direct-contact heat-transfer devices, also called a heat exchanger, evaporator or condenser (in some embodiments, these also provide a water evaporation (in the case where cool air is used to dry agricultural material later in the overall process) or water condensation (in the case where warm, moist air is used to pre-moisturize and heat incoming agricultural material earlier in the overall process function, wherein the latent heat of evaporation of water is used to enhance heat transfer), located at an early pre-heat portion of the system and a later cooling portion of the system. In a counter-flow device, incoming air and incoming product are input at opposite ends of the device and flow through one another in direct contact and in opposite directions, providing a greater amount of heat and moisture trans-

fer within the device. This increased efficiency reduces operating costs by allowing for a greater degree of heat and moisture transfer between the agricultural product and the air in the cooling portion, and this heat and moisture are then more efficiently transferred to the mash in the pre-heat portion.

One aspect of the invention, in some embodiments, provides a method that includes transferring heat and moisture from a warm, moist exhaust stream to incoming agricultural material, steam conditioning the material, pelletizing the material into warm pellets, cooling and/or drying the warm pellets with make-up air to produce the warm, moist exhaust air used in the transferring of heat to the incoming material and to produce cooled pellets, wherein the cooled pellets are at a temperature lower than the warm, moist air. In other embodiments, this general method is used in the production of starch, ethanol, sugar, syrup, or other agricultural products.

Another aspect of the invention, in some embodiments, provides an apparatus that includes a steam conditioner that adds heat and moisture to an incoming mash, a pellet mill coupled to receive the heated, moisturized mash and generate hot, moisturized pellets, and means for recovering heat and moisture from pellets and transferring the heat and moisture to an incoming material stream.

Still another aspect of this invention, in some embodiments, provides an apparatus that includes a heat-recovery system that provides direct contact between an incoming agricultural product mash and a warm, moist exhaust, a steam conditioner operatively coupled to receive warm mash from the heat-recovery system and that injects steam, an agricultural-product processor operatively coupled to receive steam-injected warm mash and that outputs warm, moist processed product, an agricultural-product dryer/cooler operatively coupled to receive warm, moist processed product and that outputs cooled processed product at a temperature lower than the warm moist exhaust, and a controller operatively coupled to dynamically adjust an amount of heat or moisture transferred based on an ambient-air temperature.

Still another aspect of this invention, in some embodiments, provides an apparatus that includes a heat-recovery system that provides direct contact between an incoming agricultural product and a warm, moist exhaust, a product conditioner operatively coupled to receive warm product from the heat-recovery system and that injects steam or hot water, an agricultural-product processing system operatively coupled to receive warm wet agricultural product and that outputs warm, moist processed product, an agricultural-product dryer/cooler operatively coupled to receive warm, moist processed product and that outputs dry processed product at a temperature lower than the warm moist exhaust, and a controller operatively coupled to dynamically adjust an amount of heat or moisture transferred based on an ambient-air temperature.

The apparatus and method described herein may be used in agricultural-product processing, ethanol production, wet corn milling, and sugar refining. By using this invention for any of these purposes, operating costs will be reduced, output quality may be improved, and greater control of the system and the component devices may be achieved.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a block diagram of a system 100 of some embodiments of the invention that provides agricultural-product production with heat and moisture recovery and control.

FIG. 2 is a side-view cross-sectional diagram of a counter-flow pellet dryer/cooler 200.

5

FIG. 3A is a side-view cross-sectional diagram of prior-art louver discharge system **300** in a closed position **320**.

FIG. 3B shows louver discharge system **300** in a partially open position **325**.

FIG. 3C shows louver discharge system **300** in a fully open position **350**.

FIG. 4 is a block diagram of a system **400** of some embodiments of the invention that provides ethanol production with heat recovery and control.

FIG. 5 is a flowchart of a method **500** of some embodiments of the invention used for agricultural-product production with heat and moisture recovery and control.

FIG. 6 is a block diagram of functions of a controller **600** of some embodiments.

FIG. 7 is a block diagram of a system **700** of some embodiments of the invention used in wet corn milling with heat and moisture recovery and control.

FIG. 8 is a block diagram of a system **800** of some embodiments of the invention that provides agricultural-product production with heat- and moisture-recovery and control.

FIG. 9 is an abstract block diagram of a system **900** of some embodiments of the invention that provides agricultural-product production with heat-and-moisture-recovery and control.

DESCRIPTION OF PREFERRED EMBODIMENTS

In the following detailed description of the preferred embodiments, reference is made to the accompanying drawings that form a part hereof, and in which are shown by way of illustration specific embodiments in which the invention may be practiced. It is understood that other embodiments may be utilized and structural changes may be made without departing from the scope of the present invention.

The leading digit(s) of reference numbers appearing in the Figures generally correspond to the Figure number in which that component is first introduced, such that the same reference number is used throughout to refer to an identical component which appears in multiple Figures. Signals (such as, for example, fluid pressures, fluid flows, or electrical signals that represent such pressures or flows), pipes, tubing or conduits that carry the fluids, wires or other conductors that carry the electrical signals, and connections may be referred to by the same reference number or label, and the actual meaning will be clear from its use in the context of the description.

System Environment

The present invention provides improved heat and moisture recovery (i.e., extracting heat and moisture from product being cooled and dried later in the process, and transferring that heat and moisture to incoming material earlier in the process). In many of these environments, the warm moist air from the dryer/cooler also contains oil, food or dirt particulates, and other contaminants from the cooling product, which would quickly foul a conventional heat-transfer device. Accordingly, in some embodiments, the warm moist air is forced through the incoming material in direct contact (with measures to prevent "channeling") to achieve better efficiency and reduce fouling. Because the incoming material is constantly being replenished and is absorbing much of the oil, particulates, and other contaminants along with a substantial amount of heat and moisture, the exhaust air is cooler, cleaner, and/or less polluted than the exhaust air from conventional systems.

In some embodiments, the present invention also provides adjustments and controls that better address process differences, e.g., between summer and winter ambient air condi-

6

tions and other variables. In some embodiments, one or more variables are measured, such as ambient air temperature and/or humidity, raw material temperature and/or moisture content, air and product flow rates, final product temperature, color, and/or moisture content. Based on those measurements and on formulas, tables, or other conversion methods, control signals are generated to adjust various process parameters, such as the amounts of water, steam, and/or heated dry air to add, flow rates, etc. In some embodiments, such process control, optionally including closed-loop feedback, provides a higher-quality and higher-weight final product at higher throughput and lower energy costs.

In some embodiments, little or no heat recovery is utilized (this is also the situation when such a process that normally uses heat recovery is just starting up and no warm moist air from cooling the end product is yet available). In some such embodiments, the control systems described herein are used to control the amount of dry heat and moisture that are added together and then mixed with the incoming grain in order to obtain a carefully controlled process and high-quality output product. In contrast to certain conventional systems that separately add dry heat (which dries the mash, thus wasting the energy used to vaporize the water dried from the mash) and liquid water to obtain their preheated mash, these embodiments of the present invention mix controlled amounts of dry heat and liquid water or steam together prior to contacting the mash, in order to obtain the desired temperature and moisture content of the mash without the inefficiency of drying the mash prior to adding the liquid water.

FIG. 1 is a block diagram of a system **100** that provides for agricultural-product production with heat and moisture recovery and control. In some embodiments, system **100** includes grinder **105**, such as a hammer mill, that takes raw material **99**, such as corn or other grains, and grinds the raw material **99** to some consistency suitable for use by system **100**. In some embodiments, grinder **105** may be of the type described in U.S. Pat. No. 6,330,982, allowing for processing of both coarse and fine particles.

In some embodiments, an optional storage hopper **110** is included in system **100**. Storage hopper **110** provides a buffer to maintain a constant flow of material from the grinder through the agricultural-product-processing system. Output from the hopper remains constant, even as input to the hopper may vary. Also, the rate of material flow through grinder **105** may vary. Hopper **110** provides a means of adjusting for these variables and maintaining a constant flow of material into ration mixer **115** and through system **100**. This will prevent the grinding system from overloading while maintaining the highest possible flow rate through system **100**.

In some embodiments, ration mixer **115** takes raw milled material **99'** from storage hopper **110** and adds one or more ration additives **98**, mixing the material **99'** and additives **98** together to form a material sometimes known as mash, milled product, processed product, mixed ration or feedstuff. Ration additives may include various combinations of other grains (to improve nutrient value of the resulting agricultural product), protein-rich concentrates, carbohydrate-enrichments, fat-rich additives, *Lactobacillus acidophilus* and *Lactobacillus bulgaricus* ("to provide a non-hygroscopic free-flowing, self-preserving animal feed supplement"), lactic acid (for foodstuff preservation), mineral substances, antibiotics, enzymes, hormones, trace elements, vitamins, pharmaceuticals, and/or preservatives.

Moisture-and-heat-recovery system **120** takes hot, moist air **93** recovered from pellet dryer/cooler **140** later in system **100** and forces the hot, moist air **93** through the material **99'** flowing in from ration mixer **115** (or, in other embodiments,

from grinder **105** or hopper **110**) in order to pre-moisturize and preheat the material **99'**. In some embodiments, moisture-and-heat-recovery system **120** preheats and pre-moisturizes the mash material **99'** by efficient direct-contact heat transfer before material **99'** flows into steam conditioner **125**. Moist exhaust air **93** from later in system **100** enters moisture-and-heat-recovery system **120** and moisture and heat is extracted and applied to the mash material **99'**. By reusing moisture and heat from warm, moist exhaust **93**, system **100** provides a more cost-efficient method for making agricultural products. In some embodiments, hot, moist exhaust air **93** contains high oil and particulate content that will foul a typical heat-recovery device, and which usually needs to be removed from the exhaust stream before it is released to the outside to avoid polluting the environment. By forcing the hot, moist exhaust air **93** having high oil and particulate content through the incoming agricultural product, the exhaust stream is both cooled and cleaned of at least some of the oil and particulate content, reducing pollution, and reducing the natural resources that are otherwise needed to heat the incoming agricultural product for processing.

When pelleted mash is dried out in the pellet dryer, sensible heat, latent heat and moisture are released by the pelleted mash to the drying air. At dryer/cooler **140**, the latent heat of vaporization (970 BTUs of heat per pound of water=540 calories/gram of water) is extracted from the output product stream by evaporation of the water removed. This air becomes the warm, moist, exhaust air from the exhaust stream and contains water vapor, which, when transferred to a liquid state in the moisture-and-heat-recovery system, contributes heat into the mash. At heat-recovery system **120**, the latent heat of vaporization (970 BTUs of heat per pound=540 calories/gram of water) is transferred into the incoming product stream by condensation of the water absorbed. Thus, the amount of latent heat injected into the mash is roughly about 1000 British Thermal Units (BTUs) per pound of condensed water (one BTU is the amount of heat needed to raise one pound of water one degree Fahrenheit). The specific heat for mash is on the order of 0.5 BTU/lb/degree F. (raising the temperature of mash by one degree Fahrenheit requires roughly one-half BTU per pound of mash) (about 0.5 calories/gram/degree Celsius). When mash is heated by warm air, with sufficient moisture, heat will be transferred to the mash from reducing the temperature of the warm, moist air (sensible heat) and the condensation of moisture from the warm, moist air (latent heat). By taking an amount of moisture out of the moist exhaust stream and adding it to the mash, latent heat of the moisture is transferred. The amount of sensible and latent heat which is transferred reduces the amount of heat which must otherwise be added with steam by the steam conditioner later in the process. By replacing some of the heat and moisture transfer through the moisture-and-heat-recovery system **120**, less addition of heat and moisture through steam injection is required, thereby reducing the costs (both in the expense of energy and the capital costs of the machinery) of producing that steam. Far less energy is required to heat the mash using air with sufficient moisture than if dry, hot air is used, since using dry hot air will result in moisture in the mash evaporating, using about 1000 BTUs per pound (540 calories/gram) to dry water out of the mash. Each time water changes physical state, energy is involved. "Sensible heat" is heat that can be measured by a dry-bulb thermometer, using, e.g., Celsius or Fahrenheit scales of measurement. "Latent heat" is the energy required (absorbed) to change a substance to a different state of matter, e.g., from liquid to a gas state. This same energy is released from the substance when the change of state is reversed, e.g., when moisture condenses. In

particular, preheating the raw product at this point using dry heat only or separately from moisture or steam requires more energy since the heating both heats the mash and causes water in the product to go to a gas phase or state (i.e., the latent heat of vaporization for that water). In contrast, passing warm moist air through the cool incoming product causes the moisture in the air to condense onto the product, transferring that latent heat to the product and cooling and cleaning the air. To avoid having to provide the extra energy for latent heat to dry the product, warm moist air is used having sufficient moisture to avoid drying the product. This warm moist air for system **120** comes from either the exhaust air of a cooling/drying operation (in which case, system **120** is a heat-recovery system) or from adding liquid water or steam to heated air (in which case system **120** is a preheating and premoisturizing system).

