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(54) Title: PROCESS AND APPARATUS FOR COMMERCIALLY PRODUCING MOTOR FUEL-GRADE ETHANOL

(57) Abstract: Process for producing fuel-grade ethanol in which a mixture of approximately 95 volume % ethanol and 5 volume % is distilled in a vacuum retort in a pressure range of 0.145 atmospheres to 0.110 atmospheres, while the minimum boiling point remperature of the azeotrope is controlled in the range of 34.28°C to 32.34°C. The process of the present invention has very low energy requirements as compared to commercially known processes for producing fuel-grade ethanol. Accordingly, the corn stover from only the cob and shucks of the associated ear of cord provides, not only the amount of energy necessary to convert the grain of each ear into fuel-grade ethanol but also at least 33 % more energy than is necessary for the energy requirements of the entire process. Through cogeneration, the additional or excess energy provided by the cob and shucks of each ear may be used to produce co-product electricity for sale to a commercial utility's electrical grid. Thus, the entire system for producing fuel-grade ethanol described herein is self-sufficient.

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PROCESS AND APPARATUS FOR COMMERCIALLY PRODUCING MOTOR FUEL-GRADE ETHANOL

FIELD OF THE INVENTION

[0001] This application relates to a commercial, industrial process for making anhydrous and/or premium quality motor fuel-grade ethanol solely from the feedstock and energy provided by ears of corn including the cob, grain, and shuck. More specifically, the present invention provides a commercial, industrial process for producing at least 99.19 weight % motor fuel-grade ethanol, by distilling a mixture of approximately 95 volume % ethanol and 5 volume % water at very low pressures and at predictable associated minimum boiling point temperatures.

BACKGROUND OF THE INVENTION

[0002] According to Fuel Ethanol Industry Guidelines, Specifications, and Procedures: Fuel-Grade Ethanol should not typically be below 197 proof (98.5 volume % ethanol, 97.6 weight % ethanol) prior to denaturing.

[0003] Heretofore, the practice of using agricultural refuse, specifically, corn stover, as fuel for an industrial boiler, has not been economically feasible. All efforts in the area have been directed at the concepts of utilizing all of the corn stover associated with a crop, including the stalk, since it was not heretofore discovered that the cobs and the shucks alone would produce enough energy to power any known commercial, industrial ethanol producing processes. The use of the, “whole stalk” corn stover was not economically feasible for at least the following reasons: additional expensive machinery would be required to harvest, bail, and transport the stover; the procedure would be very costly in terms of time and fuel for the farmer; the land would be stripped of its nutrients as a result of continued harvesting of the whole corn stalk; and the projected price per unit volume of corn stover would be an insufficient return for the farmer and prohibitive for the industry in need of fuel.

[0004] Accordingly, the “whole stalk” concept of utilizing corn stover has proven to be too expensive and inefficient for the reasons set forth above. In continued pursuit of a simple agricultural procedure to supply both fuel (corn stover) and feedstock from grain corn for making anhydrous ethyl alcohol (anhydrous ethanol), we have discovered a commercial, industrial process for producing motor fuel-grade to anhydrous ethanol with energy requirements low enough to make it feasible to utilize only the cob and shuck portions of each ear of corn from which the grain is derived.

[0005] In typical processes known heretofore for making fuel-grade ethanol, grain, such as corn, is converted into a "beer" feedstock containing about 10% ethanol by volume from conventional fermentation processes. The "beer" containing 10% ethanol by volume is then inserted into a distillation column which is heated with steam so that a precise boiling point is maintained at the top of the column. Therefore, the end result in the distillation column is the emission of nondehydrated ethanol vapor from the top of the column. This nondehydrated ethanol vapor is a mixture of approximately 95 volume % ethanol and 5 volume % water. Since minimum motor fuel-grade ethanol requires at least 98.5 % ethanol by volume (97.6 weight % ethanol), it is necessary to dehydrate the mixture to achieve this percentage of ethanol.

[0006] Atmospheric fractional distillation of ethanol/water mixtures produces a minimum boiling-point azeotrope. Therefore, conventional commercial processes in the past have effected this dehydration by the use of azeotropic distillation or molecular sieve technologies. Azeotropic distillation incorporates hydrocarbon strippers, such as benzene or diethyl ether, which are used to entrain the mixture in a dehydration tower to effectively remove and strip the required amounts of water from the mixture. Commercial processes of the type described require well over 22,000 BTU's per gallon in the boilers of the distillation columns. In addition, the drying agents, such as benzene and other hydrocarbons, have been deemed hazardous materials by the Environmental Protection Agency, and the use of such materials has been discouraged for fear of contamination of the environment. Molecular Sieves contain Zeolite beads (synthetic, highly ordered aluminosilicates) or corn grits. Like Zeolite beads having very precise pore sizes, corn grits have also been found to be equally adsorptive with respect to the water molecules of the ethanol/water azeotrope. The porous openings are very small void spaces, on the molecular scale, and are usually measured in Angstroms or nanometers. Water molecules have a molecular diameter, which is small enough to allow them to fit into the pore spaces of molecular sieve's packing medium. However, the molecular diameter of ethanol molecules is larger than that of water molecules, too large in fact for ethanol molecules to fit into the pore spaces of the adsorptive medium of molecular sieves. It is this size-sorting property of the Zeolite beads and corn grits that is responsible for the "sieve" term in the descriptive name, molecular sieve. This basic, separative principle of molecular sieve technologies provides the basis for the dehydration of ethanol in this prior process art form.

[0007] As molecular sieve technologies are implemented in commercial production of anhydrous ethanol, two molecular sieves are usually employed in order to provide for a continuous operation of the process. Pressurized, superheated nondehydrated ethanol vapor in a mixture of approximately 95 volume % ethanol and 5 volume % water is forced into a tank containing a bed of molecular sieve adsorbent packing medium. The ethanol water mixture passes over the adsorbent medium and the pressure forces the water into the pores of the adsorbent medium where it is trapped within the internal cavities. The ethanol, being too large to enter the pores, passes over the adsorbent medium and through the bed leaving the water behind. This anhydrous ethanol is cooled back to a liquid where it is sent to storage tanks ready for further processing. Once the sieve has adsorbed its working capacity of water, the superheated ethanol flow is diverted to a second, dry molecular sieve and the first molecular sieve put under vacuum for regeneration. The pressure drop with the vacuum pulls out the adsorbed water thereby regenerating the packing medium of the molecular sieve so it is dry and ready to pull more water out of additional nondehydrated ethanol vapor.

[0008] While molecular sieve technologies are much superior to the azeotropic distillation method described above, and even though energy recovery systems can minimize net energy cost, the process remains very energy intensive. An additional concern in using molecular sieve technologies is that the high pressure anhydrous ethanol vapors produced are highly flammable and catastrophic molecular sieve tank rupture is a legitimate safety concern.

[0009] Thus, a need in the art exists for a commercial, industrial process of making motor fuel-grade to anhydrous ethanol with low energy requirements, one which does not need to employ potentially harmful drying agents to effect sufficient dehydration of ethanol/water azeotropes and one which may be accomplished without imposing legitimate safety concerns as those associated with prior art molecular sieve technologies.

[0010] Further, in the commercial, industrial production of dewatered ethanol by vacuum dehydration, good vapor-liquid contact is essential to the establishment of a vapor-liquid equilibrium from the bottom to the top of the dehydrating retort. Conventionally, this has been accomplished by installing various plates in ascending order within the column. However, the use of plates brings about such a severe pressure differential from the top to the bottom of the retort that their use in a vacuum dehydration unit is impractical. Reduced pressure drop may be realized if column packing material is used in place of the plates. However, in this instance, vapor-liquid contact is not homogeneous in any cross-sectional area of the packing material due to preferred channeling of the vapor and liquid through the packing. The net result is that vacuum dehydration utilizing the packed column approach has also been determined to be impractical for commercial, industrial production of anhydrous ethanol.

SUMMARY OF THE INVENTION

[0011] The present invention provides a system for the commercial, industrial production of dehydrated ethanol of premium quality fuel-grade to anhydrous quality by vacuum dehydration which will overcome the above-stated disadvantages and other historically perceived obstacles. The present invention provides a system for commercially and industrially producing premium quality motor fuel-grade ethanol containing, at least 99.5 % ethanol by volume (99.19 weight % ethanol), which utilizes substantially less energy than conventional industrial process equipment.

[0012] The present invention provides a commercial and industrial process for producing ethanol which may be fueled utilizing only the shuck and cob of the ears of corn from which the grain is derived for the feedstock of the process. The present invention provides a method of commercially, and industrially producing fuel-grade to anhydrous ethanol wherein the dehydration of ethanol/water mixtures requires no dehydrating agent such as benzene which may have harmful effects on the environment.

[0013] The present invention provides a system for continuously maintaining the proper operating parameters for commercially, and industrially distilling an ethanol mixture at low pressures in order to dehydrate or remove undesired quantities of water.

[0014] The present invention provides a vacuum dehydration unit for commercially, and industrially producing fuel-grade dehydrated ethanol which eliminates the use of plates and packing material while, at the same time, achieving particularly good vapor-liquid contact resulting in a vapor-liquid equilibrium throughout the retort so as to produce industrial flow rates of fuel-grade to anhydrous ethanol. The present invention provides a vacuum dehydration unit for commercially, and industrially producing fuel-grade to anhydrous ethanol without the need for or the use of molecular sieve technologies. The present invention provides a vacuum dehydration unit for commercially and industrially producing fuel-grade to anhydrous ethanol which requires less capital expense, less operating energy and is easier and safer to operate and maintain than conventional industrial process equipment.

[0015] The foregoing and other embodiments of the present invention are accomplished, generally speaking, by providing a vacuum dehydration retort into which approximately a 95 volume % and 5 volume % mixture of ethanol and water, respectively, is introduced. The mixture is distilled in this vacuum retort at sufficiently low pressures, and at minimum boiling point temperatures, so as to produce the desired percentage of ethanol required in the final product which is removed from the top of the vacuum retort as a vapor. At the optimum operating pressures in the vacuum retort, the vapor-liquid equilibrium and retort temperatures are regulated thermodynamically via computer process-quality control. Sufficient heat input is supplied to the liquid reflux in the base of the vacuum retort to insure vapor boil-up rates necessary to produce vapor product flow rates consistent with yielding desired industrial production volume flow rates of fuel-grade to anhydrous ethanol. A heat-removal unit, positioned within the vacuum retort as a fine tube coil serves to maintain a carefully controlled thermal gradient from the surface of the reflux in the retort to the head of the retort and from the feed entry point into the retort to the head of the retort.

[0016] The present invention achieves particularly good vapor-liquid contact resulting in a vapor-liquid equilibrium from the bottom to the top of the retort without using plates of any kind. There is little or no pressure drop within the retort due to the fact that there is no packing material or plates to obstruct the ascending vapor and descending liquid reflux.

