

# MEASUREMENT AUTOMATION STRATEGY KEY TO BIO-ETHANOL REFINERY EFFICIENCY

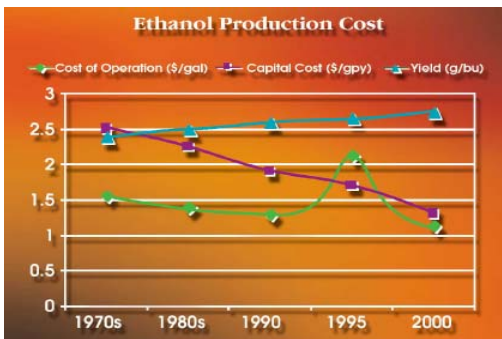
By Hemant Narayan – Krohne Inc- Industry Manager- Biofuels & Energy

The conversion of corn into fuel ethanol is once again gaining popularity and an appealing business opportunity for farm communities and agribusinesses in the mid-western United States. The prospect of turning a bushel of corn into 2.75 gallons of fuel ethanol and 17 lbs of animal feed plus value added byproducts has attracted high levels of investments in ethanol production facilities not only in the Midwest but all over the country including into Canada .



In the U.S. alone over 120+ plants are now producing ethanol from corn feedstock, and another 75+ are under construction. Dozens more are in various stages of planning, with total domestic production capacity expected to double during the next five years. The Des Moines Register recently reported that farmers planted more corn in 2007 than in any year since 1944, based on expectations of increased ethanol production.

The rapid increase in production reflects the expanding market for bio-ethanol, driven by growing recognition of the economic, social and environmental benefits of biofuels. Ethanol which is increasingly in demand being used as an octane-enhancing substitute for the additive MBTE, which is being banned in many states. The 2005 Energy Policy Act stimulated the growth of this industry by offering federal incentives and goals for replacing portion of our nations gasoline requirements with a renewable fuel source by 2012. Current estimates indicate we will surpass these benchmarks well before 2012 which has already forced the need for introducing a new alternate fuel standard . US alone is estimated to consume over 140 billions gallons in gasoline and even if we were to consider a 10% substitution of this with ethanol (E10) blends the annual 14 billion gallons Ethanol market is extremely appealing for investors. Add to this a strong push from local legislatures to accept E85 in lieu of E10 and with Canadian & foreign markets also subscribing to this concept the possibility of this fuel ethanol market exponentially over the next five years is inevitable.



## Thin Profit Margins

The strong demand, however, represent only one part of the profitability equation. With demand increasing and more and more production facilities going online the cost of feedstock ( corn) has also seen a significant

jump which cuts directly to the overall profit margins. Also the whole proposition is not profitable if the production process itself adds more cost to the conversion process which is a direct result of poor yields, expensive use/waste of raw material (enzymes/chemical) and wastage of utilities air/water/energy. Unfortunately, in many cases, that is exactly what's happening as high energy costs eat up profit margins. The cost of natural gas and other utilities far exceeds the other major cost components, including the cost of plant construction and labor. Example, each gallon of ethanol requires the expenditure of at least 15% energy cost if using natural gas to fuel boilers, evaporators, dryers and other equipment. For a 100MGY plant that constituent to over millions of dollars in operating cost and conserving energy by even 1% can help save several thousands of dollars in profits.

The elevated price of natural gas & corn is not the only financial challenge. When an ethanol production facility comes online, the availability of local corn feedstock not only applies an upward price pressure on corn prices however also pose problems with the variability of feedstock. Some producers report that ethanol yields vary as much as 7 percent, depending on the variety of corn. Lower yields adds considerable financial risk – an anathema to investors.



### **Need for Tight Process Control**

For these reasons, achieving consistent profitability can be a tough challenge for bio-ethanol producers. An individual ethanol producer has little influence on the market price it receives for the product it ships and little control over the price of feedstock and natural gas. What ethanol producers can do – must do – is tightly control their own manufacturing process, and thereby produce consistently high yield, while reducing the amount of energy & raw materials (yeast/enzymes/nutrients /chemicals etc) consumed



As any business guru will tell you, process control depends on accurate and reliable measurement. Process improvement methodologies, such as Lean Manufacturing and Six Sigma, are fundamentally measurement-based strategies that seek to maximize productivity while eliminating variation. In fact, measurement is both the second step and the fifth step of the Six Sigma DMADV

process (define, measure, analyze, design, verify). However implementing process control strategies require a careful understanding of process needs including identifying challenges and applying proper customized measuring solution with cutting edge technologies & superior sensor designs to maximize end results.

## Measurement Devices

Measurement devices serve several purposes in an ethanol plant.

**Flowmeters** measure the speed and volume (in some instances mass flow rate) of liquids and gases that move through a pipe, including beer, stillage, syrup, enzymes, water, steam, CO<sub>2</sub> and natural gas or methane (alternate fuel feeds). A wide variety of flow metering technology is available, including Coriolis, magnetic, ultrasonic, variable area, and vortex-based devices.