In some embodiments, heat-recovery system **120** includes a counter-flow bin similar in structure to pellet dryer/cooler **140**, as afterward described. In some embodiments, a Bliss Op-Flow Counter-Flow device, or a similar unit, is used for heat-recovery system **120** and/or pellet dryer/cooler **140**. In other embodiments, heat-recovery system **120** is a flash dryer/cooler, or modified flash dryer/cooler. In still other embodiments, heat-recovery system **120** is a fluid-bed dryer/cooler, a ring dryer/cooler, rotary-drum dryer/cooler or any other mechanical device providing contacting of dry powders, cakes, mixes, or other some such material with a gas stream to effect heat and/or mass transfer. In some embodiments, the heat-recovery device is a single co-flow device in which the mixed ration and warm, moist exhaust both move in the same direction. In other embodiments, heat-recovery device **120** is a single counter-flow device, in which the mixed ration and warm, moist exhaust move in opposite directions. In still other embodiments, a plurality of co-current flow and/or counter-current flow devices are used in the heat-recovery device.

Counter-flow heat-recovery devices differ from co-flow heat-recovery devices in that the flow of make-up air is in a direction opposite to the flow of the cooling agricultural product, while in a co-flow device these flows are in a concurrent direction. In a co-flow device the output product and output air have temperatures that, at best, approach a median temperature of the incoming thermal masses. The same is true of cross-flow devices such as described in U.S. Pat. No. 4,659, 299, wherein the airflow is moving vertically upward through product moving horizontally on a belt. The advantage to utilizing a counter-flow device is that the opposite flow directions allow for a higher amount of heat transfer between the air and product. The air exhaust from the device approaches a temperature quite close to the temperature of the incoming solid/liquid product, and the output product approaches a temperature quite close to the temperature of the incoming air. This increased transfer of heat allows the preheated agricultural product from heat-recovery device **120** to attain a temperature higher than that of its exhaust air **92** and cooled agricultural product from dryer/cooler **140** to attain a temperature less than the temperature of hot, moist air exhaust **93**, a feat which is unachievable in a co-flow or cross-flow device.

In some embodiments, steam conditioner **125** is a device that conveys materials coming out of moisture-and-heat-recovery system **120** and injects high-pressure steam into the material. The amount of steam injected by steam conditioner **125** is adjusted based upon temperature and moisture content of raw material **99**. In summer months, when raw product having a temperature of, e.g., 90 degrees Fahrenheit (32 degrees C.) is input into system **100**, 2 to 3 points of steam is injected (if the desired temperature is achieved with less

steam, more hot water may have to be added to obtain the desired moisture content). The amount of heat required increases as the raw product's initial temperature drops, possibly requiring, e.g., 4 to 5 points of steam to achieve the desired temperature (e.g., 200 degrees F=93 degrees C.) when raw product having average temperatures of, e.g., 30 to 50 degrees Fahrenheit (about -1 degrees C. to 11 degrees C.) are input during the winter months. Additional steam injection occurs in winter months due to the colder temperature of input material and ambient air, requiring more steam conditioning to create good gelatinization. However, if too much moisture is added before the mash enters the pellet mill, "pellet-roll slip" may occur which can affect pellet mill performance. The amount of steam which must be injected by steam conditioner 125 into the material is reduced due to the mash preheat and pre-moisturizing done in moisture-and-heat-recovery system 120, thereby reducing operating costs. In some embodiments, material coming out of steam conditioner 125 contains, e.g. a moisture content of 17 or 18% and a temperature of 200 degrees Fahrenheit (93 degrees Celsius).

In some embodiments, pellet mill 130 is a Bliss Pioneer Pellet Mill. In other embodiments, pellet mill 130 includes a device as described in U.S. Pat. No. 5,486,102, or other suitable device. In some embodiments, product coming out of steam conditioner 125 is dropped into a pellet mill that has a die face around it. Three wheels or rollers push and squeeze the mash of materials into the die face. The die face includes holes through which the mash can exit the pellet mill and a scraper mechanism is used cut the product. The agricultural product output from the pellet mill consists of formed and shaped pellets having temperatures of, e.g., 200 degrees Fahrenheit (93 degrees Celsius). The pressure needed to force the agricultural product through the holes in the die face serves to increase the density of the pellets. In some embodiments, pellets leaving pellet mill 130 are input into a pellet dryer/cooler and dryer 140 after passing through a water sprayer 135.

In some embodiments, water sprayer 135 is provided that adds additional moisture, e.g., one pound of water for every 100 pounds of pellets depending on conditions, to the outer surface of the pellets before the pellets are removed from pellet dryer/cooler 140. When ambient air temperatures are higher, e.g., in summer months, pellet dryer/cooler and dryer 140 transfers roughly 3% of moisture from the pellets to incoming make-up air 96, a transfer rate which may be roughly three times the transfer rate observed in winter months. Without this additional 1% of water sprayed onto the pellets by water sprayer 135, this moisture transfer would result in cool pellets having a moisture composition of, e.g., only 14 pounds of water and 86 pounds of processed pellet material. This over-dry composition makes for fragile pellets with a less-than-ideal pellet durability index (PDI). The 1% of water added to the pellets will be part of the 3% of moisture transferred in the pellet dryer/cooler, resulting in pellets having a composition of, e.g., 15 pounds of water and 86 pounds of processed pellet material, providing a better PDI and about one percent more final product by weight.

Alternative methods of remedying the problems caused by warm-weather operations and to control (decrease) the exhaust temperature are also available. In some embodiments, the total pounds of dry air coming in contact with the product (which can be measured as SCFM=Standard Cubic Feet Per Minute, or standard cubic meter/minute=35.3 SCFM) through the system is varied. By increasing the air-flow, there will be a proportionally lower increase in the air temperature across pellet dryer/cooler 140, while decreasing the maximum humidity ratio below saturation point exponen-

tially. However, there is a practical limit to how much airflow change may be accomplished and how much this alteration will affect pellet production. In other embodiments, additional water is added to the system from an external source other than the pelleting system. This allows control of the water-mass balance independent of the pelleting operation. This would increase the amount of evaporative cooling in the unit. In addition, by increasing the surface moisture on the pellets it "protects" the internal pellet moisture from evaporation, improving pellet durability and final product moisture. In some other embodiments, the amount of moisture in the pellets is increased. This increases the amount of evaporative cooling in the unit and results in reduced delta T on the air stream. There is a limitation in this application due to the maximum amount of moisture which can be added to the mash without causing slip. In still other embodiments, an external cool air source is added to the dryer/cooler.

Based on the alternative alterations, the most economical implementation is adding additional water to the system from an external source. In some embodiments, implementation of this water spraying process involves monitoring the temperature of the exhaust air from the pellet dryer/cooler and modifying a water spray system to apply moisture to the pellets using a proportional integral derivative (PID) control loop. In some embodiments, the water spray system applies moisture to the pellets between the pellet mill 130 and the dryer/cooler 140. The water addition equipment is available, since the current system is often adding water at the conditioner. Tests of this process, in some embodiments, have increased the moisture in cool output pellets by 0.5% (from 11.5% to 12%) in warm ambient air temperature conditions by decreasing the exhaust temperature from about 166 degrees Fahrenheit (74 degrees Celsius) to 159 degrees Fahrenheit (70 degrees Celsius). Additionally, pellet durability (as measured by pellet durability index (PDI)) can be increased by 2.3 PDI units by water spray.

In some embodiments, pellet dryer/cooler and dryer 140, such as the Bliss Op-Flow Cooler, is used to cool the pellets to a temperature suitable for storage and within, e.g., six degrees Celsius of ambient air temperature. In some such embodiments, pellet dryer/cooler and dryer 140 is a counter-flow device, i.e. pellets moving through dryer/cooler 140 travel in an opposite direction from make-up air 96. Pellets having temperatures of, e.g. 200 degrees Fahrenheit (93 degrees Celsius), enter pellet dryer/cooler 140 through a disperser 202 at the top of the cooler and are evenly distributed in the unit to ensure uniform cooling. Make-up air 96 having a temperature of, e.g., 90 degrees Fahrenheit (32 degrees C.) and 60 degrees (16 degrees C.) wet bulb in summer and 40 degrees Fahrenheit (4 degrees C.) and 30 degrees (-1 degrees C.) wet bulb in winter is injected into the base of pellet dryer/cooler 140. Make-up air 96 is gradually warmed and moisturized by pellets in dryer/cooler 140. For example, at some point inside dryer/cooler 140, near the place of input of make-up air, air in the winter will have temperatures of, e.g., 40 degrees Fahrenheit (4 degrees Celsius), and pellets will have temperatures of, e.g., a few degrees warmer than 40 degrees Fahrenheit (4 degrees Celsius). In some such embodiments, near the point of pellet entry in dryer/cooler 140, pellets will have temperatures of, e.g., 200 degrees Fahrenheit (93 degrees Celsius) and air will have temperatures of, e.g., a few degrees below 200 degrees Fahrenheit (93 degrees Celsius). Temperature and moisture will transfer between the pellets and air at these points, and all other points in the dryer/cooler 140, cooling the pellets and warming and moisturizing the air. In embodiments in which the pellet dryer/cooler 140 is a counter-flow device, more heat and moisture are transferred between the pellets

and make-up air, allowing the cooled pellets output by dryer/cooler **140** to reach a temperature less close to the temperature of the incoming make-up air **96**.

In some embodiments, goals of pellet dryer/cooler **140** include providing predictable pellet durability by consistently drying the pellet, controlling shrink/gain of moisture from the pelleting process, bringing the pellets close to ambient temperature to control moisture in storage bins, and drying the pellets sufficiently to control moisture in the stored product.

Variables which affect pellet drying include the total amount of moisture moving in the pellets and mixture of surface moisture versus encapsulated particle moisture, the total pounds of dry air coming in contact with the product (SCFM), the design of the dryer/cooler to provide good contact between air and the product for a sufficient amount of time, and the humidity ratio of the air. The contact between air and product is assumed to be optimized with current counter-flow dryer/cooler designs. With a conventional system, airflow is mostly a function of air density at the fan and dryer/cooler pressure drop pursuant to the fan laws. More SCFM will move through the system as air temperature is cooled. Conventionally, there is no automated control damper on the fan, leaving processing at the mercy of the system and performance characteristics of the fan.

Currently, operators only independently control the feed flow rate of the system and the retention time. Some variables are constant or driven by other processes. These variables include conditioned mass temperature (equal to 190 degrees Fahrenheit (88 degrees Celsius)), maximum mash moisture content (determined by optimization of the pellet mill and mash temperature), and exhaust temperature maximum humidity ratio (equal to some function of the warm, moist exhaust temperature). Other variables are environmental and include mash temperature, cooler inlet temperature, and cooler inlet wet bulb (which is not very important). Derived results from this system include cooler airflow (as a function of air density and cooler retention time), pellet outlet temperature, pellet outlet moisture, and warm, moist exhaust temperature.