[0017] The vacuum dehydration technique for dewatering ethanol mixtures according to the present invention requires much less energy to fuel the conversion process than required in hydrocarbon stripper or molecular sieve processes which are now commercially used. In fact, a BTU analysis of the energy requirements of the process of the present invention confirms that, if one snaps a single ear of corn from the stalk for conversion into ethanol, the BTU's contained in the shuck and cob alone will fuel the entire conversion process of the associated corn kernels for that ear with a 40% overage of energy. Thus, it is feasible to use corn stover, exclusive of the stalks, to fuel the entire industrial process of making fuel-grade to anhydrous ethanol.

[0018] The following is a comparison of the energy requirements in BTU's per gallon required for prior art hydrocarbon stripping ethanol processes, molecular sieve technologies and the vacuum dehydration process of the present invention in producing fuel-grade to anhydrous ethanol:

	Hydrocarbon Stripping	Molecular Sieve	Vacuum Dehydration
i. Distillation Area	12,000	12,000	12,000
ii. Dehydration Section	10,000	4,000	2,272

[0019] As can be seen from the above chart, prior art hydrocarbon stripping processes require a minimum of 22,000 BTU's per gallon of energy for their operation, prior art molecular sieve technologies require at least 16,000 BTU's per gallon of energy for operation, while the vacuum dehydration process of the present invention requires just over 14,000 BTU's per gallon. Perhaps even more significant is the fact that the dehydration section of the prior art hydrocarbon stripping processes require at least four (4) times as many BTU's per gallon as the vacuum dehydration section of the present invention. The prior art molecular sieve technologies require a minimum of almost two (2) times as many BTU's per gallon as the vacuum dehydration section of the present invention. In addition to the energy savings of the process of the present invention, it is estimated that a significant savings could be realized in the construction costs of a plant for practicing the process as compared to the presently used hydrocarbon stripper and molecular sieve processes.

[0020] Furthermore, as stated above, the benzene and other hydrocarbons utilized in the prior art hydrocarbons stripper processes have been deemed hazardous materials by the Environmental Protection Agency. Thus, the development of the process of the present invention, which does not require the use of any such potentially harmful drying agents, is of great benefit to the public interest.

[0021] Also, as stated above, the high pressure anhydrous ethanol vapors produced utilizing prior art molecular sieve technologies are highly flammable and catastrophic molecular sieve tank rupture is a legitimate safety concern. Thus, the development of the process of the present invention, which does not involve the generation of high pressure anhydrous ethanol vapors, is also of great benefit to the public interest.

[0022] As previously stated, the operating parameters of the present invention relating to the vacuum retort of the dehydration section can be predetermined with satisfactory accuracy. For example, by analyzing the results of both actual and projected test data and determining the mathematical relationship between all operating parameters, it has been determined that the following operating parameters for producing a premium quality 99.19 wt. % motor fuel-grade ethanol, up to 100% by weight of ethanol, are as follows:

Minimum -	99.19% by wt. ethanol (99.5 vol. % ethanol) 34.28 degrees C – azeotropic boiling point temperature 0.145 atmospheres pressure in vacuum retort
Reference Example -	99.5% by wt. ethanol 33.40 degrees C - azeotropic boiling point temperature 0.125 atmospheres pressure in vacuum retort
Maximum -	100% by wt. ethanol (100 vol. % ethanol) 32.24 degrees C - azeotropic boiling point temperature 0.110 atmospheres pressure in vacuum retort

[0023] Because of the discoveries of the present invention, there are benefits derived by the farmer, the ethanol industry, and the American people at large. Because of the discovery that only the cob and shuck portions of corn stover associated with each feedstock ear of corn processed are necessary to fuel the entire conversion process of the present invention, the farmer can confidently plant all the corn he desires, being assured of a guaranteed market, a guaranteed price and no drying penalty. Farmers selling corn to the grain market are assessed a drying penalty in the event that their grain arrives at the market too wet. A typical average drying penalty has been approximately $14.00 per ton of grain sold to the market. Increased energy costs will drive this number even higher. At harvest time there is no need for an expensive combine since only the ears of corn need be processed. Once through the field with a conventional corn snapper, loading corn in the shuck into a wagon, the farmer has supplied all of the ingredients necessary for both the feedstock and the fuel to provide the energy requirements of the process of the present invention. The farmer further benefits, since the taking of only the ear of corn returns the remaining stalk to the soil to help maintain nutritional stability thereof.

[0024] Industry benefits from the discoveries of the present invention since it is not necessary to fuel the ethanol plants with high-priced coal, natural gas, or other energy self-defeating, non-renewable fossil fuels. By allowing the farmer an easier, simpler, and more economical harvesting and paying him the going grain price for his corn, industry is purchasing fuel and feedstock simultaneously. This is a unique and heretofore, totally unpracticed renewable energy system. The agricultural industry is rewarded since it has a guaranteed price, no drying penalty and an endless market, and industry benefits since it purchases the fuel and feedstock for the entire process at regular grain prices.

[0025] The country at large benefits since the other forms of expensive energy mentioned heretofore are not being wasted on the production of ethanol, meaning that the country is on the road to energy independence. In addition, the process of the present invention does not use potentially harmful and polluting drying agents in the dehydration section of the ethanol process. The public at large also benefits, since the process of the present invention does not subject anhydrous ethanol vapors to high pressures. Thus, the likelihood of highly flammable, catastrophic safety concerns, associated with previously mentioned prior art technologies, are not present as part of the process of the present invention.

BRIEF DESCRIPTION OF THE DRAWINGS

[0026] The thermodynamic and operational characteristics of the vacuum dehydration process of the present invention and the attendant advantages thereof shall become more readily apparent by using an example production volume of 10,000 gallons per day of premium quality motor fuel-grade ethanol, having a product liquid composition of 98.73 Mole % ethanol and 1.27 Mole % water (99.5 wt. % and 0.5 wt. %), to calculate mass and heat balance figures made reference to in the drawings contained herein. However, it should be acknowledged that production volumes of the process of the present invention may be scaled up or down, in relation to the example, 10,000 gallons per day production volume, without significantly changing or altering the advantages of the thermodynamic and operational efficiencies of the process. In addition to the thermodynamic and operational characteristics, the objects of the present invention and the attendant advantages thereof shall also become more readily apparent by reference to the drawings wherein like reference numerals refer to like parts, and wherein:

Figure 1 is a schematic diagram illustrating the process of the present invention for producing motor fuel-grade to anhydrous ethanol;

Figure 2 is a graph of weight % ethanol versus pressure relating to the vacuum retort;

Figure 3 is a graph of weight % ethanol versus temperature relating to the vacuum retort;

Figure 4 is a graph of temperature versus pressure relating to the vacuum retort;

Figure 5 is a graph of pressure versus temperature versus composition ethanol in the vapor product relating to the vacuum retort;

Figure 6 is a preferred embodiment of a grain receiving, milling, and storage area to be utilized with the system of Figure 1;

Figures 7A and 7B present a diagrammatic heat and mass balance across the vacuum dehydration process of the present invention to be used in conjunction with Figure 8;

Figure 8 is a tabulation of enthalpy data relating to the vacuum retort and to be utilized in reference by the heat and mass balances of Figures 7A and 7B; and

Figure 9 is a diagrammatic representation illustrating rigid-transformation and rotation of axes performed during mathematical modeling and equation development.

DETAILED DESCRIPTION OF THE INVENTION

[0027] Referring in detail to Figure 1, there is illustrated a schematic diagram of a system for incorporating the process of the present invention, generally indicated 20. "Beer" from fermented corn grain, in a fermentation area, having approximately 10% to 12% by weight ethanol is pumped from that fermentation area through condenser preheater 12, and condenser preheater 24 into a prior art stripping and rectifying fractional distillation column 14. Process steam (from the extraction port of a co-generation turbogenerator) is supplied to the stripping and rectification distillation area at Reboiler 16. The process steam flows through Reboiler 16 where it transfers (no live steam comes in contact with the "beer") enough heat to maintain a column head (of distillation column 14) temperature at approximately 87.8°C.

[0028] As a result of distillation in column 14, a mixture of about 93.8% ethanol and 6.2% water by weight (95 volume % and 5 volume %) emerges from point 14E in column 14 and passes through S/R Product cooler 18 where the mixture vapor cools down from 87.8°C to 77.8°C and condenses. Entering from this point the process of the present invention, the mixture flashes into a vacuum retort 20 at the rate of approximately 48.1 pounds or 7.15 gallons per minute and a temperature of approximately 77.8°C. At the optimum operating pressures in the vacuum retort, the vapor-liquid equilibrium and retort temperatures are regulated thermodynamically by computer process-quality control. The vacuum retort, maintained at the preferred reduced pressure, is herein equipped with a heat-removal system (internal cooling coil). The purpose of the heat-removal system is to maintain a carefully controlled temperature gradient from the surface of the liquid reflux in the bottom of the retort 20 (51°C or higher as necessary) to the head of the retort (33.4°C) such that the head temperature is maintained equal to the appropriate minimum boiling point temperature, and from the feed entry point into the retort (77.8°C) to the retort head (33.4°C). Computer process-quality control of the removal of heat from the vacuum dehydration unit provides an internal temperature gradient so that sufficient heat-input, supplied to liquid reflux in the base of the vacuum retort, insures vapor boil-up rates, causing vapor product flow rates, consistent with producing industrial volumes of fuel-grade to anhydrous ethanol. The cooling medium for the heat-removal system within the vacuum retort is herein represented as chilled water. However, any suitable coolant may be utilized such as carbon dioxide, especially if CO_2 is being captured during a fermentation process.

[0029] The liquid reflux in the bottom of the retort 20 is returned to the prior art stripping and rectification column 14 at approximately 2.8 pounds (0.33 gallons) per minute, at a point 14R appropriate for its composition.

[0030] A vacuum pump 36 is provided in series with a condenser 32. Also provided in the bottom of vacuum retort 20 is a recirculating pump 38 which recirculates out of the bottom of the vacuum retort 20 liquid which is a reflux mixture made up predominantly of water with some residual ethanol. This reflux in the bottom of retort 20 is pumped back to the stripping and rectification column 14 at approximately 2.8 pounds (0.33 gallons) per minute, at a point 14R appropriate for its composition. In a preferred embodiment the pressure within the vacuum retort 20 is maintained at approximately 95.0 m.m. of mercury, or 0.125 atmospheres.