**Density meters** measure the % solids during feed stock preparation & also final alcohol quality (proof) to monitor/control energy intensive processes & document ASTM fuel grade quality requirements necessary to sell final products into the transport fuel distribution system.

**Level meters** indicate the volume of solids or fluids in a tank, for process control and inventory management. A number of technologies are available most commonly used being a hydrostatic pressure based level transmitter which is fast being replaced by superior direct level measuring technologies such as guided wave radars. & non-contact methods that employ through air radar & ultrasonic waves.

At various points in the production process, it is also necessary to measure & control **temperature (cooking/fermentation & distillation)** and other attributes such as **pressure, pH, conductivity, moisture, etc.**

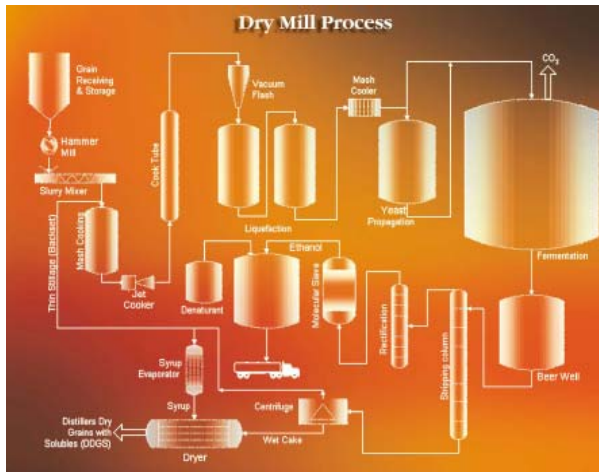
Every stage of production demands precision, and a plant's measuring device supplier must have a deep understanding of the entire ethanol production process, as well as the best technology available & suitable for each type of measurement required.

Though there are various processes deployed today to convert "starch" rich feedstock (viz. sugarcane, corn, wheat, potatoes, cassava, rice etc) to grain alcohols there is a real push today for introducing newer processes that could then use cellulose feedstock to convert bonded sugar (cellulose/hemi cellulose) from non food grain to cellulosic alcohol which obviously has more value and less economic impact as it is less threatening to our regular food chain which is also heavily dependent on the availability of food grain stock mentioned above diverted to fuel ethanol production today.

Unfortunately cellulosic ethanol is still under research & development phase and though there are few pilot plants in operation today that show a lot of promise for future these newer processes are still in demonstration phases and have yet to prove commercial viability when scaling up to a commercial production level without significant financial impact. Until such time the use of grain based ethanol production using corn still contributes significantly in meeting majority of today's fuel ethanol demand.

Corn can be processed to ethanol using the **wet milling** or **dry milling** process. Obviously as wet milling provides higher value by products it was a preferred method mainly used by food industry for producing corn oil, fructose syrup, high protein meal and ethanol was typically seen as a byproduct of the process. However with the increased demand of ethanol today wet milling is losing ground to the more preferred dry

grind/milling process which though less efficient is more in use due to the simplicity of the process and low investment costs.



A typical corn based **dry milling (grind)** process is described here in this article. There are five main parts to the ethanol process. Conversion, fermentation, Distillation, Dehydration, recovery of byproducts (CO<sub>2</sub>, DDGS etc).

**Conversion** takes place before fermentation where it uses two enzymes to facilitate conversion of starch from the corn (or wheat) into simple sugars required for fermentation into alcohol. It all starts with a milling process when corn is grinded to fine particles and

mixed with water to prepare a consistent slurry. The goal here is to increase surface area and to free the starches from inside their protective cell walls. The first enzyme is alpha amylase which is typically used for the liquefaction of the starch rich grain. The second enzyme used is glucoamylase which converts the liquefied starch into glucose (simple sugar) which is called scharificaion.

**Fermentation** then uses yeast to convert the enzyme-produced glucose into ethanol and carbon dioxide. Depending on yeast strain, fermentation can take one to five days. Yeast dosage is dependant on sugar content and percent of alcohol to be fermented to. Fermentation severely slows past 14%, since alcohol denatures the process, however, some yeasts can ferment up to 21%. Things like sugar and molasses are not very nutrient rich and may require additional yeast nutrients to be added. Maintaining controlled temperatures to maximize the efficiency is critical as for most parts past 85F, fermentation will cease. Fermentation can be done in batches or continuously when combined with saccharification. The fermented beer then containing diluted alcohol & solids is extracted from the beer and purified in steps to achieve absolute 100% (200 proof) purity required for E100 fuel ethanol specifications. CO<sub>2</sub> or Carbon Dioxide is a second co-product of the ethanol production process, and is given off in large quantities during fermentation. As a gas, CO<sub>2</sub> is colorless, odorless, and incombustible however in its liquid form, CO<sub>2</sub> reaches an extreme minus 17 degrees Fahrenheit, which makes it an excellent source for cooling and freezing applications. CO<sub>2</sub> vapors released from fermentation is usually scrubbed to recover alcohol vapors present and cleaned and liquefied (if selling to commercial users) or most instances released back into atmosphere.

