Improving the Moisture Control of Distillers Dry Grain

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Abstract

This paper is a case study of a moisture control improvement project done on a distillers grain dryer. Dryers can have very long time lags, making moisture control a real challenge. This paper analyzes problems experienced with poor moisture control, identifies three areas for improvement, describes the solutions, and covers their systematic implementation. Results from the various stages of implementation are presented, showing how each phase contributed to improve the overall control performance of the dryers.

Introduction

Ethanol and hard spirits like whiskey and rum are made by fermenting grain and extracting the alcohol through distillation. The starch-less grain, now a byproduct of the process, is sold as high-protein livestock feed. The grain is often dried by the distiller to allow storing the product without spoiling. The dried grain, called Distillers Dried Grain (DDG), is an important source of income for distillers.

Distillers grain is dried in a continuous process at the rate it is produced. Depending on the equipment used and the type and location of the instrumentation, the DDG drying process can have very long time lags. These create a challenge for automatically controlling the DDG moisture. This is a concern to distillers, because the moisture content of DDG is important from a financial, product quality, and materials-handling point-of-view.

This paper is a case study of a moisture control improvement project done on the distillers grain dryer at a whiskey distiller. It analyzes the problems experienced, identifies areas for improvement, describes the solutions, and covers their systematic implementation with results from the various stages of implementation.

Process Description

At the front end of the whiskey-making process, grain is ground into coarse flour in a hammer mill. The flour is mixed with water and enzymes, and the slurry is called mash. The mash is cooked to kill any bacteria in it, and held at an elevated temperature while the enzymes convert starch to sugar.

The mash is then mixed with yeast and held in fermentation tanks while the yeast converts the sugar to alcohol. After fermentation, the mash is pumped to the distillation process where the alcohol is extracted.

The remnants of the mash, now referred to as stillage, are pumped from the bottom of the first distillation column to a centrifuge. Here the stillage is separated into liquid called thin stillage, and solids called Distillers Wet Grain (DWG). Some of the thin stillage is routed back to the fermentation side of the process while the remainder is reduced in volume through a multiple-effect evaporator system, ultimately called syrup. The syrup is held in a tank from where it is mixed in with the DWG before entering the dryer.

The dryer is a multi-pass, rotating kiln dryer in which a gas-fired burner produces hot air that is blown over the tumbling DWG inside the rotating dryer to dry it into DDG.

DDG Moisture Control

The flow rate of the fuel gas into the burner can be adjusted to control the moisture content of the DDG. Adding more fuel drives more water off the DWG, resulting in DDG with a lower moisture content. In this way the moisture controller can theoretically keep the moisture content of the DDG at its set point by slightly opening or closing a control valve on the burner's gas supply line.

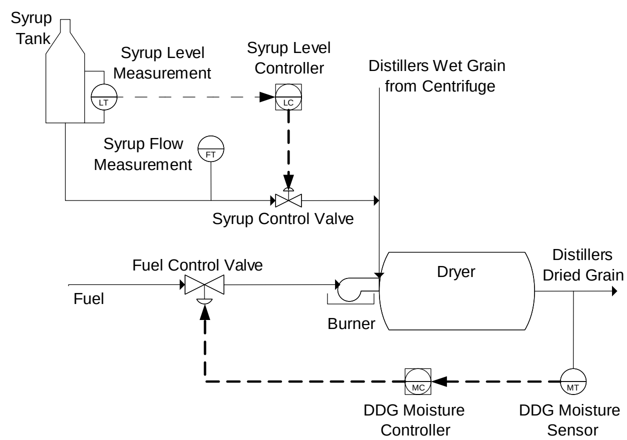

Figure 1. DDG moisture and syrup level control loops.

An infra-red moisture sensor measures the moisture content of the DDG after it exits the dryer. The moisture controller reads the moisture signal from the sensor, compares it to the moisture set point, and adjusts the position of the fuel flow control valve on the burner to make any corrections needed. The sensor, controller, valve, and drying process comprise the moisture control loop.

Syrup Level Control

Another control loop is installed to keep the liquid level in the syrup tank at its set point. A level sensor detects the level in the tank. The level controller compares this measurement to the level set point and makes changes to the position of the syrup flow control valve. If the tank level is slightly too high, the controller opens the control valve a little more to increase the syrup outflow and bring the level back to its set point.