[0031] The temperature gradient within the vacuum retort 20 maintains a bottom temperature within the retort of 51.0°C and a head temperature within the vacuum retort 20 equal to the corresponding minimum boiling point of 33.4°C. As the incoming mixture is 77.8°C, additional heat input is required for the production of industrial product flow rates during the dehydration phase of distillation. At 0.125 atmospheres (within the vacuum retort 20), the mixture flashes upon entrance to the vacuum retort. As rising vapors encounter the temperature gradient, the less volatile component (water) condenses, allowing the rising vapors to become enriched in the more volatile component (ethanol). The quantity of heat supplied to the liquid in the bottom of the vacuum retort is modified sufficiently to insure a vapor boil-up rate consistent with the desired industrial product flow rates. With the establishment of the vapor-liquid equilibrium, the necessary vapor boil-up rate and the predetermined and carefully controlled thermal balance throughout the vacuum retort, the refluxing condensate literally rains down inside the vacuum retort in intimate contact with the ascending vapor. As will be discussed further hereinafter, these are considered to be optimum operating parameters, although other parameters may be utilized at acceptable operating ranges. Under these conditions, vapor having a composition of approximately 99.5 weight % ethanol and 0.5 weight % water is removed from the top of the vacuum retort 20 and flows through the product condenser cooler 32, and is quick-cooled to a temperature of about 12.8°C. From there it passes at the rate of approximately 6.82 gallons per minute (45.34 pounds per minute) into an "anhydrous" ethanol storage area.

[0032] The effectiveness of the vacuum dehydration unit herein described is realized as a result of computer process-quality control of the heat-removal system which produces, maintains, and allows for the necessary thermodynamic heat balance which further allows the vapor-liquid equilibrium to exist at the system vacuum pressure without plates or packing. Enough of a predetermined and controlled amount of heat is added to the liquid reflux in the bottom of the vacuum retort so as to insure the necessary vapor boil-up rate to provide the desired industrial product flow rates of anhydrous ethanol. There are liquid or leak-free seals provided at the feed entry into the retort, at the liquid reflux pump-out from the bottom of the retort and at the opening of the product vapor discharge line submerged below the condensed ethanol product surface level, within the final product condenser. Once the preferred operational vacuum pressure is achieved and the process of the present invention is at steady state operating conditions, the vacuum source will cycle on and off in response to internal pressure sensors in order to maintain the vacuum pressure constant.

[0033] The system of the present invention also contemplates the reuse of products of the distillation process by providing reboilers, condensers, and similar recirculation loops for reclaiming heat to and from the process respectively. For example, a vent condenser 22 is provided adjacent condenser preheater 12 for receiving vapor vented there from, and recirculating the same into the system. In addition, flash drum 26 is coupled to condenser 24 for recirculating excess heat through the system. A series of pumps 38, 40, 42, and 44 are appropriately provided for causing the aforementioned recirculation of fluids.

[0034] As stated above, the present invention also provides for the determination of the preferred operating ranges or parameters associated with vacuum retort 20 to maintain a thermodynamic balance, based not only on test results but also on projections of preferred operating parameters from a discovered mathematical relationship between the various operating parameters. For example, it has been determined, as part of the present invention that, for achieving premium quality 99.19% by weight motor fuel-grade ethanol, the optimum minimum boiling point temperature within the head of vacuum retort 20 should be 34.28°C and the associated operating pressure within the retort should be 0.145 atmospheres. In addition, for achieving 99.5% by weight ethanol, the optimum minimum boiling point temperature within the head of retort 20 is 33.4°C, and a preferred associated operating pressure within the retort 20 is 0.125 atmospheres. Following the same reasoning, it has been determined that 100% by weight, anhydrous, ethanol can be optimally achieved by maintaining a 32.24°C minimum boiling point temperature within the head of retort 20 and an associated operating pressure within the retort of 0.110 atmospheres.

[0035] As a result of empirical studies performed, it has been established that, as a vacuum is drawn on a retort containing an ethanol-water mixture, not only does the "constant" minimum boiling point decrease, but the vapor component of the "constant" minimum boiling point azeotropic mixture increases in the weight percentage of ethanol. The relationships involving the vapor component weight percent ethanol, pressure, and "constant" azeotropic minimum boiling point temperature have been developed and quantified into a unique equation that precisely models, mathematically, this phenomenon.

[0036] The variables vapor component weight % ethanol, pressure, and temperature have been plotted against each other as vapor component weight % ethanol versus pressure, pressure versus temperature, and vapor component weight % ethanol versus temperature. In so doing, two-dimensional relationships have been extended into three dimensions, vapor component weight % ethanol versus temperature versus pressure. As a result of this graphic representation and the application of curve-fitting techniques, an equation has been derived which provides for the precise computation, for example, of the "constant" minimum boiling point and associated pressure given the desired binary azeotropic weight percentage ethanol in the azeotropic mixture's vapor component.

[0037] Referring to Figure 2, there is represented a graph of vapor component weight % ethanol versus pressure (P). The z_n or vapor component weight % ethanol axis has its origin at $z_n - 95$. It was determined that, if the z_n axis is reduced to the scale where, $Z_n = z_n - 95$, the curve approximates that of an equilateral or rectangular hyperbola. The Z_n and x_n axes represent the vertical and horizontal asymptotes, respectively. The data is recorded in Table 1.

[0038] Table 1

n	0	1	2	3	4	5
x_n,(atm.)	0	0.125	0.526	1.000	1.447	3.000
z_n,(wt%)	---	99.500	96.452	95.583	95.523	95.200
Z_n	---	4.500	1.452	0.583	0.523	0.200

[0039] Figure 3 represents a plot of Z_n or $z_n - 95$ versus Temperature (T_n), wherein $T_n = \ln(y_n - 30)$; y_n(°C) is the "constant" minimum boiling point from n=1 to n=5. There exists a near linear relationship between Z_n and T_n. The data is recorded in Table 2.

[0040] Table 2

n	1	2	3	4	5
z_n,(wt%)	99.500	96.452	95.583	95.523	95.200
Z_n	4.500	1.452	0.583	0.523	0.200
y_n,(°C)	33.400	62.800	78.150	87.300	109.000
T_n	1.223775432	3.490428515	3.875359021	4.056988776	4.369447852

[0041] Plotting pressure (atm.) versus $T_n(\ln(y_n - 30))$ represented in Figure 4, when certain translational and rotational modifications are made of the plot, it will appear as an equilateral hyperbola in the first quadrant. The data for Figure 4 is recorded in Table 3.

[0042] Table 3

n	1	2	3	4	5
x_n,(atm.)	0.125	0.526	1.000	1.447	3.000
y_n,(°C)	33.400	62.800	78.150	87.300	109.000
T_n	1.223775432	3.490428515	3.875359021	4.056988776	4.369447852

[0043] Combining the three graphic illustrations displays a three-dimensional plot of vapor component weight % ethanol versus temperature versus pressure, which is represented as Figure 5. This 2-D graphic relationship provides a visual representation of the three variables composition, pressure, and temperature. The relationship between pressure and temperature, depicted in Figure 4, is represented as visually seen from atop the Z_n axis, looking down on the plane of the x_n and T_n axes.

[0044] In deriving the mapping equation or mathematical relationship between the various operating parameters, it is assumed that there are three equations which relate (1) pressure to vapor component weight (wt.) % ethanol, (2) pressure to temperature, and (3) vapor component weight % ethanol to temperature. Thus, it follows that an equation may be established which will map any one variable in terms of the other two.

<u>Pressure, (x_n) versus wt.% Ethanol, $(Z_n = z_n - 95)$</u>

[0045] For a power function (Power Function: $Z_n = a_1 (x_n)^{b_1}$ or $\log Z_n = (\log a_1) + b_1 \log x_n$) fit by method of least squares, the values $\log a_1$ and b_1 are obtained by fitting a straight line to the set of ordered pairs $\{(\log x_n, \log Z_n)\}$ where, $Z_n = z_n - 95$, such that the slope b_1 is -0.9722022159, and the $\log Z_n$ intercept, $\log a_1 = -0.1857997585$ such that, $anti \log a_1 = 0.6519289117 = a_1$.

$Z_n = a_1 (x_n)^{b_1} = \dfrac{A^2}{2x_n}$, is the equation form of the equilateral hyperbola. For $n = 1$, Z_n must equal 4.5, which equals, $(z_n - 95)$; refer to Table 4.

[0046] Table 4

n	x_n	log x_n	Z_n	log Z_n
1	0.125	-0.903089987	4.500	0.6532125138
2	0.526	-0.2790142558	1.452	0.1619666164
3	1.000	0.0	0.583	-0.2343314452
4	1.447	0.1604685311	0.523	-0.2814983111
5	3.000	0.4771212547	0.200	-0.6989700043

[0047] However, $a_1\left(x_n\right)^{b_1}$ must be multiplied by a constant (C) in order to equal 4.5. Thus, $C\left(a_1\left(x_n^{b_1}\right)\right)=4.5$, where $C=0.9141683595$, $n=1$ and a_1, b_1 are given above. So, $z_n-95=Ca_1x_n^{b_1}$ and $\log\left(z_n-95\right)=\log Ca_1+b_1\log x_n$ or, $\log\left(z_n-95\right)=\log C+\log a_1+b_1\log x_n$. Also, $\log(x_n)=\frac{\log(z_n-95)-\log(Ca_1)}{b_1}$

or, $x_n=10^{\left[\frac{\log(z_n-95)-\log(Ca_1)}{b_1}\right]}$.

Temperature versus wt. % Ethanol

[0048] In this case, linear regressions are run on $\ln\left(y_n-30\right)$ versus z_n-95 from n=1 to n=2; n=2 to n=3; n=3 to n=4; n=4 to n=5.

[0049] As such, we have: $z_n=\left[\left(a_{n3}+b_{n3}\left(\ln\left(y_n-30\right)\right)\right)+95\right]$

or, $y_n=e^{\left[\frac{(z_n-95)-a_{n3}}{b_{n3}}\right]}+30$

∴

n	y_n	z_n
1	33.4	99.5
2	62.8	96.452
3	78.2	95.583
4	87.8	95.523
5	109.0	95.20

$a_{13}=6.145627884$
$b_{13}=-1.344713941$

$a_{23}=9.331818148$
$b_{23}=-2.257550359$

$a_{33}=1.863195221$
$b_{33}=-0.3303423537$

$a_{43}=4.716852825$
$b_{43}=-1.033735378$

These correction factors are used as indicated when within applicable ranges of n.

b_{n3}
where n=1, 2, 3, 4 are all negative values.

[0050] Note that $z_n - 95 = a_{n3} + b_{n3}\left[\ln(y_n - 30)\right]$ and,

$\log(z_n - 95) = \log\left[a_{n3} + b_{n3}\left(\ln(y_n - 30)\right)\right]$.

