Selecting Instrumentation for Ethanol Production Facilities

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Introduction: Ethanol Production

U.S. ethanol production capacity has nearly doubled in the past six years, and the Renewable Fuel Association (RFA) projects another doubling of the industry by 2012 as the U.S. increasingly seeks domestic fuel alternatives to foreign oil. Ethanol is among the most promising energy alternatives because it burns cleanly and can be produced from corn and other grains cultivated in American fields. Already some 30% of U.S. fuels contain some ethanol, and continued compliance with the U.S. Energy Policy Act will likely increase that percentage.

The challenge for ethanol producers is to find innovative ways to maintain profitability while this market matures. Most producers are finding that process automation plays a significant role at this critical juncture by helping them control product quality, output, and costs. Sensing and analytical instrumentation represents what is essentially the eyes and ears of any automation system, careful evaluation of instrumentation at the design phase can reduce both equipment and operating costs significantly, while improving overall manufacturing effectiveness. This paper describes the ethanol production process, the required process measurements, and the types of instrumentation that will deliver these measures.

The Ethanol Production Process

Ethanol can be made from feed stocks such as corn, grain sorghum, wheat, barley, and potatoes. In the U.S., the majority of ethanol is produced from corn; in Brazil, the main feed stock is sugar cane. The two main processes used to produce ethanol are wet milling and dry milling, so named for the first step in each process.

In wet milling, starch is separated from the other kernel components by a steeping process under temperature control for approximately 40 hours. The extracted starch is further processed into dextrose (glucose), which is converted to ethanol by using yeast during the process. The by-products of this process are gluten for feed and corn oil. Another co-product of this process is high-fructose corn sweetener. The yield per bushel of corn for the wet milling process is 2.5 gallons of ethanol and 18 pounds of distillers dried grains.

In dry milling, the corn kernel in its entirety is ground into what is known as meal. The next step in the process is to add water and enzymes to convert the starch to complex sugars. During this process, the pH is controlled with the addition of chemicals. Then additional enzymes are added to break down the complex sugar into simple sugars. Yeast is then added to convert the sugars into ethanol, with carbon dioxide (CO_2) being an off-product of this reaction. A removal process then extracts solids, and the remaining liquid distilled to yield purified ethanol. The by-product of this procedure is distillers dry grains, commonly referred to as DDG. The yield per bushel of corn for the dry milling process is 2.8 gallons of ethanol.

Since approximately 75% of the plants built today and under construction use dry milling, the balance of this paper will focus on instruments used in that process.

Measurements for Dry Milling

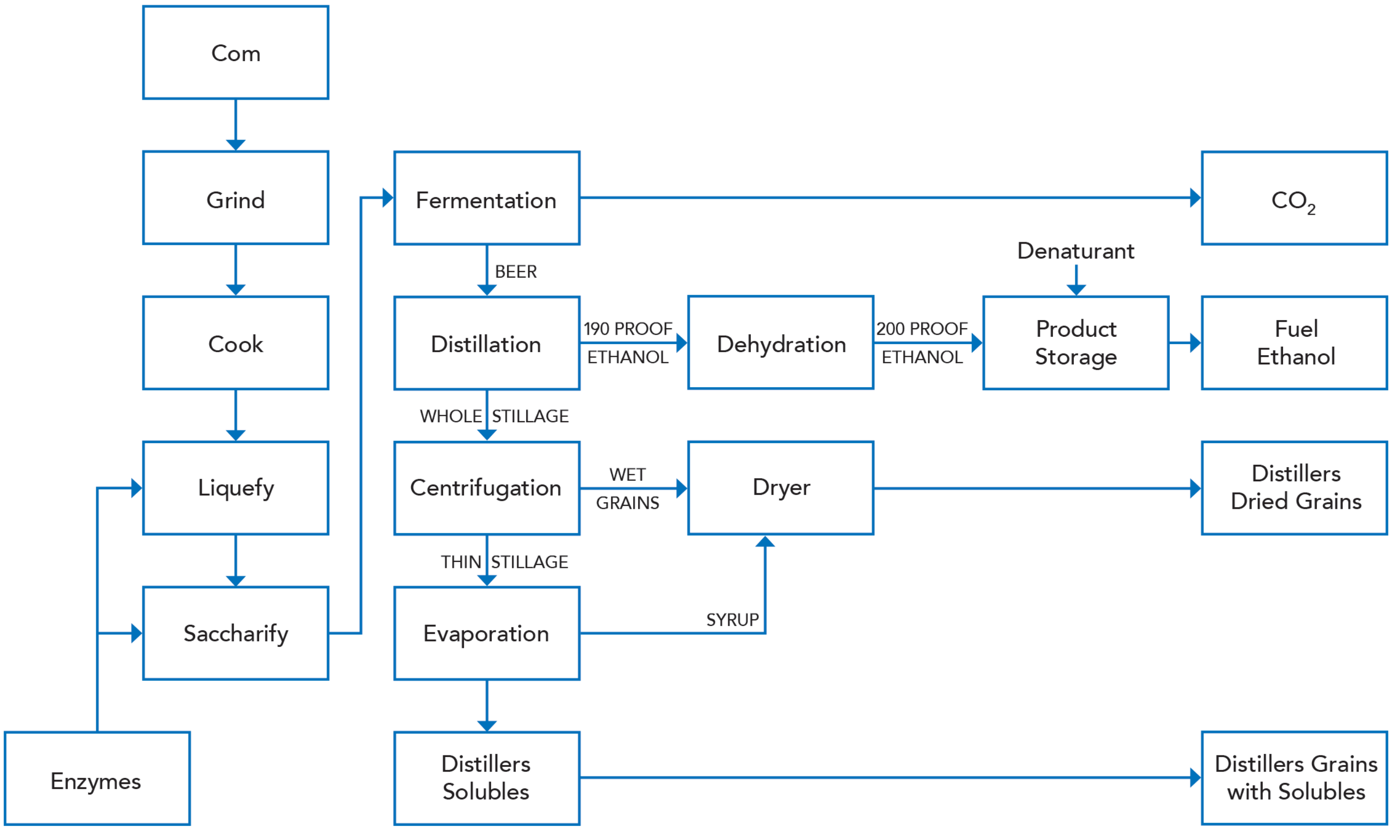
A typical 40-million-gallon-per-year ethanol plant might have as many as 250 process measurements, the actual number depending on the plant's process or the practices of the engineering firm that is constructing the plant. These instruments measure level, pH, temperature, flow, differential and absolute pressure, conductivity, and other variables at the following stages in the dry milling process:

1. Milling

Ethanol production begins at a mill which grinds corn (milo) into a powder called meal, using either roller mill or hammer mill pulverization techniques. Most plants use the hammer mill process, in which a drum with metal bars rotates at a high velocity in a cylindrical chamber. Grinding consistency is critical in the conversion of cornstarch to ethanol. Key process variables at this stage are the operation of the delivery system and the level of ingredients in the hopper.

2. Liquefaction

At the liquefaction phase, the meal is mixed with water and alphaamylase and then cooked to liquefy the starch, with heat applied to enable liquefaction. The cookers have a high-temperature stage from 120 to 150 degrees Celsius and a lower-temperature holding stage of 95 degrees Celsius. The high temperatures reduce bacteria in the mash. Variables that must be measured at this stage include temperature, pH, magnetic flow, and level.



3. Saccharification

In the saccharification stage, the mash from the cookers is cooled and a secondary enzyme, glucoamylase, is added to convert the liquefied starch to fermentable sugars (dextrose). During this process, sulfuric acid is added for pH control. This stage lasts for approximately six hours. Temperature and pH are the main variables that must be measured.

4. Fermentation

In the fermentation stage, the mash is then cooled to 32 degrees Celsius and passed through a series of cascade fermenters until fully fermented; it then leaves the final tank. In this stage, the yeast is added and the pH is controlled above 3.5 pH, usually by adding ammonia to nourish the yeast. In a batch process, the mash stays in a single fermenter for approximately 48 hours before the distillation process starts.

5. Distillation

The fermented mash, now called “beer,” is about 10% alcohol and contains all the non fermented solids from the corn and yeast cells. During the distillation stage, the alcohol is removed or separated from the solids and water. The liquid that leaves the final distillation column is 96% ethanol. The solids and water combine into what is called “stillage,” which settles at the lower portion of the column and is transferred from the base to the co-products processing area. In the distillation stages, pressure, temperature, and flow are critical process measurements.

6. Dehydration

Dehydration separates the last remaining water, usually with a molecular sieve. The alcohol or anhydrous ethanol at this stage is approximately 200 proof. Temperature, pressure, level, and flow are the main process measurements.

7. Denaturing

The denaturing stage renders the ethanol unfit for human consumption by adding gasoline (usually 2%–5%). Otherwise, ethanol could be subject to a beverage alcohol tax. Measurements in this stage are magnetic flow, absolute pressure, differential pressure, and level.

8. Co-products

CO_2 and DDG are the two main co-products generated from ethanol production. The fermentation stage produces CO_2, and most plants collect it, clean it (separating any alcohol), and sell it to the bottling or freezing industries. The distiller’s grains, wet or dried,are high in protein and nutrients and are sold as a livestock feed ingredient. The measurements required for this stage are absolute pressure, differential pressure, level, and flow.

Mapping Process Instrumentation to Ethanol Production Areas

The following table shows the typical ethanol application and plant areas, and the sensing products that are usually associated with each.