Problem Description

The distiller experienced several difficulties with the moisture control of the DDG and the level control of the syrup tank.

The DDG moisture controller was unable to handle changes in syrup flow rate. Because of the water content of the syrup, changes in syrup flow rate affected the moisture content of the wet grain entering the dryer, eventually causing large deviations in moisture content of the grain exiting the dryer.

The moisture controller seemed to respond too slowly to compensate for changes in syrup flow rate. Attempts to speed up the response of the moisture controls resulted in an unstable moisture control loop, causing large oscillations in fuel gas flow and DDG moisture content.

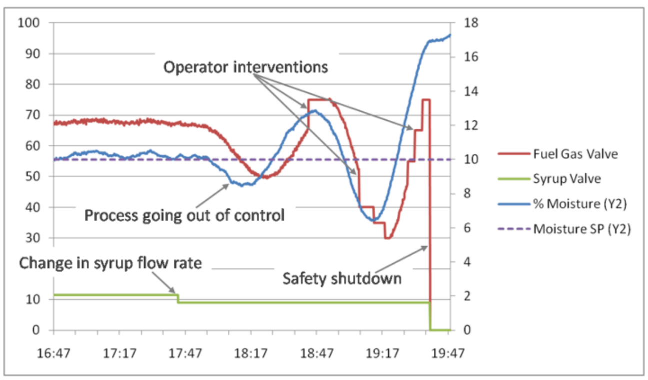

Figure 2. Unstable moisture control after changing syrup flow rate.

The operators had to continuously monitor the DDG moisture and were frequently required to intervene when the automatic controls were incapable of maintaining the moisture close to the set point. It was also very hard for the operators to manually stabilize the system once it was upset. Figure 2 shows the system going unstable after a change in syrup flow, followed by unsuccessful attempts by the operator to regain control over the process.

Because of the severe deviations in DDG moisture following changes in syrup flow rate, the syrup tank level controller was kept in manual control so that the operators could manually make changes to the syrup flow rate, monitor the moisture controller's response afterward, and intervene if necessary.

Business Impacts

The unreliable DDG control had several direct impacts on the distiller's business. The DDG was seldom produced at the required dryness. It was either too wet or too dry.

When the DDG was too dry, profits were lower because the end-product contained more costly solids and less free moisture per ton sold. At times the DDG became so dry that it was scorched by the dryer because there was no more moisture to evaporate and absorb the heat. Scorched DDG had to be scrapped or sold at a reduced price, again reducing the distiller's profit.

When the moisture content of the DDG was too high, it exceeded the specified moisture limit for the product and had to be sold at a lower price. DDG with a high moisture content has less nutritional value per ton, and it is likely to spoil more easily – therefore the lower selling price.

In addition, DDG that is too moist tends to be sticky. Often the distiller had problems with moist DDG clumping together and blocking the chutes of the materials handling system downstream of the dryer. When this happened, the drying process had to be shut down and the equipment cleaned out manually.

An intangible business impact resulted from running the syrup tank level controller in manual. Operator time spent in periodically monitoring the tank level and adjusting the syrup flow rate took time away from more important activities required by the high-value distillation process.

Solutions Tried

Several solutions were tried before this project was initiated.

The distiller tried tuning the moisture controller, but was unable to get a response fast enough to eliminate large deviations caused by changes in syrup flow rate. Speeding up a control loop's response makes the loop less stable. In this case, the control loop seemed to go unstable long before the desired speed of response could be achieved.

The moisture controller could be run in manual mode, but this was not a good option because it required almost continuous attention from the operator. Also, operators found it very difficult to control this particular system manually.

The manufacturer of the dryer was asked to investigate the problem. Different moisture analyzers were tried without success. The fuel control valves on burners were replaced with different types, but that too made no difference.

New Solution Strategy

As part of the controls improvement project, the following strategy for solving the problem was proposed, accepted, and implemented.

First, the moisture controller's tuning settings had to be adjusted to ensure the moisture control loop would remain stable under changing syrup flow rates. It was recognized that while optimal tuning settings could ensure loop stability, the control loop might still respond too slowly to handle the disturbances caused by changes in syrup flow rate.

Accordingly, the second step was an investigation of the effect of syrup flow on the moisture control loop and the implementation of a feedforward control strategy to resolve this major problem.

Finally, the syrup level controller would be tuned so that it could be run in automatic control.