[0051] Substituting for $\log(z_n - 95)$ from pressure versus weight %,

$\log C + \log a_1 + b_1 \log x_n = \log\left[a_{n3} + b_{n3}\left(\ln(y_n - 30)\right)\right]$, wherein

$\log Ca_1 = \log C + \log a_1$, such that, $Ca_1\left(x_n^{b_1}\right) = a_{n3} + b_{n3}\left[\ln(y_n - 30)\right]$, or

$$Ca_1\left[10^{\left[\frac{\log(z_n-95)-\log(Ca_1)}{b_1}\right]}\right]^{b_1} = a_{n3} + b_{n3}\left[\ln(y_n - 30)\right].$$

Solving for y_n :

$$\frac{Ca_1\left[10\left[\frac{\log(z_n-95)-\log(Ca_1\ )}{b_1}\right]\right]^{b_1} - a_{n3}}{b_{n3}} = \ln(y_n - 30)$$

$$e^{\left[\frac{Ca_1\left[10^{\left[\frac{\log(z_n-95)-\log(Ca_1)}{b_1}\right]}\right]^{b_1} - a_{n3}}{b_{n3}}\right]} + 30 = y_n$$

Pressure vs. Temperature

[0052] Up to this point, pressure and "constant" minimum boiling point temperature have been derived separately in terms of the weight percentage ethanol. It is now appropriate to introduce the relationship of pressure versus temperature. Referring back to the graph illustrated in Figure

4, it was stated that with some rigid-transformation and rotation of axes, the curve would appear as an equilateral hyperbola. The rigid-transformation and rotation of axes are performed according to the diagrammatic representations, (A), (B), (C) and (D) of Figure 9.

[0053] In (A) of Figure 9 is seen a diagrammatic representation of the 3-D graph from Figure 5. Of main attention is the x versus T curve. The next few steps concern the rigid-transformation of this particular curve such that it will appear as an equilateral hyperbola in a first quadrant space.

[0054] To begin with, (1) the first rotation (90° about the T-axis) as indicated from diagram (A) to diagram (B) involves no change in data. Therefore, the first effective operation will be translation (2) of the x-axis to x'-axis as in from diagram (B) to diagram (C).

[0055] Translation of axes:

$x'_n = x_n - k = x_n$, wherein $k = 0$, and

$T'_n = \ln(y_n - 30) - h$, wherein $h = 4.62$.

The final operation (3) involves rotation of the T'-axis, 180° about the x'-axis. The plot will occupy the space as in (D).

[0056] Rotation of axes:

$x'_n = x''_n$; $T'_n = Z''_n \sin\theta + T''_n \cos\theta$; $Z'_n = Z''_n \cos\theta - T''_n \sin\theta$, where $\theta = 180^\circ$ and T_n is of main importance. Thus, $x''_n = x'_n = x_n$ and

$T''_n = (T'_n - Z'_n \sin\theta)(\cos\theta)^{-1} = (\ln(y_n - 30) - h)(\cos 180^\circ)^{-1}$, wherein $\sin\theta = zero$, when $\theta = 180^\circ$.

[0057] Power Function: $x_n = a_2\left[(\ln(y_n - 30) - h)(\cos 180^\circ)^{-1}\right]^{b_2}$, or

$\log x_n = \log a_2 + b_2 \log\left[(\ln(y_n - 30) - h)(\cos 180^\circ)^{-1}\right]$.

[0058] As in pressure versus weight % ethanol, for a power function fit by the method of least squares, the values $\log a_2$ and b_2 are obtained by fitting a straight line to the set of ordered pairs $\{\left(\log\left[(\ln(y_n - 30) - h)(\cos 180^\circ)^{-1}\right], \log x_n\right)\}$ such that the slope

$b_2=-1.249499407$, and the $\log x_n$ intercept $\log a_2 = -0.2065312604$;

$anti\log a_2 = 0.6215395079 = a_2$.

$$x_n = a_2\left[\left(\ln\left(y_n-30\right)-h\right)\left(\cos 180^\circ\right)^{-1}\right]^{b_2} = \frac{A^2}{2\left[\left(\ln\left(y_n-30\right)-h\right)\left(\cos 180^\circ\right)^{-1}\right]}$$

.

The above is in the equation form of an equilateral hyperbola.

$$x_n\left[\left(\ln\left(y_n-30\right)-h\right)\left(\cos 180^\circ\right)^{-1}\right] = \frac{A^2}{2} =$$

	n
0.4245280710	1
0.5941546009	2
0.7446409769	3
0.9146772416	4
0.7516564426	5

$$x_n = \frac{A^2}{2\left[\left(\ln\left(y_n-30\right)-h\right)\left(\cos 180^\circ\right)^{-1}\right]} = a_2\left[\left(\ln\left(y_n-30\right)-h\right)\left(\cos 180^\circ\right)^{-1}\right]^{b_2}$$

$\therefore$

$$\frac{A^2}{2} = \left[\left(\ln\left(y_n-30\right)-h\right)\left(\cos 180^\circ\right)^{-1}\right]\left[a_2\left[\left(\ln\left(y_n-30\right)-h\right)\left(\cos 180^\circ\right)^{-1}\right]^{b_2}\right]$$

.

As in pressure versus weight % ethanol, $a_2\left[\left(\ln\left(y_n-30\right)-h\right)\left(\cos 180^\circ\right)^{-1}\right]^{b_2}$, must be multiplied by an empirical correction coefficient (D) that changes as n ranges from 0 through 5 such as:

$$D\left[\left[\left(\ln\left(y_n-30\right)-h\right)\left(\cos 180^\circ\right)^{-1}\right]\left[a_2\left[\left(\ln\left(y_n-30\right)-h\right)\left(\cos 180^\circ\right)^{-1}\right]^{b_2}\right]\right]$$

, wherein

$$D = \begin{array}{l|l} 0.926661158 & 0 \le n \le 1 \\ 0.9854456272 & 1 < n \le 2 \\ 1.11308679 & 2 < n \le 3 \\ 1.135719277 & 3 < n \le 4 \\ 0.8562016973 & 4 < n \le 5 \end{array}$$

such that,

$$x_n = \frac{D\left[\left[\left(\ln\left(y_n-30\right)-h\right)\left(\cos 180^\circ\right)^{-1}\right]\left[a_2\left[\left(\ln\left(y_n-30\right)-h\right)\left(\cos 180^\circ\right)^{-1}\right]^{b_2}\right]\right]}{\left[\left(\ln\left(y_n-30\right)-h\right)\left(\cos 180^\circ\right)^{-1}\right]}$$

wherein,

$$y_n = e\left[\frac{Ca_1\left[10\left[\frac{\log\left(z_n-95\right)-\log Ca_1}{b_1}\right]\right]^{b_1}-a_{n3}}{b_{n3}}\right]+30$$

, as developed in the case of temperature versus weight % ethanol.

[0059] The equation, $x_n = f\left(y_n\right) = f\left(z_n\right)$, as previously developed herein, maps the relationships graphically depicted in Figure 5. Given any one of the three variables of vapor product weight % ethanol, pressure, or "constant" minimum boiling point temperature, one may compute the values of the other two, not only to within an acceptable and usable degree of accuracy, but more so, with significantly more precision and greater accuracy than values predicted by any prior art equations of state, vapor-liquid equilibrium equations, gas law equations, or empirical equations ever devised. This fact and this unique equation, combined with state of the art computer technology provides for and allows the immediate prediction of the most precise and accurate process control parameters possible for an optimized and preferred degree of control over the dehydration phase of the process of the present invention. Without this equation's unique ability to so accurately model and compute these preferred and optimized operational parameters, the advantages of the process of the present invention would not be possible and could not be achieved.

[0060] The operating parameters, i.e., composition, temperature, and pressure, are determined from the system of equations developed above which mathematically models the process and when implemented appropriately provides a rapid and accurate means of computing the required conditions of interest, from 95.2 weight % ethanol to 100 weight % ethanol, through real-time computer process-quality control. Further, although the system of the present invention is designed to accept a 95 volume % ethanol feed, the system concept allows it to be engineered to dehydrate any suitable beer feed stream.

[0061] The system and process illustrated and described with respect to Figure 1, as stated hereinabove, has very low energy requirements as compared to other commercially known processes for producing fuel-grade ethanol. Accordingly, as explained above, the corn stover from only the cob and shucks of the ear of corn provides 40% more energy than that actually required to convert the grain of each ear into fuel-grade to anhydrous ethanol. Through co-generation, not only is station service electricity provided but, the 40% excess energy provided by the cob and shucks of each ear may be further used to produce additional co-product electricity for sale to a commercial utility's electrical grid. Thus, the entire system is self-sufficient. One preferred form of processing those ears of corn for use in the process of Figure 1 is illustrated in Figure 6.

[0062] The grain receiving, milling and storage area of the system of the present invention is illustrated generally as 50 in Figure 6. This area of the plant 50 will receive the ears of corn including the grain, cob, and shucks to be utilized with the process of the present invention. The shucks and cobs will be utilized to fuel the system of Figure 1, while the corn kernels (60.84% starch) are utilized as the primary ethanol production feed stock from which the "beer" is derived.

[0063] The ears of corn, in the shuck, can be received via rail or truck, weighed for payment and inventory, and dumped into the respective unload hoppers 52, illustrated in Figure 6. From these hoppers 52, the ears are screw conveyed into a bucket elevator 54 into a corn sheller 56. The kernels from sheller 56 are then dropped into a kernel corn silo 62 for storage. The shucks, cobs, and trash are conveyed to a fuel storage area by belt conveyor 58, where all boiler fuel is stored until needed. Dirt and other nonflammable material is discharged from the corn sheller 56. If the capacity of corn sheller 56 is temporarily exceeded, the ears of corn may be transported by belt conveyor 60 to storage and, when needed, back through a second run of the conveyor to the corn sheller 56, when the latter is once again available for use. Kernels of corn from the kernel corn silo are screw conveyed from the bottom of the silo 62 to the entrance of a hammer-mill 63 where they are crushed into meal, and then elevated via a bucket elevator 64 to a meal silo 66 for storage. As needed in the process illustrated in Figure 1, the meal is removed from the silo 66 and air conveyed, if desired, to the fermentation area for conversion to "beer".

[0064] Thus, the subject matter of the present invention having been described, it should be understood that modifications may be made to this process, and the apparatus for effecting the same, without departing from the spirit and scope of the present invention.