To control the process, a selected variable, usually the temperature of the warmed, moisturized air at the warm, moist exhaust, is kept constant. The temperature of the warmed, moisturized air at the warm, moist exhaust is usually chosen as the constant because it has the biggest effect on how much water can be carried out of the system and thus the water-mass balance.

The temperature of outlet, exhaust air from dryer/cooler **140** varies directly with the inlet temperature of make-up air **96**, because there is a constant delta-T (change in temperature) in the air stream if airflow rate and flow rate of pellets are constant, with the energy in the pellets creating the only heat source for the dryer/cooler. Also, the humidity ratio (in pounds of water per pound of dry air), representing the amount of water the air is capable of removing from the system, and the differential partial pressure which drives mass transfer rates, vary relative to temperature following psychrometric principals (the measurements and relationships of moist air, such as dry-bulb temperature, wet-bulb temperature, dew-point temperature relative humidity, humidity ratio (kg water/kg dry air), enthalpy, and density). That is, as the temperature of input make-up air increases, the output air-saturation point humidity ratio increases exponentially. Relative humidity of the incoming air is inconsequential because of the exponential relationship of maximum humidity ratio versus temperature. Therefore, in winter months, when the ambient air temperature is lower, the satu-

rated humidity ratio is lower, reducing the amount of water which may be removed from the system. This is reversed in summer months, with a higher potential of water removal from the air because the incoming air temperature is higher. Furthermore, in winter months, exhaust temperature of the dryer/cooler **140** is low, e.g. around 140 degrees Fahrenheit (60 degrees Celsius) and the air stream becomes saturated without fully drying the pellets. Adjustments to system **100** including a water-spraying apparatus **135** and airflow controller **155** are introduced to account for the changes in moisture-transfer rates due to temperature changes.

Different alternations may be made to the system in order to control (increase) the exhaust temperature to remedy the problems incurred in winter months. In some embodiments, the SCFM is varied through the system. By reducing the airflow, there will be an increase in air temperature across the dryer/cooler proportionately, while allowing the humidity ratio to increase exponentially following psychrometric principals. In other embodiments, an external heat source may be added to the dryer/cooler and two zones (a drying zone and a cooling zone) may be created in the unit. Simply pre-heating the air for the dryer/cooler inlet will not work, since the system will be temperature limited on the pellet outlet temperature, but operators still want to get the pellets close to the ambient air temperature. In still other embodiments, the amount of moisture in the pellets may be decreased. This would reduce the amount of evaporative cooling in the unit and result in additional delta T on the air stream. This process may only be accomplished by controlling the mash temperature without adding steam and would require an external energy source and an additional process.

Out of the alternative alternations, varying the SCFM through the system is the most economical implementation. Therefore, in some embodiments, speed of make-up air **96** is adjusted by flow/speed controller **155**. Flow controller **155** adjusts the speed of air flowing into pellet dryer/cooler **140** to compensate for, e.g., changes in ambient air temperature. Hot make-up air entering dryer/cooler **140** is capable of holding a higher amount of moisture than cold make-up air. Therefore, in winter months, when air temperatures are considerably lower than in summer months, less moisture would be transferred from the pellets to the air. Pellets are then output having, e.g., 16% water content, which is unsuitable for pellet storage and causes moldy pellets. To remedy this, flow controller **155** reduces the speed of make-up air flow in winter months. This allows the air to heat up more in the pellet dryer/cooler **140**, allowing more moisture to transfer from the pellets to the make-up air, reducing the moisture content of cool pellets **94** and giving them a more desirable PDI. Flow/speed controller **155** increases the speed of air flow back to an appropriate speed as ambient air temperatures increase.

In some embodiments, implementation of this air-flow-alteration process includes monitoring the temperature of warm, moist exhaust and modifying an exhaust-fan damper position using a proportional integral derivative (PID) control loop. In some embodiments, this is accomplished with a variable frequency drive (VFD) on the exhaust fan. In testing this process in some embodiments, increasing the temperature of exhaust air from 160 degrees Fahrenheit to 165 degrees Fahrenheit by reducing the cooler air flow reduced the pellet moisture by 0.5% from 13.7% moisture to 13.2% moisture in reduced ambient temperature conditions (for example, 40 degrees Fahrenheit (4 degrees C.)).

Outputs from pellet dryer/cooler **140** are cooled pellets and heated, moist air. Cooled pellets **94** are dropped from dryer/cooler **140** and are ready to go to storage. Dry-bulb temperature of the cooled pellets may be maintained at a constant or

near constant level through the adjustments made to the water sprayer and pellet dryer/cooler, which are based at least in part on measurements of ambient-air temperature. Near the top of pellet dryer/cooler **140**, the heated and moisturized air which has passed through the dryer/cooler leaves the cooler as exhaust **93**. This exhaust air has temperatures of, e.g., 160 degrees Fahrenheit (71 degrees Celsius) with **152** degree Fahrenheit (67 degrees Celsius) wet bulb, and a high oil and particulate content, including pollutants and waste, and causes fouling of whatever this polluted air contacts. According to the invention, the hot, moist air is fed into moisture-and-heat-recovery system **120**, which removes the moisture and heat from the warm, moist exhaust **93** as well as removing some of the pollutants. This heat and moisture is transferred into mash entering system **100**. In some embodiments, each pound of moisture released into incoming mash corresponds to approximately 1000 BTUs of additional heat. The recovery of heat and moisture performed by wet heat-recovery system **120** helps cut down on operating costs of system **100**.

Waste products from warm, moist exhaust **93** are removed by the moisture-and-heat-recovery system and the remaining air is output as cooler, cleaner exhaust **92**. Exhaust **92** is the less-hot, less-oily, and/or less-particulate-filled air, which would be undesirable and difficult to dispose of. The dry-bulb temperature of this exhaust air stream is measured and is used to control airflow volume through the heat-and-moisture-recovery system. If the heat-recovery system's exhaust stream temperature is too high in comparison with the temperature of incoming mash, the amount of airflow from the exhaust system is reduced. Conversely, if the temperature of the heat-recovery system's exhaust stream is too low in comparison to the temperature of mash, the control system will adjust the amount of airflow (e.g. increase) in cooled exhaust system **92**. Cooled exhaust **92** is input into cyclone cleaner **150**, which removes the majority of any remaining particulates. In some embodiments, cyclone cleaner **150** includes a device such as described in U.S. Pat. No. 4,674,418.

In some embodiments, mixer **145** injects a variable amount and/or temperature of dry heated air **95** ("dry heat") coming from, e.g., a steam coil, electric coil or gas burner, into the warm, moist exhaust **93**. In some embodiments, the variable amount or temperature of the added air is based, at least in part, on a control signal from controller **160**.

Controller **160** may be any suitable electrical circuit, programmable logic controller, computer, or other information-processing system (IPS). In some embodiments, controller **160** is implemented as a plurality of separate subcontrollers, each responsible for its own portion of the overall process, and each receiving one or more input signals, and generating one or more control signals. In some such embodiments, one or more of these subcontrollers monitors and/or controls operation of one or more others of subcontrollers. In other embodiments, controller **160** includes a single master computer that receives all the signals from the various sensors and generates the control signals needed for the overall process.

Particularly in winter months, the warm, moist exhaust **93**, having a temperature of, e.g., 150 degrees Fahrenheit (66 degrees Celsius), together with the later-added steam, is not able to heat the mash **99'** warm enough unless too much water is also transferred to the mash **99'**. Exhaust air **93** having a moisture content of, e.g., humidity ratio=0.30 KG of water/KG of air, already contains enough moisture to pre-moisturize the mash, so adding more steam to the conditioner or to warm, moist exhaust air **93** would make the mash too wet and cause "pellet-roll slip." Therefore, in some embodiments, dry heat **95** is added to warm, moist exhaust **93** through mixer **145** to increase the temperature of the air entering the moisture-

and-heat-recovery system to, e.g., 160, 180 or 200 degrees Fahrenheit (71, 82, or 93 degrees Celsius). Dry heat may also be added in summer months to reduce the relative moisture content of the exhaust air **93** when the air becomes too saturated. Adding heat to the cooler exhaust **93** air flow directly by a heating coil in the air flow would foul the coil with the oil and particulates from the exhaust air **93**. Accordingly, in some embodiments, the additional dry heat is channeled into a mixer **145** through a smaller duct that empties into an, e.g., 20-inch duct that is carrying the bulk of the hot, moist air **93**. The amount of additional heat added to the exhaust air **93** is based at least in part on measurements of the dry-bulb temperature of the air inlet and outlet of the moisture-and-heat-recovery system **120**.

In some embodiments, water **89** may be added to warm, moist exhaust **93** through mixer **145**. Additional water **89** may be added when temperatures of the exhaust are too high, thereby causing some of the water to be heated up and evaporated and reducing the dry-bulb temperature of the air. This process may be controlled until air temperature is at a lower and more suitable point. Water **89** may also be added in winter months to increase the amount of moisture input into the moisture-and-heat-recovery system **120**. The amount of additional water **89** added to the warm, moist exhaust air **93** is based at least in part on measurements of the wet-bulb temperature of the air fed into the moisture-and-heat-recovery system. The control levels for the air infeed dry-bulb temperature, air exhaust dry-bulb temperature and air infeed wet-bulb temperature are based on the desired temperature and moisture content of the mash and also serve to control the levels of condensation and latent and sensible heat recovery in the system.

In some embodiments, controller **160** is used to adjust a variety of activities, including ration mixing, steam conditioning, water spraying, speed of make-up air, and/or mixing of dry heat within system **100** based on measurements taken both within and outside of the system **100**. Measurements are taken by and reported to controller **160** pertaining to temperatures (i.e. of ambient air, pellets, and exhaust), air-humidity levels, pellet levels, flow rates, steam quality and/or amount of moisture transfer between pellets and air in dryer/cooler **140**. In some embodiments, controller **160** is coupled to ration mixer **115**, whereby it monitors and adjusts the amount and flow rate of ration additives mixed with the mash. In some embodiments, steam conditioner **125** is adjusted by controller **160** to provide more or less steam, depending upon temperature and moisture content of raw material **99**. In some embodiments, depending upon ambient air temperature and levels of moisture conversion in dryer/cooler **140**, controller **160** adjusts water sprayer **135** to provide more or less water and flow/speed controller **155** to increase or decrease flow of make-up air **96** into pellet dryer/cooler **140**. For example, in summer months when ambient air temperature is high, controller **160** will cause an increase of water **91** sprayed by pellet wetter (water-sprayer) **135** on to the outer surface of the pellets where it easily evaporates to the cooling air to prevent over-drying of the pellets and will maintain the appropriate air-flow speed. As winter brings cooler ambient air temperatures, controller **160** will make adjustments to these devices which will decrease or eliminate the amount of water sprayed and will reduce the air-flow speed of make-up air **96** through flow/speed controller **155**. The amount of dry heat and/or water added by mixer **145** is also controlled by controller **160** based upon moisture content and temperature of the warm, moist exhaust **93**. Adjustments to the flow of overall system **100**, will also be made by controller **160**.

15

There are commercially available temperature controller systems, which can accomplish the implementation of airflow control and water flow control based on whether or not the process variable is below or above the set point. These units can control two loops in a heat/cool configuration. The addition of a fan damper VIV (variable inlet vanes) is a relatively easy retrofit. If a damper exists, a motorized actuator may need to be added to provide control. In addition, in some embodiments, the system provides instrumentation to other parts of the system in order to monitor performance of the system.