Tuning the Moisture Controller

Proper controller tuning methods require step testing the process so that the process' gain and dynamic characteristics can be determined. Once these quantities are known, they are entered into controller tuning formulae to obtain appropriate tuning settings.

Step tests are done by placing the controller in manual mode and changing its output by a few percent. The resulting process response is recorded and the process characteristics are graphically or numerically determined from it.

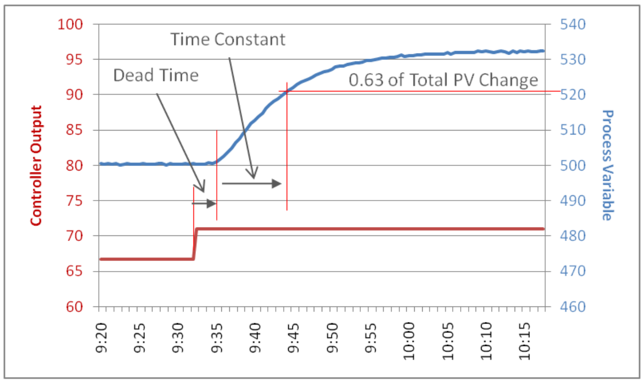

Figure 3. Example of process characteristics for tuning.

Three process characteristics are required for controller tuning (see Figure 3):

- Process Gain: The total change in process measurement (DDG moisture in this case) divided by the change in controller output.
- Dead Time: The time delay between the change in controller output and process first beginning to move.
- Time Constant: The time between the initial process movement and the process reaching 0.63 of its total change.

Several step tests were done on the dryer, and the results were recorded and analyzed. Figure 4 shows two of these step tests.

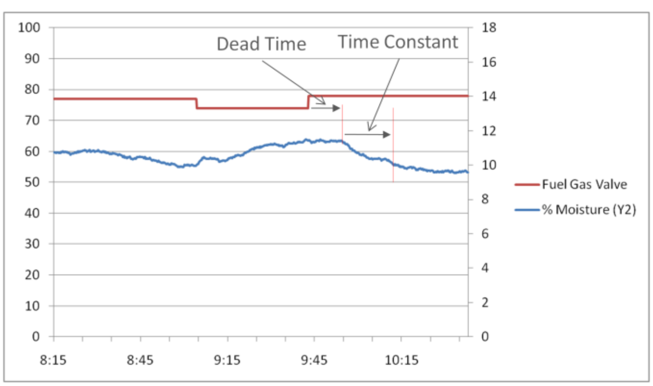

Figure 4. Dryer step test data showing controller output changes and their effect on DDG moisture.

The process dead time was measured to be 10 minutes and the time constant 13 minutes. These delays are very significant in duration and are the reason why the dryer moisture was so difficult to control. (Imagine taking a shower and having a 10-minute delay between changing the hot water flow rate and feeling the result.)

With the actual process characteristics available, the new controller settings were calculated. The controller's newly calculated Integral Time setting (Ti) was almost three times the original setting. This change would significantly improve the control loop stability. The appropriate controller gain setting (K) was lower than the original, and would further improve control loop stability. Also, it was decided not to use the derivative control mode (Td setting) because the moisture measurement was a noisy signal and noise greatly reduces the usefulness of derivative control.

	K	Ti (minutes)	Td (minutes)
Original	0.45	5	1
New	0.33	14	0

Table 1. Controller settings before and after proper tuning.

With the new controller settings in place, the moisture control loop was placed in automatic control. Then changes were made in syrup flow rate to test the stability of the moisture control loop. As expected, changes in syrup flow rate drove the moisture away from set point, but the moisture controller with its new settings brought the moisture back to its set point in a controlled and stable fashion (Figure 5). This was a significant improvement over the control loop's previous response, shown in Figure 2. However, the deviations in DDG moisture caused by syrup flow rate changes were still a concern.

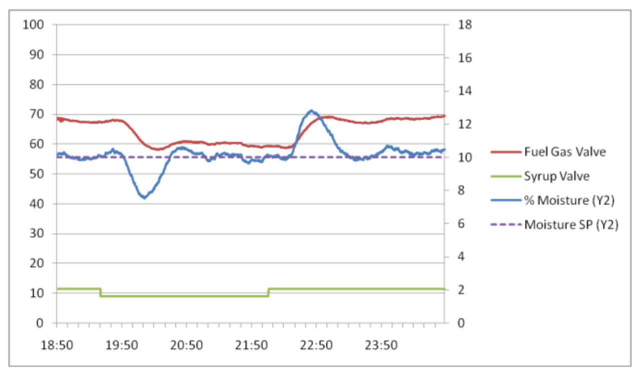

Figure 5. Improved performance after tuning.