What is claimed is:

1. A method of producing a motor fuel-grade ethanol, having an ethanol concentration in the range of 99.19% to 100% by weight ethanol, comprising the steps of:

introducing a mixture of approximately 95 volume % ethanol and 5 volume % water into a vacuum dehydration retort provided with a temperature gradient controlling heat-removal unit for maintaining a proper thermodynamic balance within said retort;

maintaining the proper vapor-liquid equilibrium within said retort, given the desired weight % ethanol in the final fuel-grade ethanol produced, by directly computing the controlling parameters of "minimum" boiling-point temperature, and pressure in the retort according to the following mathematical expression:

$$x_n = \frac{D\left[\left[\left(\ln\left(y_n-30\right)-h\right)\left(\cos 180^\circ\right)^{-1}\right]\left[a_2\left[\left(\ln\left(y_n-30\right)-h\right)\left(\cos 180^\circ\right)^{-1}\right]^{b_2}\right]\right]}{\left[\left(\ln\left(y_n-30\right)-h\right)\left(\cos 180^\circ\right)^{-1}\right]}$$

wherein,

$$y_n = e^{\left[\frac{Ca_1\left[10^{\left[\frac{\log\left(z_n-95\right)-\log\left(Ca_1\right)}{b_1}\right]}\right]^{b_1}-a_{n3}}{b_{n3}}\right]}+30$$

wherein: x_n = pressure in atmospheres;

y_n = constant minimum boiling point in °C;

z_n = weight % ethanol in fuel-grade ethanol;

Curve Fitting Coefficients - for Intercepts (a_n) and Slopes (b_n) involving Pressure vs. wt. % ethanol for n = 1 and Pressure vs. Temperature for n = 2:

$a_1 = 0.6519289117$

$a_2 = 0.6215395079$

$b_1 = -0.9722022159$

$b_2 = -1.249499407$

Empirical Constants:

$h = 4.62$

$C = 0.9141683595$

Empirical Correction Coefficient:

$D = 0.926661158$ for $0 \leq n \leq 1$; 0.9854456272 for $1 < n \leq 2$; 1.11308679 for $2 < n \leq 3$; 1.135719277 for $3 < n \leq 4$; 0.8562016973 for $4 < n \leq 5$.

Correction factors:

$a_{13} = 6.145627884$ and $b_{13} = -1.344713941$ for $n = 1$ to $n = 2$, where y_n ranges from 33.4 to 62.8, z_n ranges from 99.5 to 96.452

$a_{23} = 9.331818148$ and $b_{23} = -2.257550359$ for $n = 2$ to $n = 3$, where y_n ranges from 62.8 to 78.2, z_n ranges from 96.452 to 95.583

$a_{33} = 1.863195221$ and $b_{33} = -0.3303423537$ for $n = 3$ to $n = 4$, where y_n ranges from 78.2 to 87.8, z_n ranges from 95.583 to 95.523

$a_{43} = 4.716852825$ and $b_{43} = -1.033735378$ for $n = 4$ to $n = 5$, where y_n ranges from 87.8 to 109.0, z_n ranges from 95.523 to 95.20

and distilling and dehydrating said mixture in said vacuum dehydration retort while maintaining the temperature and pressure parameters in the foregoing equation in the indicated relationships to produce motor fuel-grade ethanol having a selected concentration value in the range of 99.19 to 100 weight % ethanol.

2. The method of claim 1, wherein said mixture of about 95 volume % ethanol and 5 volume % water is obtained by the steps of:

providing ears of corn including kernels, cobs, and shucks which have been previously separated from their associated stalks;

separating said kernels from the associated cobs and shucks thereof to produce a feedstock;

fermenting said feedstock into "beer" feed; and distilling and dehydrating said "beer" feed to produce said mixture of about 95 volume % ethanol and 5 volume-% water,

wherein the energy for the distillation and dehydration is provided solely by combustion of the cobs and shucks of the associated corn kernels used as the feedstock being processed into fuel-grade ethanol.

3. The method of claim 1, wherein the dehydration step is performed by distilling said mixture in a vacuum from 0.145 to 0.110 atmospheres while maintaining the retort head temperature equal to the associated "minimum" boiling point temperature of from 34.38°C to 32.24°C, respectively, to produce a premium quality motor fuel-grade ethanol having a concentration of 99.19% to 100% by weight of ethanol, respectively.

4. The method of claim 1, wherein 99.5% by weight of motor fuel-grade ethanol is provided by maintaining a pressure of 0.125 atmospheres in said vacuum dehydration unit and maintaining the retort head temperature in said unit to an azeotropic minimum boiling point temperature of 33.4°C.

5. The method of claim 1, wherein a predetermined amount of heat is added to the liquid reflux within the base of said vacuum dehydration retort so as to insure the necessary vapor boil-up rate to provide the desired industrial product flow rates of fuel-grade ethanol.

6. The method of claim 1, wherein said temperature gradient controlling heat-removal unit comprises a heat-removal coil placed inside said vacuum dehydration unit.

7. An apparatus for producing a premium quality motor fuel-grade ethanol having a concentration in the range of from 99.19% to 100% by weight ethanol, said apparatus comprising in combination:

a stripping and rectifying unit for distilling a "beer" feed introduced from a fermentation stage to produce a mixture of about 95 volume % ethanol and 5 volume % water; and

a vacuum dehydration retort suitable for practicing the process of the present invention, for further concentrating said mixture to said premium quality fuel-grade ethanol ranging in concentration from 99.19% to 100% by weight ethanol, said retort comprising a heat-removal unit associated therewith for producing and maintaining the appropriate thermodynamic balance required within said dehydration retort to produce said fuel-grade ethanol.

8. The apparatus of claim 7, wherein said temperature gradient controlling heat-removal unit comprises a heat-removal coil placed inside said vacuum dehydration retort.

9. A method of converting the starch of corn kernels from ears of corn into motor fuel-grade ethanol utilizing only energy derived from the cobs and shucks of said ears of corn, comprising the steps of:

separating the corn kernels of each of said ears from the associated cobs and shucks to produce a feedstock;

fermenting said feedstock into "beer" feed containing about 10% ethanol by volume;

distilling said "beer" feed to produce a mixture of about 95 volume % ethanol and 5 volume % water;

dehydrating said mixture by distilling the mixture in a vacuum retort, under controlled operating parameters of pressure and temperature, wherein a heat-removal unit is provided in combination with said vacuum retort which continuously removes predetermined and controlled amounts of heat from said retort, thus maintaining vapor/liquid equilibrium and essential temperature differentials therein while allowing predetermined and controlled amounts of heat to be added as necessary to the liquid reflux within the base of said vacuum retort so as to insure vapor boil-up rates required to provide the desired industrial product flow rates of fuel-grade ethanol;

wherein all of the energy for both the distilling and dehydrating steps is provided solely by combustion of the cobs and shucks of the associated corn kernels used as the feedstock being processed into said ethanol.

10. The method of claim 9, wherein a predetermined amount of heat provided solely by combustion of the cobs and shucks of the associated corn kernels is added as needed to the liquid reflux within the base of said vacuum retort so as to insure vapor boil-up rates required to provide the desired industrial product flow rates of fuel-grade ethanol.

11. An electricity cogeneration process which includes converting the starch of associated corn kernels from ears of corn into motor fuel-grade ethanol, comprising the steps of:

separating said corn kernels of each of said ears from the associated cobs and shucks to produce a fermentable feedstock;

fermenting said feedstock into "beer" feed containing about 10% ethanol by volume;

distilling said "beer" feed to produce a mixture of about 95 volume % ethanol and 5 volume % water;

dehydrating said mixture by distilling the same in a vacuum retort under controlled operating parameters of pressure and temperature wherein a heat-removal unit is provided in combination with said vacuum retort which continuously removes predetermined and controlled amounts of heat from said retort thus maintaining vapor/liquid equilibrium and essential temperature differentials therein while allowing predetermined and controlled amounts of heat to be added as needed to the liquid reflux within the base of said vacuum retort so as to insure vapor boil-up rates required to provide the desired industrial product flow rates of fuel-grade ethanol;

wherein all of the thermal energy for both the distilling and dehydrating steps is provided from combustion of the cobs and shucks of the associated corn kernels used as the feedstock being processed into said ethanol and wherein electricity is generated by combustion of the cobs and shucks of the associated corn kernels used as the feedstock being processed into said ethanol.

12. The cogeneration process of claim 11, wherein the amount of thermal energy provided from combustion of the cobs and shucks of the associated corn kernels used as the feedstock being processed into said ethanol exceeds the amount of energy necessary for both the distilling and dehydrating steps by at least 33%.

13. The cogeneration process of claim 12, wherein the excess thermal energy is utilized to generate electricity which is supplied to an electrical power grid.