**Distillation** is the process by which alcohol is separated from the mash and water. It exploits the difference in boiling points of alcohol and water. Water and alcohol form an azeotrope at atmospheric pressure hence by distillation alone once can only achieve a certain proof quality.

Past about 94% ethanol (6% water) distillation is not a viable option hence in order to remove the excess water additional steps for **dehydration** is required to purify ethanol to 100% (0% water or 200 proof) strength. Though there are different ways to achieve this e.g. azeotropic distillation, membrane separation etc, the simplest ( though not energy efficient) method in use is a molecular sieve (zeolite) to purify ethanol from 190 to 200 proof.

The bottoms from beer well ( solids waste) is processed separately in a **centrifuge/evaporation/drying process** to produce dry distillers grains with solubles (DDGS). Distillers grains are rich in cereal proteins, fat (energy), minerals, and vitamins. They are an excellent source of digestible protein and energy.

When using sugar rich feedstock sources like sugarcane in lieu of corn/wheat/rice barn etc the enzymatic conversion process becomes redundant as there is no starch to convert, on the other hand when converting cellulosic feedstock a more complex conversion process involving complex hydrolysis is required to break down the closely bonded cellulose & hemi-cellulose from the lignin and release the fermentable sugars. However once the sugar has been broken down to simple sugar by acid hydrolysis, enzyme hydrolysis, steam explosion etc conversion process(s) the subsequent downstream process involving fermentation/ distillation and dehydration steps are pretty common for any process.

In a nut shell each area of the plant described briefly above – milling, slurry preparation, liquefaction, fermentation, distillation, dehydration, evaporation and drying — requires a measurement & control solution that provides the best performance for the price. This performance includes not only accuracy, but also reliability and durability, as well as the frequency and method of calibration, and lifetime maintenance costs.

Performance is not just a question of selecting the best device & technology for the particular application. Proper placement of the device in the pipeline or tank is also critically important to ensure not only accurate measurement but also to avoid distortions, clogging and damage. Preventive maintenance and periodic calibration checks on some instruments are also required to be conducted inhouse.

### **Importance of Meter Selection and Placement**

Careful selection and installation of measurement devices is important for three reasons:

*Measurement Accuracy.* First and foremost, measurement devices give visibility to the process, allowing plant operators to “see” what is going on inside the pipes and production systems and how full each tank is. This is actionable information that provides the basis for planning and management systems and for real-time process control. To be useful, this information must be accurate.

*Automation.* Accurate and reliable measurement devices enable automation by programmable logic controllers and computer systems. Automation improves plant efficiency and production consistency. Measurement devices should have self-diagnostics and alarming capabilities to automatically monitor conditions on a continual basis and to alert operators of problem states such as changes in flow caused by solids,

entrained gas, or temperature changes, as well as problems with the functioning of the measurement device itself.

*Maintenance Costs.* High performance measurement devices may have a higher initial purchase cost, but they will typically have lower total lifetime costs, because of the elimination of downtime for recalibration and repair. Some manufacturers now offer interchangeable components, such as a universal signal converter that is compatible with a variety of meters with different sensor technologies or different pipe diameters and flow rates. This flexibility greatly simplifies engineering, procurement, and parts inventory.

**Some key areas of improvement are outlined below. These relate directly to improving yield and reducing wastages & conserving energy**

### **OPTIMIZING SOLIDS MEASUREMENT**

Most production operators understand the importance of percent solids control for an effective fermentation process and measurements are routinely conducted at various points in the process. Most % solids measurements however are done offline in lab where samples drawn from a process are measured periodically on a lab moisture analyzer. The lab analyzer may be calibrated for high accuracies, however the sampling/testing process is known to be unreliable as there is always scope for inconsistency due to human errors introduced which makes it extremely difficult to get repeatable results.

Today more operators understand the benefits of a real time online measurement that can help track %solids in real time by providing a continuous monitoring of contents of the mixing tank thereby allowing making instantaneous changes to process possible to help maintain process requirements within acceptable tolerances (typically within 0.5%). This real time measurement & control allows more consistency in the slurry mix solids and facilitates operators to push the solids



higher than they typically run their process to reduce flow issues thereby reducing enzyme usage & costs. By trending continuously the solids concentration in the process any slow decrease in solids can be promptly detected and corrected. Also by maintaining a record of solids data by each fermentation batch realistic prediction on outcome from a fermentation process can be made thereby optimizing the overall process by reducing problems with previous known flow issues and also improving the beer well averages which is a key factor in improving alcohol yields.