Measures Within Plant Areas	Process Instrumentation	Foxboro Solution
Milling Area		
Level of corn fodder and grind silos	Level meter and level switch	
Liquidfaction, Fermination, and Saccharification Area		
pH of slurry mixing tank	pH analyzer	875pH w/pH10 & assembly
Flow of process condensate and back set to slurry mix tank	Magnetic flow	IMT25 w/8000 or 9300 flowtube
Temperature of slurry mix tank and process condensate to mix tank	Temperature	RTT15/20
Level of slurry mix tank	Level (hydrostatic)	IDP10
pH of liquefaction mash	pH analyzer	875pH w/pH10 & assembly
Flow of mash to heat recovery, backset to cooking, mash to fermenting, cooked mash to yeast propagation, water to CO_2 scrubber, and water to vent gas scrubber	Magnetic flow	IMT25 w/8000 or 9300 flowtube
CO_2 scrubber to atmospheric pressure	Absolute pressure	IAP10/20
Temperature of liquefaction tank, heated mash to cook tubes, cooled mash to fermenting, cooked mash to fermenting, yeast propagation tank, fermenter cooling loop, fermenter tank, beer well tank, water to CO_2 scrubber, and CO_2 scrubber vent	Temperature	RTT15/20
Pressure CO_2 scrubber	Differential pressure	IDP10
Level of liquefaction tank, fermenter, beer well, and yeast propagation tank	Level (hydrostatic)	IDP10 w/diaphragm seal
High level of liquefaction tank, fermenter tank, beer well, and yeast propagation tank	Level switch	
Level of CO_2 scrubber water tank	Level (hydrostatic)	IDP10 w/diaphragm seal
Distillation Area		
Flow of beer to heat recovery and whole stillage (WS) from beer column	Magnetic flow	IMT25 w/8000 or 9300 flowtube
Flow of rectifier column reflux, regenerator to preheater, and alcohol to reboiler	Vortex flow	84F/84W
Pressure of vent gas scrubber, rectifier columns, strippers, and alcohol to rectifier	Absolute pressure	IAP10/20
Level of stripper column	Differential pressure w/seals	IDP10
Temperature of heated beer to beer column, beer column, beer column vapor, reboiled beer to beer column rectifier column, condensed rectifier, column reflux, stripper column, rectifier reflux vent vapor to scrubber, and alcohol to super-heater temperature	Temperature	RTT15/20
Pressure of reboiled beer to beer column and beer column pressure	Absolute pressure remote diaphragm	IAP10/20
Flow of steam to beer column and column reboiler	Differential pressure flow orifice	IDP10
Level of WS tank level	Level	IDP10
High level of WS tank	Level switch	
Level of beer column and rectifier	Differential pressure with seals IDP10	IDP10

Measures Within Plant Areas	Process Instrumentation	Foxboro Solution
Dried Distillers Grain Production Unit		
Flow of syrup to syrup tank, stillage from evaporator feed pump, WS to centrifuge, and syrup to dryer	Magnetic flow	IMT25 w/8000 or 9300 flowtube
Pressure of effect evaporator shells and evaporator vacuum educator suction	Absolute pressure	IAP10/20
Level of effect evaporators	Differential pressure, with seals	IDP10 w/diaphragm seals
Level of evaporator vacuum receiver	Continuous level	IDP10 w/diaphragm seals
Body temperature of effect evaporators, evaporator condensate to DDE condensate	Temperature	RTT15/20
Temperature of whole stillage, thin stillage, and syrup tanks	Temperature	RTT15/20
Body pressure of effect evaporators	Absolute pressure remote diaphragm	IAP10/20
Level of thin stillage collection, thin stillage, and syrup tanks	Level (hydrostatic)	IDP10 w/diaphragm seals
High level of thin stillage collection, syrup, and ethanol tanks	Level	
Drying		
Flow of product to receiver	Vortex Flow	84F/84W
Pressure of sieve beds	Absolute pressure	IAP10/20
Temperature of superheated alcohol to sieve beds, sieve beds, and dehydration vacuum receiver	Temperature	RTT15/20
Ethanol		
Ethanol loadout	Mass flow	CFT51 w/flowtube
Level of ethanol day tank, off-spec ethanol tank, denaturant (gasoline), and ethanol storage tank	Level	IDP10 w/diaphragm seals
High level of ethanol day tank, off-spec ethanol tank, denaturant (gasoline), and ethanol storage tank	Level switch	
Utilities Area		
Flow of softened water to boiler	Magnetic flow	IMT25 w/flowtube
pH of water to boiler	pH	875pH w/pH probe
Conductivity of water	Conductivity	875EC w/871EC/871FT
Flow of wastewater	Magnetic flow	IMT25 w/flowtube
Flow of saturated steam (10” - 12” pipe), liquid water through a 10” - 12” pipe, and liquid water through a 24” pipe	Differential pressure, flow	IDP10
Pressure of cooling water header, chilled water header, chilled water return header, process water supply header, and air header	Temperature	RTT15/20
Pressure of cooling water header, chilled water header, chilled water return header, process water supply header, and air header	Absolute pressure	IAP10/20
Temperature of process condensate tank	Temperature	RTT15/20
Chemical Storage Area		
Flow of ammonia and alpha to slurry mix tank and flow of gluco and urea to yeast propagation flow	Magnetic flow	IMT25 w/flowtube
Dilute caustic tank temperature	Temperature	RTT15/20
Dilute caustic tank and caustic tank conductivity	Conductivity	875EC w/871EC/871FT
Level of caustic, sulfuric acid, ammonia, urea, alphaamylase, and glucoamylase tanks	Level	IDP10 w/diaphragm seal
High level of caustic, sulfuric acid, ammonia, urea, alphaamylase, and glucoamylase tanks	Level switch	