FIG. 1

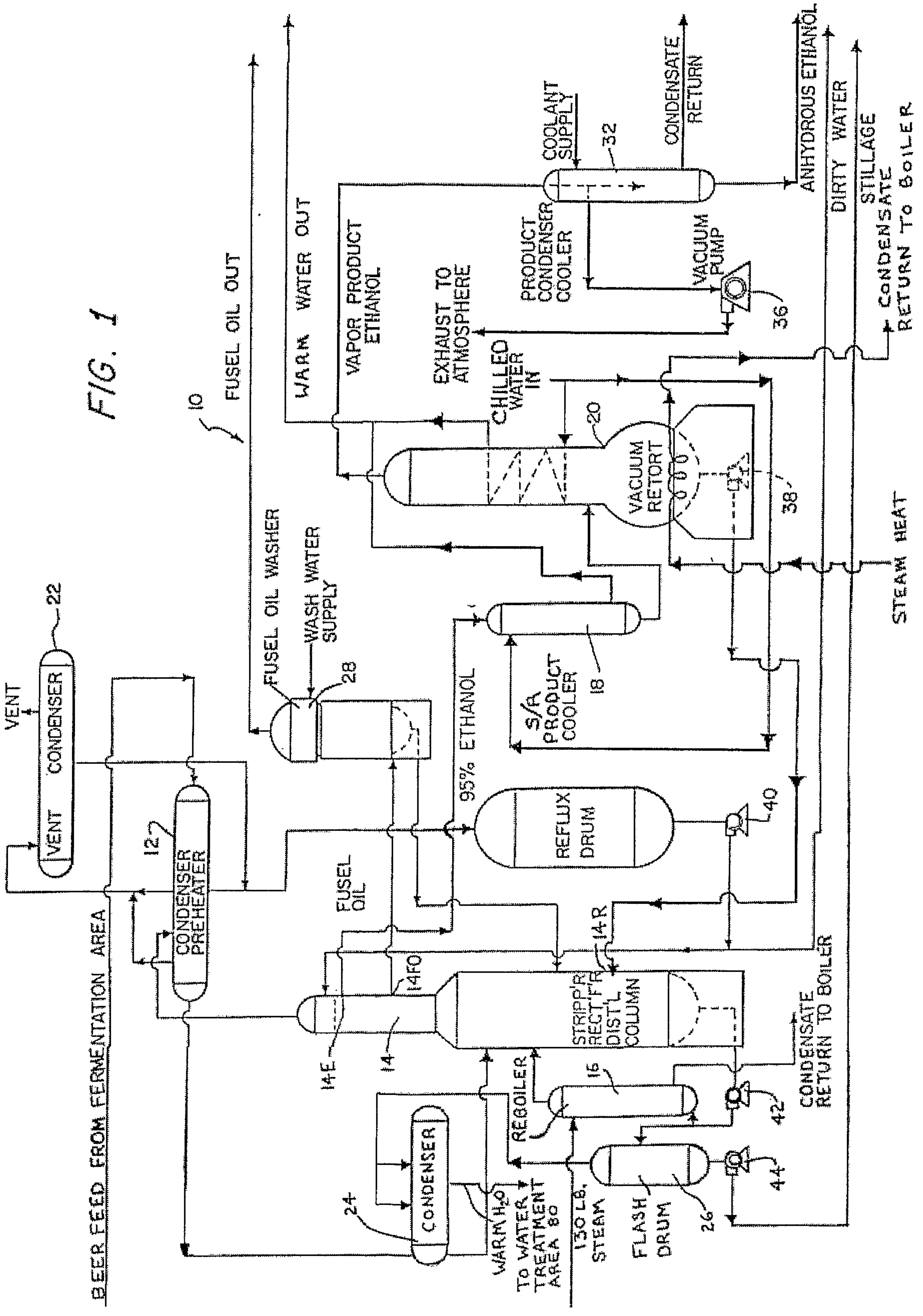

10
BEER FEED FROM FERMENTATION AREA
VENT
VENT
CONDENSER
22
12
CONDENSER PREHEATER
FUSEL OIL
14FO
14E
14
STRIPP'R RECT'FR DIST'L COLUMN
14R
REBOILER
16
CONDENSER
24
WARM H2O
TO WATER TREATMENT AREA 80
130 LB. STEAM
FLASH DRUM
26
44
42
CONDENSATE RETURN TO BOILER
REFLUX DRUM
40
95% ETHANOL
FUSEL OIL WASHER
WASH WATER SUPPLY
28
FUSEL OIL OUT
WARM WATER OUT
VAPOR PRODUCT ETHANOL
S/R PRODUCT COOLER
18
CHILLED WATER IN
20
VACUUM RETORT
38
STEAM HEAT
EXHAUST TO ATMOSPHERE
PRODUCT CONDENSER COOLER
VACUUM PUMP
36
COOLANT SUPPLY
32
CONDENSATE RETURN
ANHYDROUS ETHANOL
DIRTY WATER
STILLAGE
CONDENSATE RETURN TO BOILER

FIG. 2

WT. % ETHANOL (z_n) v. PRESSURE (x_n) atm.