Industrial grade coriolis meters have already demonstrated their value in process measurement & control by providing very accurate/repeatable density measurements that provides the basis of a good solids measurement. Unfortunately conventional coriolis meter design employing bent tubes & internal flow splitters have often caused fouling and blockages leading to high unreliability with their implementation. However Krohne technology breakthrough in coriolis measurement technology has allowed a significant improvement over the older "bent tube" design and the introduction of an "affordable" single straight tube design( Optimass 7000 series) has once again reestablished credibility by demonstrating their dependability and benefits on a real time density measurement.

## **OPTIMIZING ETHANOL RECTIFICATION & DEHYDRATION**

Rectification & dehydration is common to any fuel ethanol process whether wet milling, dry grind or cellulosic and provides a textbook case of the importance of accurate measurement for process control. The goal of the rectification process is to achieve maximum purification upto 190 proof and then dehydration process converts 190 proof ethanol into 200 proof ethanol, going from 5% moisture content to 0%, using molecular sieves.

If the process fluid moves too quickly through the molecular sieves and some moisture remains, then the entire batch must be run back through the dehydration system again – a completely inefficient step that wastes energy and ties up production capacity and potentially causes a bottleneck for the entire plant. To avoid this problem, a plant could extend the dwell time in the molecular sieves to ensure that all moisture is removed. However, this margin of comfort comes at a cost in terms of productivity loss and unnecessary energy consumption.

Alcohol Proof measurement at rectifier(190 proof) and dehydration outputs (200 proof) of the process can help optimize the rectification and dehydration process efficiency. Here too a real time coriolis density measurements can provide the basis for an accurate and repeatable proof measurement providing continuous trends allowing instantaneous correction of process upsets and ensure a consistent & tight control of proof values in final product which is key for maintaining important quality control specifications and improved profitability of plant by increasing its throughput. On the final output a precise density measurements, detects exactly when the ethanol reaches the anhydrous threshold, so that the dehydration process can meet its target without overreaching, thereby obviating the need for any wasteful comfort margin.

On these same measurement points temperature and final throughput (GPM) measurement are also considered crucial measurement parameters and for this most installation would use a dedicated density/proof measurements usually



on slipstream and additional temperature and flow rate meters installed in main line for the additional measurements required increasing installation cost for each additional instruments. In contrast a Krohne straight tube coriolis meters can be installed inline to the main line and provide multi parameter capabilities by providing value added measurements on the same points all this without creating significant pressure drops due to the single straight tube design. Check out Krohne 7000 series T80 Optimass coriolis based proof meter solutions which provides multi parameter measurement of proof/density/temperature/flow rate all with one meter thereby reducing installation cost, maintenance cost and overall cost of ownership

## **MORE EFFICIENT DRYER OPERATION**

On the distiller grain section this multi parameter capability with a single straight tube process coriolis meter can provide extremely high pay backs when installed on the evaporator syrup draw. Installations of an online flow/density meter at the intermittent /final stages of the evaporators have successfully demonstrated that significant savings in energy can be achieved by controlling the syrup % and flow rate through the evaporators at optimum levels.

Running syrups at higher solids is desirable as it helps reduce moisture added with syrup to the distillers grains before drying. Less moisture implies less work for the dryers and hence lower energy consumption in the drying process. Higher solids in the syrup drawn from the evaporators can be achieved by reducing flow rate through evaporators and increasing retention time, unfortunately lower flow rates can cause extensive build up inside the lines and can also affect the evaporator efficiency. Also frequent line plugging would add to costly downtime, hence it is imperative to operate the process at an optimum solids level at all times. Offline measurements using lab samples clearly shows wide swings in solids rate of final syrups and can be easily avoided by real time monitoring of flow/%solids. Here again maintenance and reliability concerns with a conventional " bent tube" design have been overcome with the introduction of Krohne "single" straight tube coriolis sensor technology with adaptive sensing technologies (AST). This patented design can make accurate measurements even of mixtures with high viscosity or solid matter content and the straight-tube design causes less pressure drops than other flow meters, resulting in lower energy costs.



## VOLUMETRIC FLOW METERING



Volumetric flow measurement upstream of fermentation make use extensively of inline electromagnetic flow meters on various points such as backset, corn slurry , mash, beer, on whole, thick and thin stillage etc with high solids to monitor and control the process. Most magnetic flow meters available in the market today use a pulsed DC technology which has replaced older AC technology due to its inherent problems with drift and zero stability. However pulsed DC magnetic flow meters have its limitations over AC technology when used on high noisy applications such as slurry applications necessitating the need for proper meter selections. Krohne proven solutions using advanced digital noise filtering inbuilt with the IFC300 signal converter and low noise electrode configuration offers a optimum solution for these measurements. In addition standard inbuilt multi parameter measurement capability in Krohne meters allow for additional temperature & conductivity measurement from the same meter. Inbuilt advanced diagnostic functionality for detecting sensor coating and predicting electrode/liner failure can provide valuable information for operators & maintenance personnel by providing self validation and advance intelligence on possible failures minimizing expensive downtimes.