In some embodiments, various combinations of amounts of moisture transferred in heat transfer devices and the temperatures obtained and various amounts of moisture transfer from steam and heat transfer from steam are used. In some embodiments, about 0.25 point of water is transferred in heat-recovery system **120** to the incoming material **99'**. In some embodiments, about 0.5 point of water is transferred. In some embodiments, about 0.75 point of water is transferred. In some embodiments, about 1.0 point of water is transferred. In some embodiments, about 1.25 points of water is transferred. In some embodiments, about 1.5 points of water is transferred. In some embodiments, about 1.75 points of water is transferred. In some embodiments, about 2.0 points of water is transferred. In some embodiments, about 2.25 points of water is transferred. In some embodiments, about 2.5 points of water is transferred. In some embodiments, about 2.75 points of water is transferred. In some embodiments, about 3.0 points of water is transferred. In some embodiments, about 3.25 points of water is transferred. In some embodiments, about 3.5 points of water is transferred. In some embodiments, about 3.75 points of water is transferred. In some embodiments, about 4.0 points of water is transferred. In some embodiments, about 4.25 points of water is transferred. In some embodiments, about 4.5 points of water is transferred. In some embodiments, about 4.75 points of water is transferred. In some embodiments, about 5.0 points of water is transferred. In some embodiments, about 5.25 points of water is transferred. In some embodiments, about 5.5 points of water is transferred. In some embodiments, about 5.75 points of water is transferred. In some embodiments, about 6.0 points of water is transferred. In some embodiments, about 6.25 points of water is transferred. In some embodiments, about 6.5 points of water is transferred. In some embodiments, about 6.75 points of water is transferred. In some embodiments, about 7.0 points of water is transferred. In some embodiments, about 7.25 points of water is transferred. In some embodiments, about 7.5 points of water is transferred. In some embodiments, about 7.75 points of water is transferred. In some embodiments, about 8.0 points of water is transferred. In some embodiments, about 8.25 points of water is transferred. In some embodiments, about 8.5 points of water is transferred. In some embodiments, about 8.75 points of water is transferred. In some embodiments, about 9.0 points of water is transferred. In some embodiments, about 9.25 points of water is transferred. In some embodiments, about 9.5 points of water is transferred. In some embodiments, about 9.75 points of water is transferred. In some embodiments, about 10.0 points of water is transferred. In some embodiments, the amount of moisture transferred is varied and/or controlled by controller **160**.

In some embodiments, the heat and water added comes from warm moist air obtained from exhaust of a cooling/drying process. In other embodiments, the heat and water added comes from warm moist air obtained from, e.g., spraying or otherwise adding liquid water (such as by using a "swamp cooler" evaporation unit with a sponge rotating

16

between a water supply and the air) or steam into a hot-air stream heated by a coil, electric heat coil, direct fired burner or other heating device, wherein the amount of heat and the amount of water are individually controlled, e.g., by a controller that measures the wet-bulb and dry-bulb temperatures of the warm moist air stream entering the heat recovery device **120** or leaving the heat recovery device **120**. Any heat transferred to the liquid water to change its state to a gas is immediately recovered when the moisture condenses onto the product in the heat recovery device **120**. In some embodiments, a combination of the above mentioned exhaust and added hot air and water spray is used.

In some embodiments, various amounts of steam are used in steam conditioning that is added to the heat and/or moisture content that is used and/or transferred in the heat recovery device **120** as listed above, under the control of controller **160**. In some embodiments, about 0.25 point of steam is used. In some embodiments, about 0.5 point of steam is used. In some embodiments, about 0.75 point of steam is used. In some embodiments, about 1.0 point of steam is used. In some embodiments, about 1.25 points of steam is used. In some embodiments, about 1.5 points of steam is used. In some embodiments, about 1.75 points of steam is used. In some embodiments, about 2.0 points of steam is used. In some embodiments, about 2.25 steam of water is used. In some embodiments, about 2.5 points of steam is used. In some embodiments, about 2.75 points of steam is used. In some embodiments, about 3.0 points of steam is used. In some embodiments, about 3.25 points of steam is used. In some embodiments, about 3.5 points of steam is used. In some embodiments, about 3.75 points of steam is used. In some embodiments, about 4.0 points of steam is used. In some embodiments, about 4.25 points of steam is used. In some embodiments, about 4.5 points of steam is used. In some embodiments, about 4.75 points of steam is used. In some embodiments, about 5.0 points of steam is used. In some embodiments, about 5.25 points of steam is used. In some embodiments, about 5.5 points of steam is used. In some embodiments, about 5.75 points of steam is used. In some embodiments, about 6.0 points of steam is used. In some embodiments, about 6.25 points of steam is used. In some embodiments, about 6.5 points of steam is used. In some embodiments, about 6.75 points of steam is used. In some embodiments, about 7.0 points of steam is used. In some embodiments, about 7.25 points of steam is used. In some embodiments, about 7.5 points of steam is used. In some embodiments, about 7.75 points of steam is used. In some embodiments, about 8.0 points of steam is used. In some embodiments, about 8.25 points of steam is used. In some embodiments, about 8.5 points of steam is used. In some embodiments, about 8.75 points of steam is used. In some embodiments, about 9.0 points of steam is used. In some embodiments, about 9.25 points of steam is used. In some embodiments, about 9.5 points of steam is used. In some embodiments, about 9.75 points of steam is used. In some embodiments, about 10.0 points of steam is used.

FIG. 2 is a diagram of a counter-flow pellet dryer/cooler **200**. In some embodiments, pellet dryer/cooler **200** is based on a Bliss Op-Flow Cooler or similar device. Warm, moist agricultural product enters pellet dryer/cooler **200** through rotary valve feeder **201**. In some embodiments, feeder **201** utilizes an airlock system, wherein air-tight compartments rotate to allow product into the dryer/cooler.

In some embodiments, discharge device **205** rotates to control the amount of product retained in the dryer/cooler at a given time. Discharge device **205** will retain more material in dryer/cooler **200** when product level in the dryer/cooler is

17

too low, and will release more material from dryer/cooler **200** when the dryer/cooler is overloading. Measurements of product level are made by sensors placed at various positions on dryer/cooler **200**.

In some embodiments, product spreader **202** is located near feeder **201** and is used to spread the agricultural product evenly and consistently over the base of the dryer/cooler. Because of spreader **202**, no buildup or gaps will occur in the spread of product throughout dryer/cooler **200**. It is important that the product be spread evenly and uniformly throughout the dryer/cooler to ensure that the product is cooled thoroughly, consistently, and completely. If a buildup or gap of product were to occur in dryer/cooler **200**, it would change the flow of make-up air through the dryer/cooler and among the product. Air would flow through the path of least resistance, or where gaps in product occurred. This inconsistent air flow would leave some pellets warm and moist, while overly drying and cooling other pellets, resulting in a low-quality and possibly unusable product. Spreader **202** remedies this problem by creating a consistent, uniform, and even spread of product which will not provide a path of lower resistance for make-up air and will, consequently, result in a thoroughly dried and higher-quality product.

In some embodiments, selectable level sensors **204** and overload sensor **203** are provided. Level sensors **204** may be selected to reflect the optimal level of product within dryer/cooler **200**. These sensors send a signal to controller **160**, indicating the actual level of product within the dryer/cooler. The actual levels are compared to the desired level of product and adjustments in product flow are made. Controller **160** sends an output message to discharge device **205**, adjusting the rate and amount of material outflow from dryer/cooler **200**. If the product level is too low, as indicated by level sensors **204**, the discharge will retain more material into dryer/cooler **200**. Overload sensor **203** sends a signal to controller **160** when product levels are too high, thereby signaling discharge device **205** to reduce the amount of product retained in dryer/cooler **200**. In some embodiments, controller **160** also adjusts the rate and amount of material inflow into dryer/cooler **200** based on the moisture-content of pellets within dryer/cooler **200**. If the pellets are too moist, the level of product and the time spent within the dryer/cooler is increased so the pellets will have more direct contact and moisture transfer into the air. If the pellets are too dry, controller **160** will increase the flow of product out of dryer/cooler **200**, decreasing the level of product and time spent and causing less direct contact between individual pellets and airflow, thereby leaving additional moisture in the output pellets.

In some embodiments, at the bottom of dryer/cooler **200** is a perforated floor through which the make-up air **96** is allowed to flow in to the dryer/cooler and the pellets are discharged. In some embodiments, this floor includes a louver discharge system for discharge device **205** and is operated by an air cylinder or electric drive. Pellets are prohibited from exiting the dryer/cooler when the bars of this discharge system **205** are in a horizontal, or closed, position as shown in FIG. 2. This floor may rotate, allowing different amounts of product to flow out of dryer/cooler **200**. Air flow into dryer/cooler **200** also comes through the gaps in discharge system **205**.

Upon flowing out of dryer/cooler **200** through the floor of discharge device **205**, agricultural product enters cooled product discharge **206** and settles into collection hopper **207**. Product discharge **206** is used to channel the product into the collection hopper **207** in a formulation which allows for

18

proper storage of the product. After entering collection hopper **207**, the product is ready for use or storage.

An air exhaust pathway **208** is located on the upper portion of dryer/cooler **200** and provides a path for the exhaust air to exit the dryer/cooler. Air which has become hot and moist through contact with the agricultural product leaves the dryer/cooler through pathway **208**. This air will eventually reach the moisture-and-heat-recovery system and will be used to pre-moisturize and preheat the mash.

FIG. 3A is a diagram of a prior-art louver discharge system **300** (such as provided in a Bliss Op-Flo Cooler or heat transfer device) in the closed position. When lever arm **305** is in the horizontal, or closed position, the agricultural product **99'** is prohibited from leaving the dryer/cooler. Lever arm **305** is just long enough that no product may escape off the edge through the gap between arm **305** and flap **304** due to the angle of repose of the product. This causes the product to build up within the dryer/cooler, between and along dryer/cooler wall **301**. The gap between arm **305** and flap **304**, permits air flow up through the product and into the dryer/cooler. To allow product **99'** to escape the dryer/cooler bin, axle **306** rotates, adjusting lever arm **305**, e.g., rotating clockwise in FIG. 3A, and allowing material **99'** to be dispelled from the dryer/cooler.

FIG. 3B is a diagram representing louver discharge system **300** in a discharge, or partially open, position **325**. Axle **306** has rotated position from the axle position in FIG. 3A, thereby rotating the lever arm clockwise, and making the gap angle between lever arm **305** and flap **304** suitable for product **99'** to be discharged. The positions of axle **306** and lever arm **305** are variable and may be adjusted to allow more material (greater clockwise rotation in FIG. 3B) or less material (less clockwise rotation in FIG. 3B) to be dispelled.

FIG. 3C is a diagram of louver discharge system **300** in a cleanout position **350**. In this representation, axle **306** and lever arm **305** have been rotated to such an extent that all material **99'** has been dispelled from the dryer/cooler.

FIG. 4 is a block diagram of a system **400** that provides ethanol production for some embodiments with heat recovery and control. In some embodiments, raw corn **99** is input into system **400** and enters a storage hopper **110** used to control the flow of corn into grinder **105** and the rest of system **400**. Storage hopper **110** generates a constant flow of material into system **400**, thereby providing a buffer against the inconsistencies in the amount of corn provided. Corn levels in storage hopper **110** vary depending upon the amount of corn provided (e.g., hopper fills up as more corn is provided than is used and levels diminish as usage exceeds the corn provided), but the output from the storage hopper remains constant.

Corn output from storage hopper **110** enters grinder **105**. In some embodiments, grinder **105** includes a hammer mill. Grinder **105** grinds the corn into flour/meal **499**, otherwise known as meal **499**. The flour/meal **499** is a consistency suitable for use within the remaining devices of system **400**.

This meal **499** is then input into a heat recovery system **120** which takes heat and moisture from other devices later in system **400**, such as dryer **475** and inputs this heat and moisture to meal **499**. By reusing moisture and heat from later in system **400**, system **400** provides a more cost-efficient method for producing ethanol. Further, in some embodiments, makeup water **89** is added to the heat recovery system **120** to increase the mass of the incoming mash components to further utilize the energy recovered.

Meal **499** is then input into additive slurry mixer **125**. In some embodiments, additives **498**, including enzymes and ammonia, are added to the meal. Enzymes serve to convert the starch to dextrose, while ammonia is both a nutrient to the

yeast and controls pH levels. Along with the enzymes and ammonia, cook water is also added to the meal by slurry mixer **125**. The resulting product is called mash **499**.