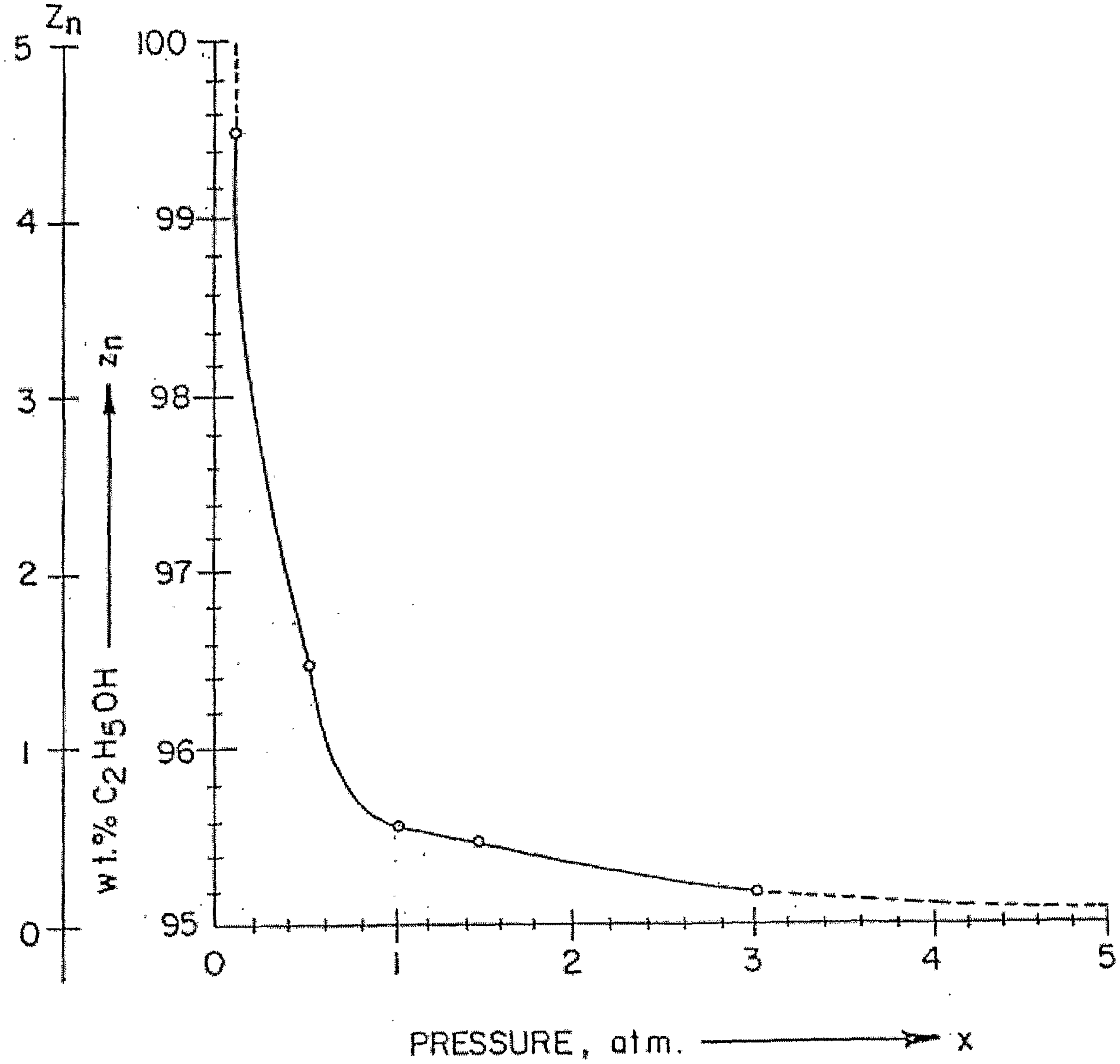


FIG. 3

$Z_n = z_n - 95 \quad v. \quad T_n = \ln(y_n - 30)$

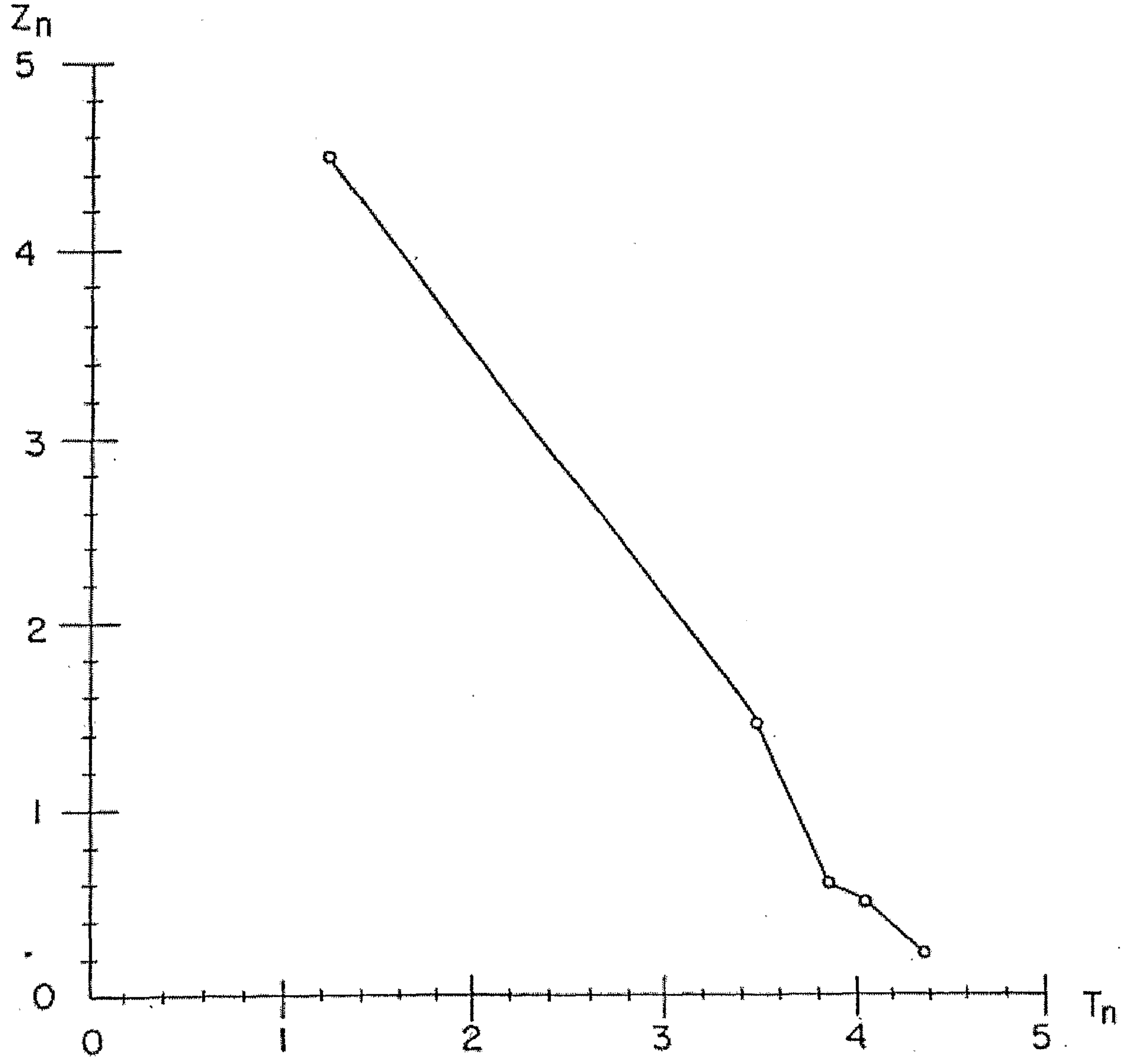


FIG. 4

T_n v. PRESSURE (x_n) atm

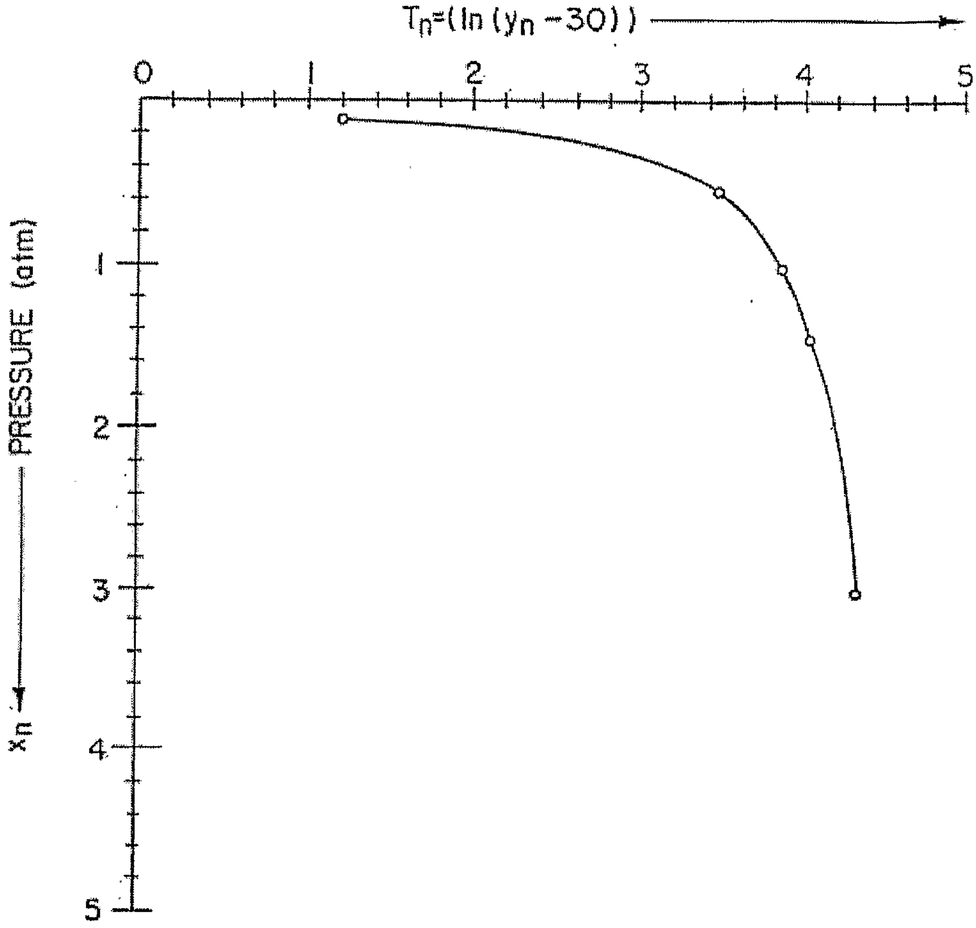
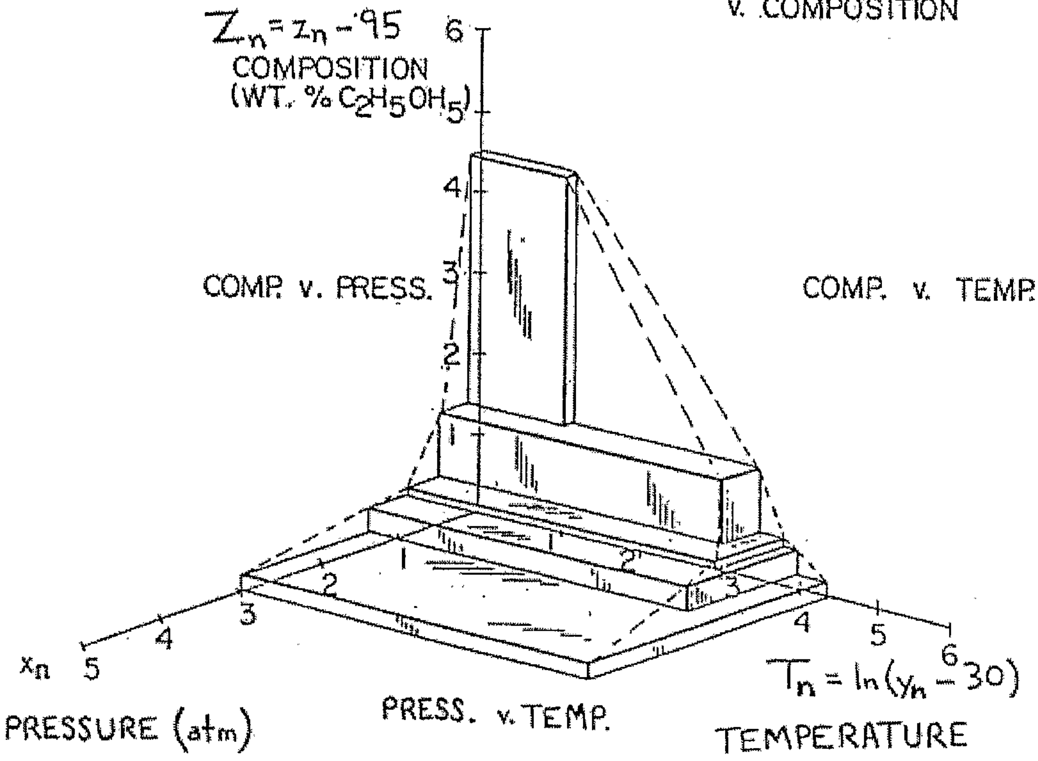


FIG. 5

PRESSURE v. TEMPERATURE v. COMPOSITION



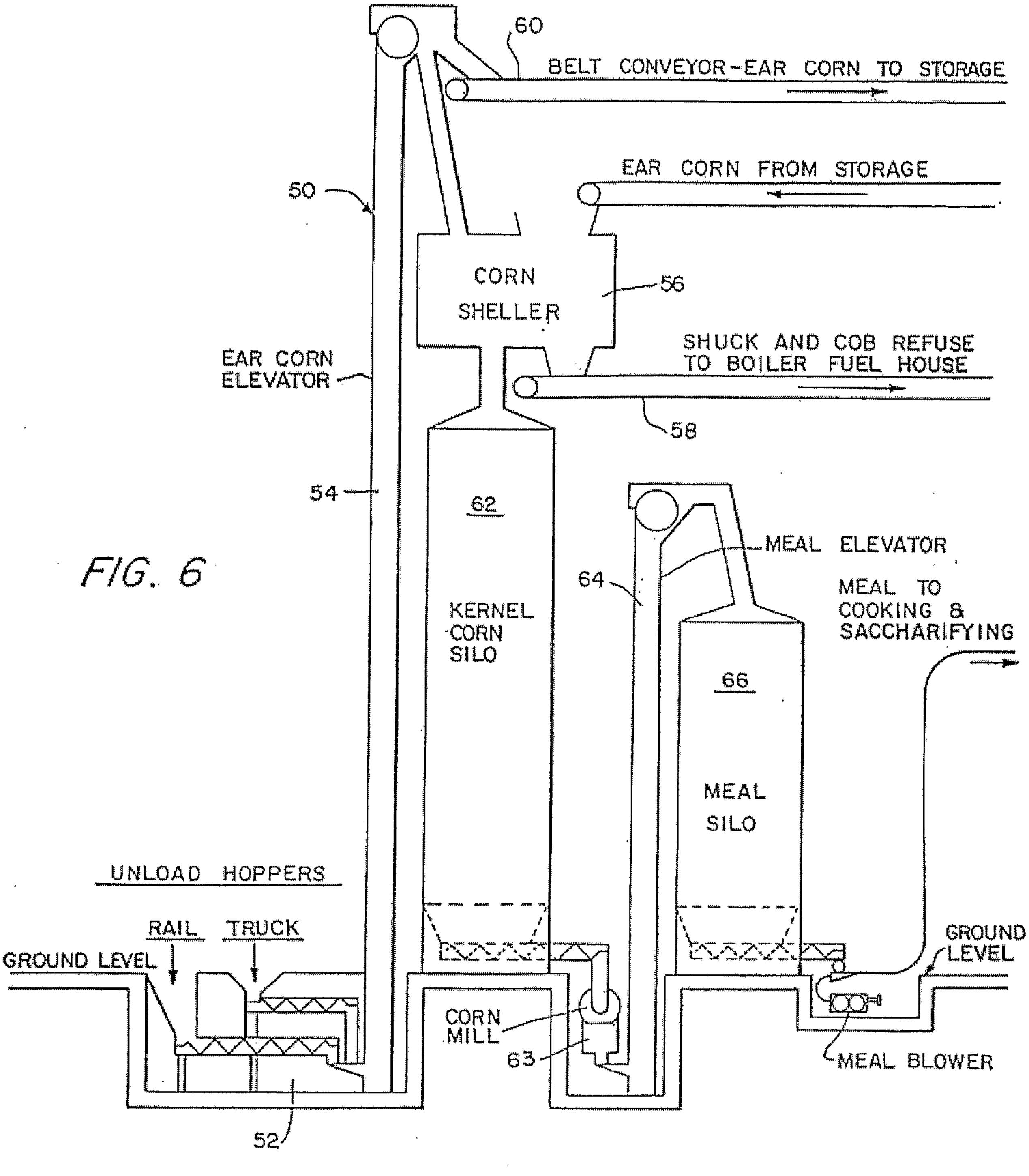
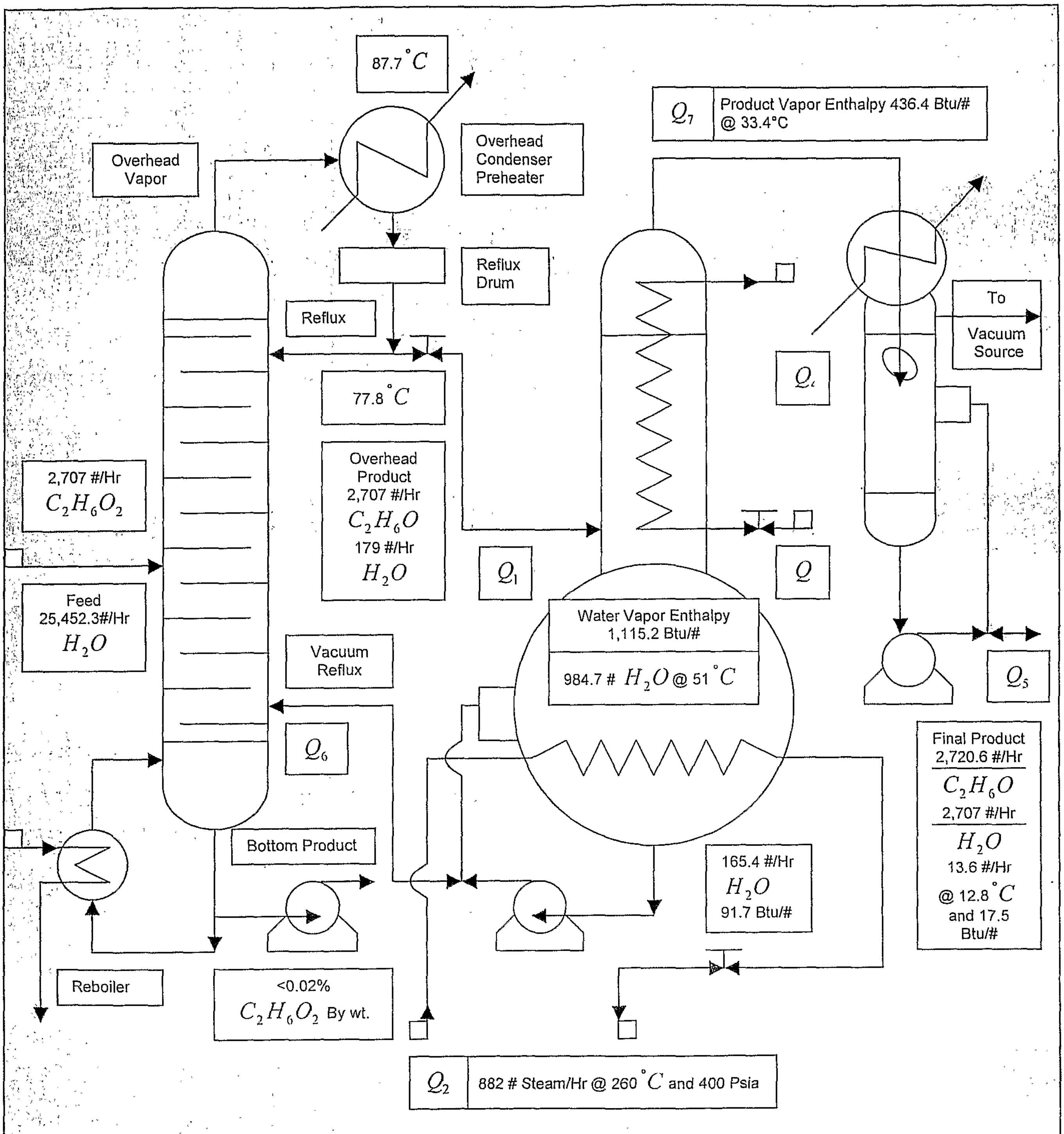