Some ethanol producers are already using the inbuilt conductivity and temperature capabilities offered with the Krohne OPTIFLUX 4300C as a value added measurement over and above its high accurate flow capabilities to provide critical inputs for implementing an automated CIP wash frequently deployed between batches in a typical ethanol plant. The CIP wash cycle includes flushing the lines & recirculation chemical in a specific sequence such as acid-water-alkali-water etc and here by using the conductivity feature inbuilt with the flow meter valuable information of product phase change taking place in the process can be detected and wash cycle controlled remotely to ensure a more efficient CIP cycle. This also facilitates make up of chemicals for reuse for subsequent wash and helps reducing waste.

Applications downstream of the rectification process pose a challenge for magnetic flow meters due to very low conductivities here alternate technologies like vortex shedding, ultrasonic etc provide a better solution. Flow meters with moving parts such as turbines/paddle wheel etc are prone to coating and mechanical failure. Here Krohne inline triple beam ultrasonic flow meters UFM3030 have demonstrated a high value over competing vortex shedding technologies due to its high accuracy, repeatability over a wider turndown which is of high interest on such applications.



## Controlling Steam Consumption

Flowmeters also play a critical role in controlling energy consumption by measuring the flow of steam used extensively in cooking, dehydration and evaporation process. All steam measurements are done on mass flow basis yet true mass flow sensing designs such as coriolis/ thermal mass meter fail on this application due to the high moisture contents

in saturated steam vapors. Here as a compromise for reliability a volumetric device such as orifice plates/vortex meter etc are being extensively used.



Unfortunately most of these volumetric device measure velocity of steam in the pipeline and compute volumetric flow rate from the line size installed accurately. When outputting mass flow they use a fixed density correction preprogrammed inside the meter electronics to convert volumetric flow to mass flow usually calculated around a fixed operating pressure. This fixed correction can cause significant errors in the final mass flow if the operating pressure /density of steam changes. Changes in steam pressure cannot be avoided and is inherent and it has been demonstrated that a 10# change in sat steam

line pressure can cause to a fixed density compensated meter to over/under read by up to 25% even though the primary volumetric measurement from meter is well below 1%. This 26% uncertainty in itself can posse significant challenges for the production manager when trying to do mass balances and determine cost control measured for steam consumption/wastage in their process. The Krohne Optiswirl 4070 multivariable steam meter was designed specifically to overcome these challenges and precisely measures flow rate , pressure and temperature using its integrated sensors and provides accurate density compensation for a high accuracte mass flow independent of operating conditions. THis not only help achieve precisely control the flow of steam to fuel the process and regulate required temperature but also provides a dependable means for determining loss and wastage. The fully-welded stainless steel construction makes the measuring tube of the Optiswirl highly resistant to pressure, temperature, corrosion and aging and provides high immunity to water hammer even of wet steam applications.

## Level Meters Improve Inventory Management



Level meters also play an important role in improving the plants bottom line by enabling tighter inventory management and process control. For example, accurate measurement allows close tracking of the use of the enzymes used in the slurry tanks during the mash preparation process, and of the chemical consumption in the clean-in-place routines. To do this, you need to know exactly how much material you have, and how much you are using. Measurement of level on fermentation tanks allow regulate foam control which can be a challenge when controlling a fermentation process.

Level measurements is reboilers /distillation and final storage tank farms are also critical. Here a BM26A side mount level gauge offers high reliability over technologies that have problems measuring under tough conditions of vacuum, high temperatures, vapor phases and foaming.

Inventory management is key and on most storage tanks level measuring systems deployed use hydrostatic pressure to measure from the bottom of the tank due to its low initial cost. However the problem with this method is that this is a indirect measurement and using density of medium to determine the effective level, hence when the temperature changes, the density of the product will change, causing a change in pressure even though the level of material in the tank has not changed.





Pressurized tanks need additional compensation to eliminate compensation for pressure changes inside the tank. Further more frequent calibration & maintenance can significantly add up for a high cost of ownership. Alternatively, non-contact radar or guided radar level devices measure from the top of the tank, and are direct measurement of distance and level and unaffected by pressure changes/vapors or tank pressure. Top-of-tank placement also makes repair or replacement easier. Bottom-of-tank implementations can only be serviced when the tank is empty — a rare occurrence in active, high-volume plants.