The heated mash coming from slurry mixer system **125** enters a slurry tank **140** which adds heat and moisture to the mash, acting as a cooker to reduce the level of bacteria within the mash and begin breaking down the starch in the product.

In some embodiments, the cooled mash output from mash cooler **140** enters a fermenter **440**. It is here that yeast is added to convert sugar into ethanol and carbon dioxide. Fermenter **440** is air locked in order to prevent oxygen, unwanted and undesirable bacteria and other organisms from entering during fermentation. This airlock system also allows the carbon dioxide produced by the yeast in the fermentation process to escape.

In the fermenter **440**, mash is kept at cool temperatures of, e.g., between 18 and 26 degrees Celsius to facilitate the process. If mash temperature is too high and outside a suitable range, fermentation will occur at a rapid pace and an unwanted byproduct may be produced and/or the yeast may die. Also, if mash temperature is too low and below a suitable range, fermentation will occur at a slow rate and may come to a complete stop. Therefore, it is important that the mash maintain a suitable temperature so the fermentation process is efficient. The mash is generally left in the fermenter for between 40 and 50 hours, before being further processed.

Output from fermenter **440** is a mixture of ethanol and stillage. The fermenter output is preheated by mixture preheater **445**. In some embodiments, preheater **445** is a counter-flow device. Preheater **445** adds energy using steam or electricity to mixture output of fermenter **440**. By using a counter-flow device, the output preheater output flow **488** is able to achieve cool temperatures of nearly that of the input ethanol mixture material, while output ethanol product reaches temperatures of nearly that of the hot incoming heat transfer media.

Ethanol and stillage output from mixture preheater **445** is input into a boiler/distillation column **450**, where alcohol is boiled out of the water mixture. In some embodiments, this concentrates the ethanol to, e.g. 190 proof (95% ethanol and 5% water). This ethanol is then input into a cooler/sieve **455**, where the remaining water is removed (the ethanol is dried out). In some embodiments, the resulting ethanol **493** which is output from cooler/sieve **455** is, e.g., 200 proof.

Stillage output from boiler/distillation column **450** enters centrifuge **470**, where it is separated into coarse grain and liquids. The liquids are evaporated to create a concentration of about 30% solids, creating syrup **490** which may then be stored or transported. Distillers' grain with solubles may also be made out of syrup **490**, by drying the syrup with the coarse grain. The grain from centrifuge **470** enters a dryer **475**. Dryer **475** takes cool make-up air **96**, adds dry heat **95**, the flow of which is controlled by flow/speed controller **155** and is adjusted based in part on temperature of material and ambient air, and uses this air to dry the warm, moist grain input from centrifuge **470**. The air flow through dryer **475** removes moisture and heat from the grain input, eventually leaving dryer **475** as a warm, moist exhaust stream which is recovered by heat recovery system **120**. In some embodiments, warm, moist air exhaust output from dryer **475** has a temperature of nearly that of the input grain material, whereas the output grain material achieves a temperature of nearly that of the input air stream. Dried grain output from dryer **475**, known as distiller's grain **491**, is then ready to be transported or stored. Warm, moist air from dryer **475** is transported through similar

methods as the warm air from mash cooler **140**, back to heat recovery system **120** and is injected into mash at this earlier stage of system **400**.

FIG. 5 is a flowchart of a method **500** according to some embodiments of the invention. Method **500** includes grinding **505** the raw material **99** to some consistency suitable for the uses of method **500**. After grinding raw material **99**, the material becomes a milled material **99'**. In some embodiments of the invention, milled material **99'** is stored **510**. This storage provides a buffer for the flow of material within method **500**. As grinding rates or raw material amounts increase, more material is stored **510**. Similarly, as grinding rates or raw material amounts decrease, less material is stored. This allows for a constant and consistent stream of material to flow from storage through the rest of method **500**.

Material which leaves storage is then subjected to a process of ration mixing **515**. In mixing rations, ration additives **98** are combined with the milled material **99'** to form mash, sometimes called processed product, milled product, or feed-stuff. Ration additives **98** may include combinations of other grains (to improve nutrient value of the resulting agricultural product), protein-rich concentrates, carbohydrate-enrichments, fat-rich additives, *Lactobacillus acidophilis* and *Lactobacillus bulgarium* ("to provide a non-hygroscopic free-flowing, self-preserving animal feed supplement"), lactic acid (for foodstuff preservation), mineral substances, antibiotics, enzymes, hormones, trace elements, vitamins, pharmaceuticals, and/or preservatives.

In some embodiments of the invention, mash coming from ration mixing **515** is input into a device which is used for recovering moisture and heat **520**. This function allows for cost-efficiency and cost-cutting methods in the production of agricultural products by using moisture and heat taken from the pellet cooling and drying stage later in method **500**. Recovering moisture and heat permits heat and moisture that is unnecessary and undesirable in final agricultural products and is removed from the product later in method **500**, to be added to mash coming from ration mixing **515** in order to preheat and premoisturize the mash. Recovery of moisture and heat may be done through a co-flow system (both mash and air flow in the same direction), a cross-flow system (mash flows horizontally and air flows vertically) or a counter-flow system (mash and air flow in opposite directions).

Mash which has been exposed to the recovered moisture and heat next undergoes steam conditioning **525**. In steam conditioning **525**, steam **97** is injected into the mash. The amount of steam **97** used in steam conditioning **525** is variable depending upon temperature and moisture content of raw material **99**. The amount of steam **97** used will decrease in warmer temperatures, such as in the summer months, because hot material and air have a greater moisture-holding capacity than colder material and air. In warmer temperatures, 2 to 3 points of steam is injected. In colder temperatures, such as in the winter months, 4 to 5 points of steam may be injected. Material which has been steam conditioned will contain, e.g., a moisture content of 17 or 18 points and a temperature of 200 degrees Fahrenheit.

Mash is next subjected to product processing **530**. In some embodiments, the mash is converted to pellets. The mash is pushed and squeezed in a pellet mill through holes in a die face. A cutter will then cut the product, creating formed and shaped pellets having temperatures of, e.g., 200 degrees Fahrenheit (93 degrees Celsius).

In some embodiments of the invention, wetting **535** is included in method **500**. Water **90** is sprayed onto the outer surface of the product before the product is cooled **540**. Spraying water on the product provides, for example, an

additional one percent of moisture on the product, which makes up part of the 3% of moisture removed from the product in the product cooling and drying process 540 later in method 500. Adding this additional moisture to the product before the drying process, allows the cool product 94 to be less fragile and have a higher durability, thus making a better quality product. Water spraying is done in warmer temperatures, such as in the summer months, when ambient air temperatures are higher and cooling and drying product removes a larger amount of moisture from the product.

Cooling and drying the product 540 is done until the product is at a temperature suitable for storage, e.g., within ten degrees Fahrenheit (6 degrees Celsius) of ambient air temperature. Cooling and drying may be done with either a co-flow or counter-flow device. Counter-flow devices provide for a higher degree of heat transfer between the air and product, allowing the air exhaust, warm, moist exhaust 93, to reach a temperature close to the temperature of the incoming product, and the output product, cool product 94, to reach a temperature close to the incoming air temperature.

In embodiments in which a counter-flow device is used, product cooling and drying 540 necessitates the use of make-up air 96, input near one end of the product cooling and drying device, to cool and dry the agricultural product entered at the opposite end. Air flowing through the device cools and dries the agricultural product, picking up moisture and heat through direct contact with the product. At the opposite end from its input position, make-up air 96 escapes the cooler as the warm, moist exhaust 93. This exhaust air is warm, moist, possibly oily, and particulate-laden.

Speed of make-up air used in product cooling and drying may be varied through a device used for flow/speed controlling 555. Flow/speed controlling 555 may be adjusted due to changes in ambient air temperature. When ambient air temperature is cooler, such as in winter months, less moisture is transferred from the product to the make-up air when product is cooled and dried 540. This results in cool product 94 with a higher moisture content, which may cause moldy product and is unsuitable for product storage. Controlling the flow of air used in product cooling and drying remedies this problem by slowing the air flow to allow for a higher level of moisture transfer in product drying. When ambient air temperatures rise, air flow is again increased.

In some embodiments, air which has been used in product cooling and drying 540 and which is given off as the warm, moist exhaust 93, is mixed with air streams 545. In some embodiments, these air streams are exclusively composed of dry heat. Both temperature and flow rate of these air streams may be adjusted based on measurements of air temperature and moisture content of ambient air and temperature of the warm, moist exhaust 93. When ambient air temperature is cooler, the make-up air 96 used in product cooling and drying 540 does not heat up to high enough temperatures in the product cooling process. When this air is given off as warm, moist exhaust 93, the temperature of the exhaust is not yet sufficient to heat up the mash in the moisture-and-heat-recovery stage of method 500. Therefore, dry heat must be added to make up for this temperature differential. Since this exhaust air already contains sufficient levels of moisture to premoisturize the mash, adding additional moisture to warm, moist exhaust air 93 would make the mash too wet and cause "roll slip" in the pellet mill. Therefore, in some embodiments, dry heat is added by mixing air streams 545 to the warm, moist exhaust 93, raising the temperature of the exhaust air to, e.g., 160, 180, or 200 degrees Fahrenheit (71, 82, or 93 degrees Celsius). A similar process may be required in summer

months to reduce the moisture content of the warm, moist exhaust 93 if the warm, moist exhaust air becomes too saturated.

Moisture and heat from exhaust air 93 is then recovered and injected into milled material 99' to premoisturize and preheat the material 99'. In recovering the moisture and heat 520, heat and moisture from the warm, moist exhaust 93 are removed and absorbed into the milled material 99'. In some embodiments, exhaust air 93 contains a high oil and particulate content that will foul a typical heat-recovery device, and which need to be removed from the exhaust stream before the air is released to the outside to avoid polluting the environment. As the hot, moist exhaust air 93 is forced through the agricultural product, the exhaust stream is cleaned of at least part of the oil and particulate content. Undesirable and unused particulates and other waste products in warm, moist exhaust 93 become the heat recovery's exhaust 92, which is then cleaned 550 and discarded as cleaner's exhaust 91.

In some embodiments of the invention, a method for controlling various aspects of method 500, including the overall flow of method 500, is included. Measurements that are used for controlling the method 500 include ambient air temperature, product temperature, exhaust air temperature, air humidity levels, product levels, flow rates, and/or the amount of moisture and heat transfer as product is cooled and dried 540. These measurements are used to adjust the mixing of rations 515, steam conditioning 525, wetting 535, controlling make-up air flow/speed 555, and the mixing of air streams 545.

FIG. 6 is a diagram of functions of a controller 600. Controller 160 takes measurements throughout an agricultural-product-production system and receives signals corresponding to these measurements as inputs to control various actions throughout the system, which are the outputs of controller 160. Input measurements used by a controller include temperatures of such items as ambient air, pellets, and exhaust air. Air humidity level is also measured for both the ambient air and exhaust air. Inputs from the pellet cooler and dryer device include pellet level, air-flow rate, and moisture transfer rate. Flow rates for the entire production system are also measured and used as inputs by the controller.

In some embodiments of the invention, the controller 600 regulates a number of devices throughout the agricultural-product-production process. Included in the devices and actions regulated are the amount of ration additives added by the ration mixer, the rate at which these additives are added, and the amount of steam injected to the mash by the steam conditioner. The amount of water sprayed by the water sprayer and the flow and speed of make-up air are also regulated, at least in part based upon the temperature of ambient air. Further along in the system, the amount of dry heat that is added by the mixer is adjusted by the controller. Overall, the general flow of the system is also regulated by the controller to ensure a consistent, constant and uniform production process that generates a high-quality final product.