The Foxboro Measurements and Instruments Product Line

With the largest installed base of field instrumentation in the ethanol industry, Foxboro® offers extensive expertise to provide on-target measurement solutions. Foxboro is the leading supplier of instrumentation for both dry and wet milling plants, and continues its tradition of customer driven innovation. Founded in 1908 in Foxboro, Massachusetts, the company is credited with developing some of the original devices for making on-line, real-time measurement possible. Hallmark Foxboro innovations include pneumatic transmitters, the MagFlow magnetic flowmeter, pneumatic process gas chromatographs, and flow through conductivity sensors. Today, the company offers instrumentation for almost every stage of biodiesel production. These complement systems, software, and services to boost economic, safety, and environmental performance. The Foxboro measurement product line includes following product groups:

Foxboro pressure transmitters

Foxboro pressure transmitters combine field-proven, superior performance with application versatility, and rugged dependability. Available with a choice of electronic modules, and mounting configurations – the product line includes the industry's most extensive offerings of multi-range and multi-variable instruments, as well as absolute, gauge, and differential pressure, and low power voltage output.

Foxboro temperature transmitters

Built for long-term stability, Foxboro temperature sensors combine microprocessor-based technology to provide high reliability, maximum flexibility, and unmatched intelligence. Products support FOUNDATION Fieldbus, 4-20 mA, HART, or FoxCom Digital Output.

Foxboro flow instrumentation

From vortex and magnetic, to mass flow and digital Coriolis, Foxboro offers a full range of flow products for the accurate measurement of liquid, gas, or steam. Designed to meet even the most demanding applications and accommodate diverse communications protocols, instruments are available in 4-20 mA, HART, FoxCom and FOUNDATION Fieldbus. The product line includes sanitary 3A authorized flow products for food and beverage, dairy, pharmaceutical, and biotech applications.

Foxboro electrochemical measurement technology

Foxboro electrochemical technologies assist in analysis or control of pH, ORP, conductivity, resistivity, or dissolved oxygen. The line includes a broad range of robust, accurate, high quality liquid analytical instrumentation for industries including pharmaceutical, chemical, food and beverage, pulp and paper, metals, semiconductor, power generation, water and wastewater, and more.

Foxboro positioners

The Foxboro line of positioners covers all control applications from traditional pneumatic control and 3-15 psig control through the latest 100% solid state sensing and control circuitry to 21st century communications for HART, PROFIBUS PA, FOUNDATION Fieldbus, and FoxCom digital protocols.

In addition to its products, the following Foxboro offerings support efficient bio-diesel production:

Next day shipment

In currently running plants, downtime can be expensive. In expansion or new constructions, staying on plan, on budget requires having parts there when they are needed. Sometimes long range planning is just not possible and a project could be placed on hold waiting for instrument shipment for a critical part of the facility. To eliminate the process some instrument manufacturers are guaranteeing next day ship on certain transmitters.

Training

Foxboro Measurement & Instruments offers customer designed training classes to supply knowledge in the areas of installation, configuration, operation, and troubleshooting for all products. These classes can be done on-site or at the factory, whichever meets the customers' convenience.

24/7 Customer suppor

Given the relative infancy of the ethanol industry, and the fact that Foxboro customer support is available 24/7 can be a significant source of cost savings in and of itself.

Summary

As the U.S. increasingly seeks domestic fuel alternatives to foreign oil, ethanol is among the most promising energy options, with significant growth expected in dry mill ethanol production. The challenge for ethanol producers is finding innovative ways to maintain profitability while this market matures. Process measurements and instrumentation is an area that offers great potential. Careful evaluation of instrumentation can reduce both equipment and operating costs significantly, while improving overall ethanol production efficiency.

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