## Conclusion

The use of corn as a feedstock for fuel ethanol as a renewable source has no doubt also sparked a controversial debate on net energy value considerations & economic long term viability. One can find different reports published that indicate different calculations supporting (some discrediting) the net energy value calculations and though each of



these reports have sparked additional debates the proven fact that everyone will agree upon is that planning & implementation of customized automated solutions have demonstrated significant contributions towards achieving & maintaining higher yields and reducing energy and operating costs thus improving overall the net energy value calculations of any fuel ethanol dry grind corn process. This has been made possible by a collaborative effort of plant operators, process design engineers & equipment manufacturer by implementing advanced process control solutions by first understanding the basic needs, identifying challenges and there after implementing cutting edge measurement technologies & advanced control schemes to overcome bottle necks that frequently created roadblocks from concept to implementation.

Ethanol production holds great promise for our country's energy future and also provides and excellent opportunity to stimulate our inbuilt agri-community. Investments in plant today will yield benefits for years to come. As more and more plants come online the need for each plant to compete against each other will become that much more important as the market will demand the highest quality of end products & lowest prices which can be sustainable for the producer only by controlling his production costs, reducing waste ages and conserving energy wherever possible to still ensure profitability. Investing in the plant's measurement systems both during new construction or retrofit, is one area that has been proven to offer high returns in the form of increased productivity and lower costs. Technology advancements under testing is also showing promising results of possible near term opportunities to add additional value added by products including corn oil, protein supplements and biodiesel. The concept of a "true" multi product output biorefinery is already becoming a reality.

Confidential: Krohne Internal use only. All rights reserved. For additional details contact [Narayan@krohne.com](mailto:Narayan@krohne.com) or 978 535 6060 X1107

**KROHNE MEASUREMENT SOLUTIONS FOR A DRY GRIND FUEL ETHANOL PLANT**

Process	Application	KROHNE Solution	KROHNE Product Name
Milling/Grinding-Process	Corn silage level	TDR Contact Level	OPTIFLEX TDR
	Corn grind silo level	TDR Contact Level	OPTIFLEX TDR
	Corn silage Hi level	Tuning Fork Level Switch	OPTISWITCH
	Corn grind silo Hi level	Tuning Fork Level Switch	OPTISWITCH
Slurry Preparation	Back set to slurry mix tank flow	Electromagnetic flow	OPTIFLUX
	Mix slurry tank high level	OPTIWAVE 24GHz FMCW Radar	OPTIWAVE
	Process condensate temperature to slurry mix tank	Temperature	OPTITEMP
	Process condensate to slurry mix tank flow	Electromagnetic flow	OPTIFLUX
	Slurry mix tank temperature	Temperature	OPTITEMP
	Ammonia to Slurry mix tank mass flow and density	Straight Tube Coriolis density/mass flow/%solids	OPTIMASS
	Slurry tank, pH	pH measurement	OPTILYSIS
Slurry Tank#1 Density	Straight Tube Coriolis density/mass flow/%solids	OPTIMASS	
Liquefaction	Back set to cooking flow	Electromagnetic flow	OPTIFLUX
	Cooked mash to yeast propagation flow	Electromagnetic flow	OPTIFLUX
	Cooled mash to fermenting	Temperature	OPTITEMP
	Cooled mash to yeast propagation	Temperature	OPTITEMP
	Heated mash to cook tubes temperature	Temperature	OPTITEMP