FIG. 7 is a block diagram of a system 700 used in wet corn milling with heat and moisture recovery and control. In some embodiments, raw corn 99 is input into system 700 and goes through a long-retention moisture-and-heat-recovery system 120. Recovery system 120 takes heat and moisture from dryers 740 and 745 later in system 700 and combines this heat and moisture with the raw corn 99, thereby preheating and pre-moisturizing the corn. This preheat and pre-moisturization cuts down on the amount of heat and moisture that must be added at corn steeper 710, reducing operating costs of system 700. In some embodiments, moisture-and-heat-recovery system 120 is a counter-flow device in which hot, moist air is input into the bottom of recovery system 120 and

raw corn is input in the top of recovery system **120**. The air and corn are mixed together, cooling the output air to a temperature near that of the incoming corn and heating the output corn to a temperature near that of the incoming air. Output from recovery system **120** includes hot, moist corn, which is sent to corn steeper **710**, and cooler, dryer exhaust air **92**.

In some embodiments, preheated and premoisturized corn output from moisture-and-heat-recovery system **120** is input into corn steeper **710**. Water **90** and heat **95** are also injected into corn steeper **710**. In some embodiments, the corn is soaked in water for between 24 and 48 hours, or until the corn has achieved a consistency suitable for separating the corn into its component parts. This soaked corn is then output from corn steeper **710** and input into a series of separators **715** and **735**.

After the corn has gone through corn steeper **710**, it is separated into starch, corn slurry and wet gluten by separators **715** and **735**. These two distinct separations mark the breakdown of wet corn milling into three processes which produce a number of different products including corn oil **795**, feed product **794**, gluten meal **792**, corn starch **788**, ethanol chemicals **787**, and high fructose corn syrup **786**.

Corn slurry **798** is separated off from the other two processes by the first separator **715**. The slurry is processed through a grinder/screener **720** which separates fiber **797** out from the slurry. Fiber **797** will become feed product **794**. The component of the slurry not separated as fiber is then injected into a germ separator **725** which further separates additional fibers from the corn germ **796**. These fibers may also be used to create feed product **794**. In some embodiments, the corn germ **796** is input into an oil refiner **730** which extracts corn oil **795** from the corn germ **796**.

First separator **715** also separates a starch component out from the corn material output from corn steeper **710**, leaving a mixture of the steamed corn material to be further processed by second separator **735**. Second separator **735** separates additional starch **789** from wet gluten **793**. In some embodiments, separator **735** is a centrifugal separator. In other embodiments, separator **735** is a screen separator. In still other embodiments, separator **735** is a hydrochloric separator.

Wet gluten **793** separated from starch **789** is put through a filter and dryer **740**. In some embodiments, dryer **740** is a counter-flow device. Cool air **790** and possibly heat **791** are input into the base of dryer **740**, where the air mixes with the wet gluten product **793**, input at the top of dryer **740**. The air and gluten travel in opposite directions, allowing a larger amount of heat and moisture to transfer between the air and gluten. Moist air output from dryer **740** achieves a temperature nearly the same as the temperature of the input gluten, while dried gluten meal **792** output from dryer **740** nearly reaches the temperature of input air **790**. Exhaust air from dryer **740** is conducted back to moisture-and-heat-recovery system **120** and is used to preheat and premoisturize the raw corn **799**. In some embodiments, the flow and speed of input air **790** and heat **791** is controlled by flow/speed controller **155** and is adjusted based at least in part on temperature measurements of ambient air and input material.

Starch **789** is separated from the other two processes through both separator **715** and separator **735**. Starch **789** may be used to make products including corn starch, ethanol chemicals, and/or corn syrup, depending upon the process used.

To make corn starch **788**, starch **789** is input into dryer **745**. In some embodiments, dryer **745** is a counter-flow device. Cool air **790** and heat **791** are input into the base of dryer **745**, where the air and possibly heat mix with starch **789** input at the top of dryer **745**. The air and starch travel in opposite

directions, allowing the starch to reach temperatures near that of the incoming air and the air to achieve temperatures near that of the incoming starch. Outputs from dryer **745** include exhaust air out the top of the dryer and corn starch **788** out the bottom of the dryer. Exhaust air from dryer **745** is conducted back to moisture-and-heat-recovery system **120**, where it is combined with the raw corn **99**. The flow and speed of input air **790** is controlled by flow/speed controller **155**.

In some embodiments, ethanol chemicals are produced from starch **789**. Starch **789** is input into fermenter **440**, where it is kept cool and is combined with yeast to convert sugar to ethanol and carbon dioxide. The starch may be kept in fermenter **440** for between 40 and 50 hours. At the end of this time, ethanol chemicals **787** are removed from fermenter **440** which may be further processed or stored.

Starch **789** may also be processed into high-fructose corn syrup **786**. In this process, the starch **789** is input into syrup refiner **755**, where it is made into corn syrup **781**. This corn syrup is further processed and dextrose **780** is removed. The removal of dextrose from the corn syrup creates high fructose corn syrup **786** which may be stored or transported for use.

Controller **160** is used to control a number of features of the devices within system **700** based upon a plurality of measurements. Measurements input into controller **160** include temperatures of ambient air, dryer heat, and raw materials, as well as flow speed and moisture content levels throughout system **700**. Outputs from controller **160** include controlling the flow speed of the dryers **740** and **745**, along with the overall flow speed of system **700**, heat and moisture content levels throughout system **700** and within the numerous devices, and temperature levels throughout system **700**.

FIG. **8** is a block diagram of a system **800** of some embodiments of the invention, indicating a plurality of parameters which are measured throughout system **800**. The system and method of FIG. **1** and/or FIG. **8** can be used for making feed pellets from materials such as corn, silage, or other crops, or for making fuel pellets from materials such as wood fiber, turkey manure, or other biomass. The process for making feed pellets is described in detail above. The fuel-pellet process is similar. In some embodiments, the pelletizing process for wood includes drying, grinding, conditioning, pelleting/extrusion, cooling and screening to produce pellets that have high density, improved material-handling characteristics. The pellet shape is conducive to automatic burner-infeed systems, such as used in residential wood-pellet fed stoves or furnaces.

In some embodiments, as part of the grinding block **105** of FIG. **1**, incoming wood fibers (for making into fuel pellets) are screened or sorted to remove tramp material and foreign objects (such as stones, metal, and dirt) in order to improve machinery life and reduce ash content of the burned pellets. In some embodiments, the input wood is kiln dried (KD) and/or dried in rotary drum driers to obtain, e.g., 7% to 10% wet basis moisture (e.g., in some embodiments, 5%, 6%, 7%, 8%, 9%, 10%, 11%, 12%, 13%, 14%, or 15%). In some embodiments, the raw material is reduced to pieces no larger than about 5 cm. by 5 cm. by 1 cm. using a primary grind hog and then finely ground using a final grind hammer mill. In some embodiments, the grinding operation is performed before drying in order to expose more surface area and make the drying process faster, more even (since the ground wood material has a more even particle size, each piece dries to the same extent) and more efficient. Often, it requires more horsepower to grind wet wood fiber than it does for dry material, so some embodiments dry first, and then grind.

In some embodiments, the finely ground material from block **105** then goes to a buffer storage **110** that provides an

even flow rate of material fed to block 120 to be pre-heated and pre-moisturized by the warm moist exhaust 93 of the cooler/dryer 140, and then at block 125, the wood material is steam or water conditioned to heat the fibers and apply a thin layer of moisture to the wood particles. The heat recovery of block 120 reduces the amount of steam or hot water needed at block 125. To bind the wood fiber into a pellet, the temperature of the material must be raised to about 220 to 240 degrees Fahrenheit (104 to 116 degrees C.), so that the lignins in the wood material gelatinize and bind the fiber during the pelletizing (as compared to the starches that gelatinize in grain when processing into pellets). This reduces the amount of mechanical energy otherwise required to pelletize the wood material, increasing throughput and reducing wear on the machinery. Alternatively, rather than steam conditioning, water conditioning can be used, where water is added to assist in lubricating the fiber for extrusion at block 130. At block 130, the wood fibers are formed into pellets (in some embodiments, these pellets are about 6 mm diameter and about 18 mm long, but dimensions can vary), and the pellets are cooled and dried at block 140 to output cooled fuel pellets 94 and warm moist exhaust 93 that is used at block 120 to pre-heat and pre-moisturize the ground wood material before steam conditioning. The buffer storage 110 allows a more even/constant flow rate of material to pelletizing block 130, in order to run the pelletizer at or near its design throughput capacity. The material and thickness of the pelletizer are chosen to accommodate the wood species being pelletized, and in some embodiments, will use stainless steel or carbon-steel alloy, and have an open area of the dies of about forty percent. In some embodiments, pelletizing will increase the bulk density four fold (e.g., from about 160 kilogram/cubic meter to 640 kg/cubic meter), increasing the energy density of the material.

Optionally, the pellets can have additional water added at block 135 before cooling, in order to prevent excess drying and obtain a desired moisture content of the final product. In some embodiments, as the pellets exit the pelletizing mill, they will flash off about one to two percent water, and then have about eight percent moisture content and 93 degrees C. In some embodiments, the final pellets are dried to about 6.5 percent moisture. In some embodiments, the pellets are screened to remove "fines" (e.g., a screen of 4.5 mm openings is used for pellets having a 6 mm diameter) and are then bagged. The bagging is typically done by weight, and the bags are sealed by heat. The bags are stacked on a pallet (e.g., 50 bags of 40 pounds each for a short ton, or 50 bags of 20 kg each for a metric ton), and are shrink-wrapped). The fines are recycled into the input stream of wood material for reprocessing. In a well-run system, less than three percent fines will need to be removed. In some embodiments, the weight of the fines is measured, and if fines exceed five percent (indicating something is wrong in the process), the system is adjusted (e.g., the moisture and/or heat of the steam conditioning is increased).

Other features of system 800 are as described in FIG. 1. In some embodiments of the invention, mash temperature 850 is taken as the agricultural material is within ration mixer 115. This temperature is used as a basis on which to compare temperature measurements from later in system 800 and to adjust production devices within system 800, such as heat-recovery system 120 being adjusted to inject more or less heat into incoming material, or pellet cooler/dryer 140 to add more make-up water 90 or make-up air 96. In some embodiments, make-up water 90 is added by a pellet wetter (e.g., sprayer) that, e.g., sprays water on the pellets entering pellet dryer/cooler 140.

In some embodiments, mash moisture-content measurement 805 and temperature measurement 810 are taken after mash is output from heat-recovery system 120. These measurements are sent to controller 160 and are used to control parameters throughout system 800, such as the amount of heat and moisture transferred into incoming mash within heat recovery system 120, the amount and/or quality of steam added by steam conditioner 125, the temperature and flow of make-up air 96, and the additional make-up water 90 to be added.

Measurements are also taken that pertain to the cooled pellet output from pellet dryer/cooler 140. Measurements are made of moisture content 825 of output pellets and temperature 820 of output pellets. By adjusting parameters throughout system 800, pellet temperature and moisture can be controlled and maintain a substantially constant, ideal moisture content and temperature. In some embodiments, this is done by adding make-up water 90 if moisture content of cooled pellets 94 is too low and by reducing the flow of make-up air if moisture content of cooled pellets 94 is too high.

Temperature of exhaust air from pellet dryer/cooler 140 is also measured 815 and regulated to maintain a desired temperature. If the measured temperature of exhaust air 815 is too high, controller 160 allows for additional make-up water 90 and/or make-up water 89 to be added to system 800. This allows for control of water-mass balance independent of pelletizing and increases the amount of evaporative cooling in the unit, lowering the cooler outlet temperature. Also, by increasing the surface moisture on the pellets, less internal pellet moisture is evaporated by the cooler/dryer 140, which improves pellet durability and moisture content. If the measured temperature of exhaust air 815 is too low, airflow on the cooler exhaust system is reduced. This reduction in airflow proportionately increases air temperature across the dryer/cooler, while increasing the maximum possible humidity ratio (the moisture content), thereby removing more water from the pellets.