60
BELT CONVEYOR-EAR CORN TO STORAGE
EAR CORN FROM STORAGE
50
CORN SHELLER
56
SHUCK AND COB REFUSE TO BOILER FUEL HOUSE
EAR CORN ELEVATOR
58
54
62
KERNEL CORN SILO
MEAL ELEVATOR
64
MEAL TO COOKING & SACCHARIFYING
66
MEAL SILO
UNLOAD HOPPERS
RAIL
TRUCK
GROUND LEVEL
GROUND LEVEL
CORN MILL
63
MEAL BLOWER
52

FIG. 6



VACUUM DEHYDRATION UNIT

FIG. 7A

FIG.7B

Enthalpy Equations

$$Q_1 = 94.8\ Btu/\# = Q_3 + Q_6 + Q_7 - Q_2$$

$$^{*}Q_2 = 1,115.2\ Btu/\# = Q_3 + Q_6 + Q_7 - Q_1$$

$$^{*}Q_3 = 681.9 Btu/\# = Q_1 + Q_2 - Q_7 - Q_6$$

$$Q_4 = 418.9 Btu/\# = Q_7 - Q_5$$

$$Q_5 = 17.5 Btu/\# = Q_7 - Q_4$$

$$Q_6 = 91.7 Btu/\# = Q_1 + Q_2 - Q_3 - Q_7$$

$$Q_7 = 436.4 Btu/\# = Q_1 + Q_2 - Q_3 - Q_6 = Q_5 + Q_4$$

Heat Transfer Rates

$$Q_1' = (2,886\ \#/Hr)(94.8 Btu/\#) = 273,592.8 Btu/Hr = Q_3' + Q_6' + Q_7' - Q_2'$$

$$^{*}Q_2' = (984.7\ \#/Hr)(1,115.2 Btu/\#) = 1,098,137.4 Btu/Hr = Q_3' + Q_6' + Q_7' - Q_1'$$

$$^{*}Q_3' = 169,293.2 Btu/Hr = Q_1' + Q_2' - Q_7' - Q_6'$$

$$Q_4' = 1,139,659.3 Btu/Hr = Q_7' - Q_5'$$

$$Q_5' = (2,720.6\ \#/Hr)(17.5 Btu/\#) = 47,610.5 Btu/Hr = Q_7' - Q_4'$$

$$Q_6' = (165.4\ \#/Hr)(91.7 Btu/\#) = 15,167.2 Btu/Hr = Q_1' + Q_2' - Q_3' - Q_7'$$

$$Q_7' = (2,720.6\ \#/Hr)(436.4 Btu/\#) = 1,187,269.8 Btu/Hr = Q_1' + Q_2' - Q_3' - Q_6' = Q_5' + Q_4'$$

FIG. 8

ENTHALPY DATA

Liquid Feed Enthalpy 94.8 $Btu/\#$, @ $77.8^{\circ}C$	Composition, Mole % 85.54 - C_2H_6O; 14.46 - H_2O
Product Vapor Enthalpy 436.4 $Btu/\#$, @ $33.4^{\circ}C$	Composition, Mole % 98.73 - C_2H_6O; 1.27 - H_2O
Product Liquid Enthalpy 17.5 $Btu/\#$, @ $12.8^{\circ}C$	

Table - A Values calculated by use of FORTRAN IV subroutine 'ENTH': Computation of Pure-Component and Mixture Enthalpies, in the book, 'Computer Calculations for Multicomponent Vapor-Liquid and Liquid-Liquid Equilibria', by J. Prausnitz, et al., Prentice-Hall International Series in the Physical and Chemical Engineering Sciences.

Liquid H_2O Enthalpy 91.7 $Btu/\#$, @ $51^{\circ}C$	H_2O Vapor Enthalpy 1,115.2 $Btu/\#$, @ $51^{\circ}C$
Q_2, Closed Loop Steam Rate = 882 $\#/Hr$, @ $260^{\circ}C$ and $400 PSIA$	

Table - A' From 'Keenan and Keyes, Steam Tables'.

Note 1) $Q_7' - Q_1' = 913,677.00 Btu/Hr$, the difference in ENTHALPY of the product vapor and the liquid feed (not including the ENTHALPY of the 165.4 pounds $(\#s)$ H_2O per hour initially flashed, but then condensed and removed from the Vacuum Dehydration Unit as reflux to be returned to the Stripper-Rectifier Column).

$$(165.4\ \#\ H_2O/Hr)(1,115.2 Btu/\#\ H_2O) = 184,454.1 Btu/Hr$$

$$913,677.0 Btu/Hr + 184,454.1 Btu/Hr = 1,098,131.1 Btu/Hr$$

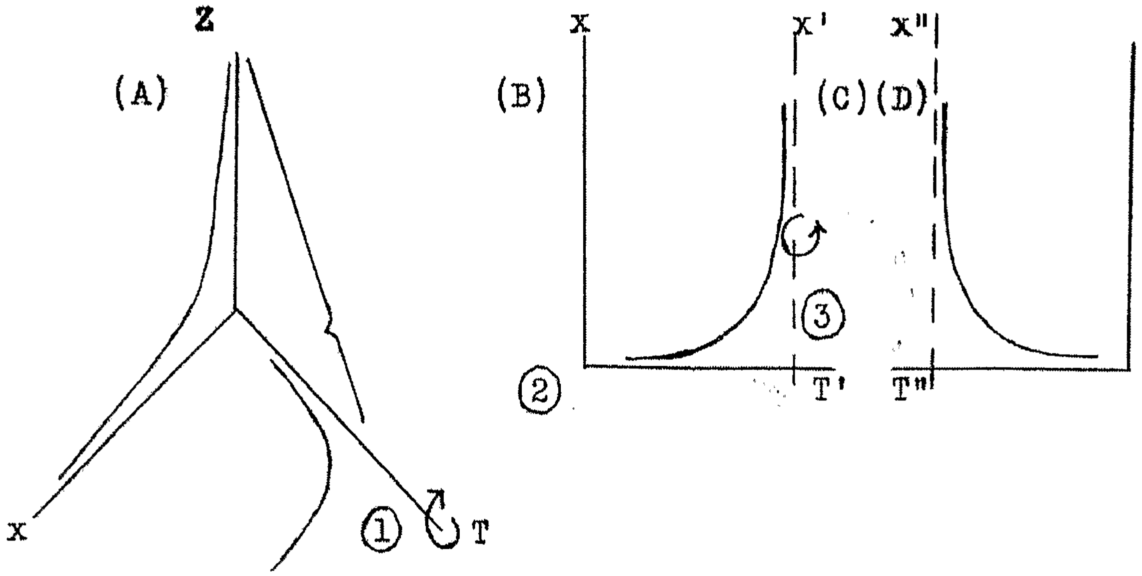
$$(1,098,131.1 Btu/Hr)/(1,115.2 Btu/\#\ H_2O) = 984.7\ \#\ H_2O \Rightarrow 118.1 Gal H_2O$$

$$\therefore$$

$$Q_2' = (984.7\ \#\ H_2O)(1,115.2 Btu/\#\ H_2O) \rightarrow 1,098,137.4 Btu/Hr$$

$$Q_3' = Q_1' + Q_2' - Q_7' - Q_6' = 169,293.2 Btu/Hr$$

FIG. 9



INTERNATIONAL SEARCH REPORT

International application No.

PCT/US06/32830

A. CLASSIFICATION OF SUBJECT MATTER

IPC: **C07C 29/80**(2007.01),**31/08**(2007.01)
C10L 1/10(2007.01),1/32(2007.01)

USPC: 203/19;44/300,301

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 203/19;44/300,301

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

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 4,217,178 (KATZEN et al) 12 August 1980 (12.08.1980), column 3, lines 15-20, 49-54, column 5, lines 14-21, 27-32, column 8, lines 29-30	1-6, 7-10
Y	US 2,440,925 (BOECKELER) 27 April 1944 (27.04.1944), column 2, lines 25-30	6,8
Y	US 4,746,610 (SMITH) 24 May 1988 (24.04.1988), column 1, lines 59-61, column 2, lines 20-33, 44-46, 53-59, column 3, lines 4-5, 22-29, column 4, lines 51-55, column 9, lines 64-68, column 10, lines 1-21	9-13
Y	US 4,345,973 (LADISCH et al) 24 August 1982 (24.08.1982), column 1, lines 6-13	11-12
Y	US 4,308,106 (MANNFELD) 29 December 1981 (29.12.1981), column 3, lines 43-46, column 4, lines 22-35, column 6, lines 33-51.	1-7

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

*	Special categories of cited documents:
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