	Liquefaction mash, pH	pH measurement	OPTILYSIS
	Liquefaction tank high level	Tuning Fork Level Switch	OPTISWITCH
	Liquefaction tank level	OPTIWAVE 24GHz FMCW Radar	OPTIWAVE
	Liquefaction tank temperature	Temperature	OPTITEMP
	Mash to fermenting flow	Electromagnetic flow	OPTIFLUX
	Mash to heat recovery flow	Electromagnetic flow	OPTIFLUX
	Liquefaction Mash Density	Straight Tube Coriolis density/mass flow/%solids	OPTIMASS
	Fermentation	Beer well high level	Tuning Fork Level Switch
Beer well level		OPTIWAVE 24GHz FMCW Radar	OPTIWAVE
Beer well tank temperature		Temperature	OPTITEMP
Fermenter cooling loop		Temperature	OPTITEMP
Fermenter high level		Tuning Fork Level Switch	OPTISWITCH
Fermenter level		OPTIWAVE 24GHz FMCW Radar	OPTIWAVE
Fermenter tank temperature		Temperature	OPTITEMP
scrubber (water) tank level		OPTIWAVE 24GHz FMCW Radar	OPTIWAVE
scrubber pressure		Differential pressure	OPTITROL
scrubber to atmosphere pressure		Absolute pressure	OPTITROL
scrubber vent temperature		Temperature	OPTITEMP
Water to scrubber flow		Electromagnetic flow	OPTIFLUX
Water to scrubber temperature		Temperature	OPTITEMP
Water to vent gas scrubber flow		Electromagnetic flow	OPTIFLUX
Yeast propagation tank high level		Tuning Fork Level Switch	OPTISWITCH
Yeast propagation tank level		OPTIWAVE 24GHz FMCW Radar	OPTIWAVE
Yeast propagation tank temperature		Temperature	OPTITEMP
Ammonia to Fermenter Flow and Density	Straight Tube Coriolis density/mass flow/%solids	OPTIMASS	
Stripping/Rectification	Alcohol to re-boiler flow	Ultrasonic-inline triple beam	OPTISONIC
	Alcohol to rectifier pressure	Absolute pressure	OPTITROL
	Alcohol to superheater temperature	Temperature	OPTITEMP
	Beer column level	OPTIWAVE 24GHz FMCW Radar	OPTIWAVE
	Beer column lower temperature	Temperature	OPTITEMP
	Beer column middle temperature	Temperature	OPTITEMP
	Beer column upper temperature	Temperature	OPTITEMP
	Beer column vapor temperature	Temperature	OPTITEMP
	Beer to heat recovery flow	Electromagnetic flow	OPTIFLUX
	Condensed rectifier column reflux	Temperature	OPTITEMP
	Heated beer to beer column temperature	Temperature	OPTITEMP
	Lower beer column pressure	Abs. press. remote diaphragm	OPTITROL
	Lower rectifier column pressure	Absolute pressure	OPTITROL
	Lower stripper column pressure	Absolute pressure	OPTITROL
	Middle beer column pressure	Abs. press. remote diaphragm	OPTITROL
	Re-boiled beer to beer column pressure	Abs. press. remote diaphragm	OPTITROL
	Re-boiled beer to beer column temperature	Temperature	OPTITEMP
	Rectifier column level	OPTIWAVE 24GHz FMCW Radar	OPTIWAVE
	Rectifier column lower temperature	Temperature	OPTITEMP
	Rectifier column middle temperature	Temperature	OPTITEMP
	Rectifier column reflux flow	Ultrasonic-inline triple beam	OPTISONIC
	Rectifier column upper temperature	Temperature	OPTITEMP
	Rectifier reflux vent vapor to scrubber	Temperature	OPTITEMP
	Regenerator to pre-heater flow	Ultrasonic-inline triple beam	OPTISONIC
	Steam to beer column flow	Multi variable Vortex Flow	OPTISWIRL
	Steam to beer column re-boiler flow	Multi variable Vortex Flow	OPTISWIRL
	Stripper column level	OPTIWAVE 24GHz FMCW Radar	OPTIWAVE
	Stripper column lower temperature	Temperature	OPTITEMP
	Stripper column upper temperature	Temperature	OPTITEMP
	Upper beer column pressure	Abs. press. remote diaphragm	OPTITROL
	Upper rectifier column pressure	Absolute pressure	OPTITROL
Upper stripper column pressure	Absolute pressure	OPTITROL	
Vent gas scrubber pressure	Absolute pressure	OPTITROL	
Whole stillage tank high level	Tuning Fork Level Switch	OPTISWITCH	
Whole stillage tank level	Tuning Fork Level Switch	OPTISWITCH	
WS from beer column flow	Electromagnetic flow	OPTIFLUX	