Dry-bulb and wet-bulb temperatures are measured in the dryer/cooler exhaust system 830 to determine the amount of additional heat 95 and make-up water 89 and/or 90 required. The heat-recovery air infeed dry-bulb temperature 835 is measured and used to control the amount of additional heat added into the system. If the temperature measurement 835 is too low, additional heat will be added, whereas if the temperature measurement 835 is too high, cool air will be added or heat will be turned off. Similarly, heat recovery air infeed wet-bulb temperature 840 is measured and used to control the amount of make up water added to the dryer/cooler exhaust air stream. Wet-bulb temperatures below the desired temperature will cause additional water to be added to dryer/cooler exhaust system 93, whereas measured temperatures above the desired temperature will cause the water level to be reduced or turned off. In some embodiments, setup points for both the wet-bulb and dry-bulb temperatures are based on the desired mash temperature and moisture content and are set to control condensation and latent heat recovery in system 800.

In some embodiments of the invention, airflow 92 out of heat-recovery system 120 is also measured to control aspects of system 800. Heat-recovery air-outfeed dry-bulb temperature 845 is used to control airflow speed and volume through the recovery system. Temperatures that are higher than the desired level signal controller 160 to reduce the amount of airflow from the exhaust system, whereas temperatures lower than the desired level signal controller 160 to increase the amount of airflow from the exhaust system.

In some embodiments, a system and method of the present invention similar to system 800 of FIG. 8 is used to produce

steam-flaked corn, sorghum, or other grain having improved net energy for animal feed. In other embodiments, the system and method of the present invention is used for steam-rolling grain, a common processing method for barley, corn, and wheat used in dairy concentrates. For steam rolling, the grains are usually steamed for 15 minutes or less to increase grain moisture to about 15 percent and then crushed with various sizes of rollers to produce a thick flake without a specific flake density endpoint, usually about 438 to 540 g/L for corn and sorghum (34 to 42 lb./bu., in units as used in the industry

The system for steam flaking is a more extensive processing system (with careful quality control) than dry-rolling or steam-rolling grain. In some embodiments, a system similar to system 800 is used, except the following units are omitted: grinding 105, storing 110, ration mixing 115. The incoming whole grain (such as corn) is introduced to heat-recovery system 120 and preheated and premoisturized with warm moist exhaust air. In some embodiments, the whole grain is steamed for 30 to 60 min in a vertical, stainless steel steam chamber 125 (for example, one that is 3.1 to 9.2 m high and 91 to 183 cm in diameter) to increase grain moisture to about 18 to 20% and then flaked between preheated large rollers (not shown) in place of pellet mill 130. The rollers have a close-tolerance thin spacing (e.g., 46 cm diameter by 76 to 91 cm length or 61 cm diameter by 122 cm length) to obtain a specific final desired flake density (in some embodiments, about 309 to about 386 g/L or 24 to 30 lb/bu). In place of pellet dryer/cooler 140, a flake dryer cooler is used, and cool flakes (rather than cool pellets 94) are generated, having a desired temperature and moisture content as measured and controlled by the controller. Rather than starting with ground grain and ending with pellets, this process starts with whole grain and ends with flakes, but is otherwise the same as shown in FIG. 8 and FIG. 1.

In some embodiments, the grain is steam flaked to a flake density of about 360 g/L. In some embodiments, the grain is steam flaked to a flake density of about 290 g/L. In some embodiments, the grain is steam flaked to a flake density of about 300 g/L. In some embodiments, the grain is steam flaked to a flake density of about 310 g/L. In some embodiments, the grain is steam flaked to a flake density of about 320 g/L. In some embodiments, the grain is steam flaked to a flake density of about 330 g/L. In some embodiments, the grain is steam flaked to a flake density of about 340 g/L. In some embodiments, the grain is steam flaked to a flake density of about 350 g/L. In some embodiments, the grain is steam flaked to a flake density of about 370 g/L. In some embodiments, the grain is steam flaked to a flake density of about 380 g/L. In some embodiments, the grain is steam flaked to a flake density of about 390 g/L. In some embodiments, the grain is steam flaked to a flake density of about 400 g/L. The rollers become hot as the steamed grain passes through, which is important in the flaking process. The extent of processing (flaking pressure) increases as flake density decreases (i.e., 309 g/L flake is more extensively processed than a 386 g/L flake). The quality of steam-flaked grain is routinely measured by flake density, and by laboratory methods (enzymatic starch hydrolysis or percent starch gelatinization). In some embodiments, a cooling/drying device 140 is used to cool and dry the flaked grain, and to obtain warm moist air (by exhaust system 830) that is used to preheat the incoming whole grain.

In other embodiments, steam rolling of grain is performed by the present invention. This is similar to the process for steam flaking with heat recovery described above, except that less steam cooking is done, and the rollers do not squeeze the product as thin.

FIG. 9 is an abstract block diagram of a system 900 of some embodiments that provides agricultural-product production with heat-and-moisture-recovery and control. Sensors and controls are indicated in FIG. 9, with other aspects of FIG. 9 as described in FIG. 1.

In some embodiments, sensors 921-927 transmit measurements and other data from material and devices throughout system 900 to controller 160. In some embodiments, sensor 921 transmits temperature measurements of the raw material 99 to controller 160. Sensor 922 in some embodiments transmits measurements including moisture-content and temperature of mash. Moisture-content and temperature measurements are also taken by sensors 925, 926, and 927 at different points in system 900. Measurements taken at steam conditioner 125 by sensor 923 and by sensor 924 at water sprayer 135 measure quality of steam and additional water levels, respectively.

In some such embodiments, controller 160 makes adjustments to devices within system 900 based at least in part on feedback from sensors 921-927. Controller 160 then sends control outputs 931-935 to a plurality of points throughout system 900. In some embodiments, control 931 regulates the temperature, quality, and amount of steam added by steam conditioner 125, and control 932 adjusts the temperature, rate, and amount of water added by water sprayer 135. In some embodiments, control 933 is used to make adjustments to product cooler/dryer 140, including material flow and air flow adjustments. Sensors 934 and 935 are provided in some embodiments to make adjustments in the moisture-content and temperature of warm, moist exhaust air 93. Sensor 934 adjusts the amount of dry heat 95 added to warm, moist exhaust air 93, while sensor 935 regulates the amount of additional water 89 added to exhaust 93.

One aspect of the invention, in some embodiments, includes a method 500 that includes transferring 520 heat and moisture from a warm, moist air exhaust stream to incoming agricultural material, steam conditioning 525 the material, processing 530 the steam-conditioned material into warm processed product, and cooling 540 the warm processed product with air to produce the warm, moist exhaust air 93 used in the transferring of heat to the incoming material and to produce cooled processed product, wherein the cooled processed product is at a temperature lower than the warm, moist exhaust air.

In some embodiments of the invention, processing 530 of the steam-conditioned material includes pelletizing and the processed product includes warm pellets, and also includes wetting 535 the warm pellets before cooling in order to improve a pellet durability index (PDI).

In some embodiments, the method includes adding 545 a controlled amount of dry, heated air based on temperature of exhaust air.

In some embodiments, the method includes varying 555 a flow rate of air in the cooling of the pellets. In some such embodiments, the flow rate is lowered based on a lower ambient air temperature, wherein slowing air flow allows a greater percent of moisture content.

In some embodiments, the method includes receiving one or more measured parameters and generating one or more control signals to control one or more of the transferring, steam conditioning, processing, and cooling.

In some such embodiments, the processing of the steam-conditioned material includes fermenting and the processed product includes ethanol.

In some embodiments, the method includes providing raw material, grinding the raw material to produce mash, mixing

one or more rations into the mash to produce the incoming agricultural material, wherein the processing includes pelletizing.

In some embodiments, the method includes cyclone cleaning of the warm, moist exhaust air used in the transferring of heat to the incoming material.

In some embodiments of the invention, the transferring of heat and moisture adds about two points of water and steam conditioning adds about two points of water.

Another aspect of the invention, in some embodiments, includes a method **500** including transferring **520** heat and moisture from a warm, moist air exhaust stream to incoming agricultural material, steam conditioning **525** the material, processing **530** the steam-conditioned material into warm processed product, cooling **540** the warm processed product with air to produce the warm, moist exhaust air used in the transferring of heat to the incoming material and to produce cooled processed product, and controlling **560** including measuring a parameter related to heat and moisture content and varying an apparatus related to heat and moisture content within the method.

In some embodiments, the processing **530** of the steam-conditioned material includes pelletizing and the processed product includes warm pellets, and the method **500** includes wetting the warm pellets before the cooling **540** in order to improve a pellet durability index (PDI).

In some embodiments, the method **500** includes adding **545** under the control of the controller a controlled amount of dry, heated air based on temperature of exhaust air.

In some embodiments of the invention, the method includes varying **155** a flow rate of air in the cooling of the pellets. In some such embodiments, the flow rate is lowered based on a lower ambient air temperature, wherein slowing airflow allows a greater moisture content.

In some embodiments, the method includes receiving one or more measured parameters and generating one or more control signals to control one or more of the transferring, steam conditioning, processing, drying and cooling.

In some embodiments of the invention, the processing of the steam-conditioned material includes fermenting and the processed product includes ethanol.

In some embodiments, the method **500** includes providing raw material, grinding **505** the raw material to produce mash, mixing **515** one or more rations into the mash to produce the incoming agricultural material, wherein the processing **530** includes pelletizing and wherein the grinding, mixing, and processing are under the control of the controller.

In some embodiments of the invention, the method includes cyclone cleaning **550** under the control of the controller of the cooled, dried exhaust air used in the transferring of heat to the incoming material.

In some embodiments, the transferring **520** of heat and moisture adds about two points of water and wherein steam conditioning **525** adds about two points of water.

Another aspect of the invention includes an apparatus **100** including a moisture-and-heat-recovery system **120** that provides direct contact between an incoming agricultural product mash and a warm, moist exhaust, a steam conditioner **125** operatively coupled to receive the warmed, moisturized mash from the moisture-and-heat-recovery system **120** and that injects steam, an agricultural-product processor (e.g., **130**) operatively coupled to receive steam-injected warm mash and that outputs a warm, moist processed product, and an agricultural-product dryer/cooler **140** operatively coupled to receive the warm, moist product and that outputs cooled product at a temperature lower than the warm, moist exhaust.

In some embodiments of the invention, the processed product includes warm pellets, and the apparatus includes a pellet wetter **135** coupled to place water on the warm pellets before the pellets exit the dryer/cooler.

In some embodiments, the apparatus includes a controller **160** operatively coupled to adjust an amount of water sprayed by the sprayer.

In some embodiments of the invention, the apparatus includes a flow controller **155** wherein the controller **160** adjusts an amount of flow of air through the agricultural-product dryer/cooler **140**.

In some embodiments, the agricultural-product processor is a pellet mill and the agricultural-product dryer/cooler includes a pellet dryer/cooler **135**.

In some other embodiments, the agricultural-product processor is an ethanol-processor and the agricultural-product dryer/cooler is an ethanol byproduct dryer/cooler.

In still other embodiments, the agricultural-product processor **140** includes a wet-corn starch processor and the agricultural-product dryer/cooler is a cooler of an output byproduct of wet corn processing.

In some embodiments, the apparatus includes a controller that controls the flow controller and pellet wetter in order to produce pellets having a moisture content of about 15 percent.

In some embodiments, a moisture transfer is about two points and steam adds about two points of water.

In some embodiments, the apparatus includes a mixer **145** operatively coupled to the warm, moist exhaust to add a controlled amount of dry, heated air and a controlled amount of moisture based on temperature of the exhaust.

Another aspect of the invention, in some embodiments, includes an apparatus **100** including a moisture-and-heat-recovery system **120** that provides direct contact between an incoming agricultural product mash and a warm, moist exhaust, a steam conditioner **125** operatively coupled to receive the warmed, moisturized mash from the moisture-and-heat-recovery system and that injects steam, an agricultural-product processor (e.g., **130**) operatively coupled to receive steam-injected warm mash and that outputs a warm, moist processed product, an agricultural-product dryer/cooler **140** operatively coupled to receive the warm, moist product and that outputs cooled product, and a controller operatively coupled to dynamically adjust an amount of heat and/or moisture transferred based on a measured air temperature.

In some embodiments, the processed product includes warm pellets, and the apparatus includes a pellet wetter **135** controlled by the controller and coupled to place water on the warm pellets before the pellets exit the dryer/cooler.

In some embodiments, the apparatus includes a controller **160** operatively coupled to adjust an amount of water deposited by the wetter.

In some embodiments, the apparatus includes a flow controller **155** wherein the controller **160** adjusts an amount of flow of air through the agricultural-product dryer/cooler **140**.

In some embodiments of the invention, the agricultural-product processor is a pellet mill **130** and the agricultural-product dryer/cooler is a pellet dryer/cooler **140**.

In some other embodiments, the agricultural-product processor is an ethanol-processor and the agricultural-product dryer/cooler is an ethanol byproduct dryer/cooler.

In still other embodiments, the agricultural-product processor is a wet-corn starch processor and the agricultural-product dryer/cooler is a dryer/cooler of an output byproduct of wet corn processing.

31

In some embodiments of the invention, the controller **160** controls the flow controller **155** and pellet wetter **135** in order to produce pellets having a moisture content of about 15 percent.

In some embodiments, a moisture transfer is about two points and steam adds about two points of water.

In some embodiments, the apparatus includes a mixer **145** controlled by the controller **160** and operatively coupled to the warm, moist exhaust to add a controlled amount of dry, heated air and a controlled amount of moisture based on temperature of the exhaust **93**.

Another aspect of the invention, in some embodiments, includes an apparatus **100** including a steam conditioner **125** that adds heat and moisture to an incoming mash, an agricultural-product processor **130** coupled to receive the heated, moisturized mash and generate hot, moist processed product, and means for recovering heat and moisture from pellets and transferring the heat and moisture to an incoming material stream to produce the incoming mash.

In some embodiments, the apparatus includes means for placing water on the warm pellets before cooling in order to improve a pellet durability index (PDI).

In some embodiments, the apparatus includes means for adding a variable amount of dry heated air based on temperature of exhaust air.

In some embodiments of the invention, the apparatus includes means for varying a flow of air in the cooling of the pellets.

In some such embodiments, the means for varying the flow rate bases the lowered flow rate on a lowered ambient air temperature.

In some embodiments, the apparatus includes means for controlling by a controller coupled to receive one or more measured parameters and generating one or more control signals to control one or more of the transferring, steam conditioning, processing, and cooling.

In some embodiments of the invention, the means for processing of the steam-conditioned material includes fermenting and the processed product includes ethanol.

In some embodiments, the apparatus includes means for providing raw material, grinding the raw material to produce mash, and mixing one or more rations into the mash to produce the incoming agricultural material, wherein the processing includes pelletizing.

In some embodiments of the invention, the apparatus includes means for cyclone cleaning of the warm, moist exhaust air used in the transferring of heat to the incoming material.

In some embodiments, the means for transferring of heat and moisture adds about two points of water and wherein steam conditioning adds about two points of water.

In some embodiments of the invention, the means for recovering heat and moisture includes controlling the means for adjusting one or more parameters.

In some embodiments, the means for recovering heat and moisture includes counter-flow means for extracting heat from a cooling product and inserting heat and moisture to the incoming product.

It is to be understood that the above description is intended to be illustrative, and not restrictive. Although numerous characteristics and advantages of various embodiments as described herein have been set forth in the foregoing description, together with details of the structure and function of various embodiments, many other embodiments and changes to details will be apparent to those of skill in the art upon reviewing the above description. The scope of the invention should be, therefore, determined with reference to the

32

appended claims, along with the full scope of equivalents to which such claims are entitled. In the appended claims, the terms "including" and "in which" are used as the plain-English equivalents of the respective terms "comprising" and "wherein," respectively. Moreover, the terms "first," "second," and "third," etc., are used merely as labels, and are not intended to impose numerical requirements on their objects.

What is claimed is:

1. A method comprising:

spraying a controlled amount of water into a stream of warm, moist exhaust air;

transferring heat and moisture from the stream of warm, moist exhaust air to incoming agricultural material after the spraying of water into the stream of warm, moist exhaust air;

steam conditioning the material;

processing the steam-conditioned material into warm processed product, wherein the processing of the steam-conditioned material includes forming the steam-conditioned material into a form different than that of the steam-conditioned material before the forming; and

cooling the warm processed product with air to produce the warm, moist exhaust air used in the spraying and the transferring of heat and moisture to the incoming agricultural material and to produce cooled processed product, wherein the cooled processed product is at a temperature lower than a temperature of the warm, moist exhaust air.

2. A method comprising:

transferring heat and moisture from a warm, moist exhaust air to incoming agricultural material;

steam conditioning the material;

processing the steam-conditioned material into warm processed product, wherein the processing of the steam-conditioned material includes pelletizing and the processed product includes warm pellets;

cooling the warm pellets with air to produce the warm, moist exhaust air used in the transferring of heat and moisture to the incoming agricultural material and to produce cooled pellets, wherein the cooled pellets are at a temperature lower than a temperature of the warm, moist exhaust air; and

spraying water on the warm pellets before cooling in order to improve a pellet durability index (PDI).

3. A method comprising:

transferring heat and moisture from a warm, moist exhaust air to incoming agricultural material;

steam conditioning the material;

processing the steam-conditioned material into warm processed product, wherein the processing of the steam-conditioned material includes forming the steam-conditioned material into discrete pieces and the processed product includes the discrete pieces;

cooling the warm processed product with air to produce the warm, moist exhaust air used in the transferring of heat and moisture to the incoming agricultural material and to produce cooled processed product, wherein the cooled processed product is at a temperature lower than a temperature of the warm, moist exhaust air; and

adding a controlled amount of dry, heated air based on the temperature of the exhaust air.

4. The method of claim **1**, wherein the forming of the steam-conditioned material includes forming the steam-conditioned material into discrete pieces and the processed product includes the discrete pieces, the method further comprising varying a flow rate of air in the cooling of the discrete pieces.

33

5. The method of claim 4, wherein the flow rate is lowered based on a lower ambient air temperature, wherein slowing airflow allows a greater percent of moisture content.

6. The method of claim 1, further comprising controlling one or more control signals to control one or more of the transferring, steam conditioning, processing, and cooling based on one or more measured parameters.

7. The method of claim 1, wherein the processing of the steam-conditioned material includes fermenting and the processed product includes ethanol.

8. The method of claim 1, further comprising providing raw material, grinding the raw material to produce mash, mixing one or more rations into the mash to produce the incoming agricultural material, wherein the processing includes pelletizing.

9. The method of claim 1, further comprising cyclone cleaning of the warm, moist exhaust air after the warm, moist exhaust air was used in the transferring of heat and moisture to the incoming agricultural material.

10. The method of claim 1, wherein the transferring of heat and moisture adds about two points of water, and wherein the steam conditioning adds about two points of water.

11. The method of claim 1, further comprising measuring a parameter based on heat and moisture content of the warm, moist exhaust air; and controlling the controlled amount of water used in the spraying based at least in part on the measured parameter.

12. The method of claim 11, wherein the processing of the steam-conditioned material includes pelletizing and the warm processed product includes warm pellets, and further comprising spraying water on the warm pellets before cooling in order to improve a pellet durability index (PDI).

13. The method of claim 11, further comprising adding a controlled amount of dry, heated air based on the temperature of the warm, moist exhaust air.

14. The method of claim 12, further comprising varying a flow rate of air in the cooling of the pellets.

15. The method of claim 14, wherein the flow rate is lowered based on a lower ambient air temperature, wherein slowing air flow allows a greater percent of moisture content.

16. The method of claim 11, further comprising: receiving one or more measured parameters; and generating one or more control signals based at least in part on the one or more measured parameters to control one or more of the transferring, steam conditioning, processing, and cooling.

17. The method of claim 11, wherein the processing of the steam-conditioned material includes fermenting and the processed product includes ethanol.

18. The method of claim 11, further comprising providing raw material, grinding the raw material to produce mash, mixing one or more rations into the mash to produce the incoming agricultural material, wherein the processing includes pelletizing.

19. The method of claim 11, wherein the transferring of heat and moisture from the warm, moist exhaust air exhaust stream to the incoming agricultural material produces cooled, dried exhaust air, the method further comprising cyclone cleaning of the cooled, dried exhaust air produced by the transferring of heat and moisture to the incoming agricultural material.

20. The method of claim 11, wherein the transferring of heat and moisture adds about two points of water and wherein the steam conditioning adds about two points of water.

21. The method of claim 1, wherein the processing of the steam-conditioned material into warm processed product

34

includes pelletizing the steam-conditioned material into warm pelletized product, and applying a controlled amount of water to the warm pelletized product, the method further comprising

measuring a moisture amount that results from the cooling of the warm pelletized product, and based on the measurement, controlling the controlled amount of water used in the applying of the controlled amount of water.

22. The method of claim 1, wherein the processing of the steam-conditioned material into warm processed product includes pelletizing the steam-conditioned material into warm pelletized product, and applying a controlled amount of water to the warm pelletized product, wherein the applying of the controlled amount of water to the warm pelletized product includes spraying an amount that brings the resulting pelletized product to a moisture content of approximately fifteen percent (15%).

23. The method of claim 2, further comprising varying a flow rate of air in the cooling of the warm pellets.

24. The method of claim 23, wherein the flow rate is lowered based on a lower ambient air temperature, wherein slowing airflow allows a greater percent of moisture content.

25. The method of claim 2, further comprising controlling one or more control signals to control one or more of the transferring, steam conditioning, processing, and cooling based at least in part on one or more measured parameters.

26. The method of claim 2, further comprising: providing raw material; grinding the raw material to produce mash; and mixing one or more rations into the mash to produce the incoming agricultural material.

27. The method of claim 2, further comprising cyclone cleaning of the warm, moist exhaust air after the warm, moist exhaust air was used in the transferring of heat and moisture to the incoming agricultural material.

28. The method of claim 2, wherein the transferring of heat and moisture adds about two points of water, and wherein the steam conditioning adds about two points of water.

29. The method of claim 2, further comprising: measuring a parameter based on a wet-bulb-temperature of the warm, moist exhaust air; and spraying a controlled amount of water into the warm, moist exhaust air based at least in part on the measured parameter.

30. The method of claim 29, further comprising adding a controlled amount of dry, heated air based on the temperature of the warm, moist exhaust air.

31. The method of claim 29, further comprising varying a flow rate of air in the cooling of the pellets.

32. The method of claim 31, wherein the flow rate is lowered based on a lower ambient air temperature, wherein slowing air flow allows a greater percent of moisture content.

33. The method of claim 29, further comprising: receiving one or more measured parameters; and generating one or more control signals to control one or more of the transferring, steam conditioning, processing, and cooling based at least in part on the one or more measured parameters.

34. The method of claim 29, further comprising: providing raw material; grinding the raw material to produce mash; and mixing one or more rations into the mash to produce the incoming agricultural material.

35. The method of claim 29, wherein the transferring of heat and moisture from the warm, moist exhaust air exhaust stream to the incoming agricultural material produces cooled,

35

dried exhaust air, the method further comprising cyclone cleaning of the cooled, dried exhaust air produced by the transferring of heat and moisture to the incoming agricultural material.

36. The method of claim 29, wherein the transferring of heat and moisture adds about two points of water and wherein the steam conditioning adds about two points of water.

37. The method of claim 2, further comprising measuring a moisture amount that results from the cooling of the warm pellets, and based on the measurement, controlling the spraying of water on the warm pellets.

38. The method of claim 2, wherein the spraying of water on the warm pellets includes spraying an amount that brings the resulting pellets to a moisture content of approximately fifteen percent (15%).

36

39. The method of claim 1, wherein the steam-conditioned material includes a mash and the forming includes pelletizing the mash into pellets and the processed product includes the pellets.

40. The method of claim 1, wherein the steam-conditioned material includes a steamed grain and the forming includes steam flaking the steamed grain into flakes and the processed product includes the flakes.

41. The method of claim 1, wherein the steam-conditioned material includes a steamed grain and the forming includes steam rolling the steamed grain into rolled grain.

* * * * *