**KROHNE MEASUREMENT SOLUTIONS FOR A DRY GRIND FUEL ETHANOL PLANT**

Process	Application	KROHNE Solution	KROHNE Product Name
Dehydration	Dehydration vacuum receiver temperature	Temperature	OPTITEMP
	Lower sieve bed pressure	Absolute pressure	OPTITROL
	Lower sieve bed temperature	Temperature	OPTITEMP
	Middle sieve bed temperature	Temperature	OPTITEMP
	Product to receiver flow	Ultrasonic-inline triple beam	OPTISONIC
	Superheated alcohol to sieve beds temperature	Temperature	OPTITEMP
	Upper sieve bed pressure	Absolute pressure	OPTITROL
	Upper sieve bed temperature	Temperature	OPTITEMP
Final Ethanol Processing	Denaturant (gasoline) tank high level	Tuning Fork Level Switch	OPTISWITCH
	Denaturant (gasoline) tank level	OPTIWAVE 24GHz FMCW Radar	OPTIWAVE
	Ethanol day tank high level	Tuning Fork Level Switch	OPTISWITCH
	Ethanol day tank level	OPTIWAVE 24GHz FMCW Radar	OPTIWAVE
	Ethanol storage tank high level	Tuning Fork Level Switch	OPTISWITCH
	Ethanol storage tank level	OPTIWAVE 24GHz FMCW Radar	OPTIWAVE
	Ethanol to load out flow	Straight Tube Coriolis density/mass flow/%solids	OPTIMASS
	Off spec ethanol tank high level	Tuning Fork Level Switch	OPTISWITCH
	Off spec ethanol tank level	OPTIWAVE 24GHz FMCW Radar	OPTIWAVE
	Denaturant (gasoline) flow	Ultrasonic-inline triple beam	OPTISONIC
Dried Distillery Grain	1st effect evaporator body pressure	Abs. press. remote diaphragm	OPTITROL
	1st effect evaporator body temperature	Temperature	OPTITEMP
	1st effect evaporator level	OPTIWAVE 24GHz FMCW Radar	OPTIWAVE
	1st effect evaporator shell pressure	Absolute pressure	OPTITROL
	2nd effect evaporator body pressure	Abs. press. remote diaphragm	OPTITROL
	2nd effect evaporator body temperature	Temperature	OPTITEMP
	2nd effect evaporator level	OPTIWAVE 24GHz FMCW Radar	OPTIWAVE
	2nd effect evaporator shell pressure	Absolute pressure	OPTITROL
	3rd effect evaporator body pressure	Abs. press. remote diaphragm	OPTITROL
	3rd effect evaporator body temperature	Temperature	OPTITEMP
	3rd effect evaporator level	OPTIWAVE 24GHz FMCW Radar	OPTIWAVE
	3rd effect evaporator shell pressure	Absolute pressure	OPTITROL
	Ethanol day tank high level	Tuning Fork Level Switch	OPTISWITCH
	Evaporator condensate to DDE condensate tank	Temperature	OPTITEMP
	Evaporator vacuum eductor suction pressure	Absolute pressure	OPTITROL
	Evaporator vacuum receiver level	Continuous level with seals	OPTITROL
	Stillage from evaporator feed pump flow	Electromagnetic flow	OPTIFLUX
	Syrup tank high level	Tuning Fork Level Switch	OPTISWITCH
	Syrup tank level	OPTIWAVE 24GHz FMCW Radar	OPTIWAVE
	Syrup tank temperature	Temperature	OPTITEMP
	Syrup to dryer flow	Electromagnetic flow	OPTIFLUX
	Syrup to syrup tank flow	Electromagnetic flow	OPTIFLUX
	Thin stillage collection tank high level	Tuning Fork Level Switch	OPTISWITCH
	Thin stillage collection tank level	OPTIWAVE 24GHz FMCW Radar	OPTIWAVE
	Thin stillage tank level	OPTIWAVE 24GHz FMCW Radar	OPTIWAVE
	Thin stillage tank temperature	Temperature	OPTITEMP
	Whole stillage tank temperature	Temperature	OPTITEMP
	WS to centrifuge flow	Electromagnetic flow	OPTIFLUX
Evap 2nd Stage Draw Flow and Density	Straight Tube Coriolis density/mass flow/%solids	OPTIMASS	
Storage	Alpha amylase tank high level	Tuning Fork Level Switch	OPTISWITCH
	Alpha amylase tank level	OPTIWAVE 24GHz FMCW Radar	OPTIWAVE
	Alpha to slurry mix tank flow	Electromagnetic flow	OPTIFLUX
	Ammonia tank high level	Tuning Fork Level Switch	OPTISWITCH
	Ammonia tank level	OPTIWAVE 24GHz FMCW Radar	OPTIWAVE
	Caustic tank high level	Tuning Fork Level Switch	OPTISWITCH
	Caustic tank level	OPTIWAVE 24GHz FMCW Radar	OPTIWAVE
	Dilute caustic tank temperature	Temperature	OPTITEMP
	Gluco amylase tank high level	Tuning Fork Level Switch	OPTISWITCH
	Gluco amylase tank level	OPTIWAVE 24GHz FMCW Radar	OPTIWAVE
	Gluco to yeast propagation flow	Electromagnetic flow	OPTIFLUX
	Sulfuric acid tank high level	Tuning Fork Level Switch	OPTISWITCH
	Sulfuric acid tank level	OPTIWAVE 24GHz FMCW Radar	OPTIWAVE
	Urea tank high level	Tuning Fork Level Switch	OPTISWITCH
	Urea tank level	OPTIWAVE 24GHz FMCW Radar	OPTIWAVE
	Urea to yeast propagation flow	Electromagnetic flow	OPTIFLUX
	Ammonia tank pressure	Absolute pressure	OPTITROL
Utilities	Air header pressure	Absolute pressure	OPTITROL
	Chilled water header pressure	Absolute pressure	OPTITROL
	Chilled water return header pressure	Absolute pressure	OPTITROL
	Chilled water supply header temperature	Temperature	OPTITEMP
	Cooling water header pressure	Absolute pressure	OPTITROL
	Cooling water return header temperature	Temperature	OPTITEMP
	Cooling water supply header temperature	Temperature	OPTITEMP
	Liquid water flow 10" to 12" pipe	Electromagnetic flow	OPTIFLUX
	Liquid water flow 24" pipe	Electromagnetic flow	OPTIFLUX
	Process condensate tank temperature	Temperature	OPTITEMP
	Process water supply H pressure header	Absolute pressure	OPTITROL
	Saturated steam flow 10" to 12" pipe	Multi variable Vortex Flow	OPTISWIRL
	Softened water to boiler flow	Metal Tube Variable Area flow	H250/M10
	Waste water flow	Electromagnetic flow	OPTIFLUX