Reducing the Effect of Syrup Flow Rate Changes

Changes in syrup flow rate proved to have a large, but repeatable and predictable effect on DDG moisture. If a disturbance is measurable, and its effect is predictable, the problem can be greatly reduced, if not completely eliminated, using feedforward controls.

A feedforward controller uses the measured value of a disturbance to calculate an appropriate control action that will counteract the effect of the disturbance. A feedforward controller consists of an adjustable gain to get the right amount of control action, and a lead-lag function to get the right timing for the control action.

In this case, a feedforward controller was designed to use changes in syrup flow rate for making appropriate counter-active changes in fuel flow. Figure 6 shows the feedforward controller in red ink.

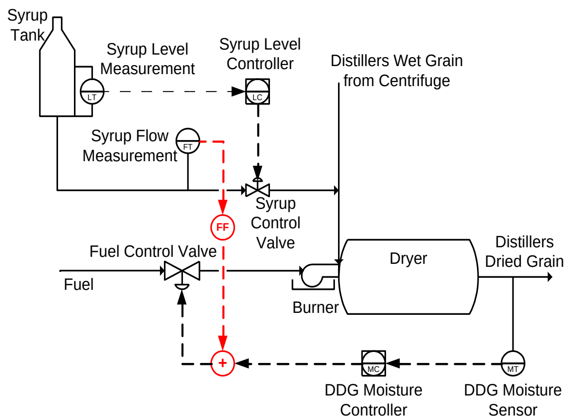

Figure 6. Feedforward controller.

The feedforward controller's gain and lead-lag settings were calculated using data already available from step tests and syrup flow rate changes. Some fine tuning was done after implementation. The result was a vastly improved capability for maintaining the DDG moisture close to set point after changes in syrup flow rate. During testing, the DDG moisture remained reasonably close to set point following changes in syrup flow rate (Figure 7).

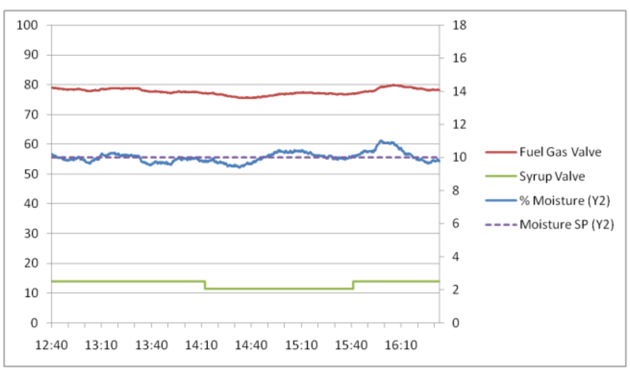

Figure 7. Improved moisture control with feedforward.

Syrup Tank Level Controller

The final step in the list of corrective actions was to tune the syrup tank level controller so that it could be run in automatic control. Once the controller was tuned, it was placed in automatic control and monitored for a while. It made only small corrections to the syrup flow rate to keep the tank level at its set point. These small changes in syrup flow were picked up by the feedforward controller and their effects were counteracted sufficiently well. The DDG moisture remained within one percent from its set point (Figure 8). The tank level was left running in automatic control.

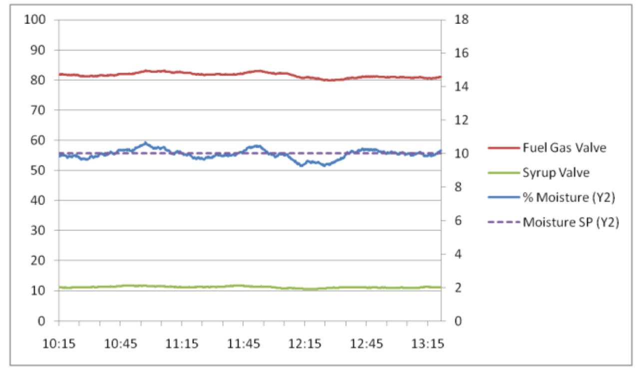

Figure 8. Syrup tank level under automatic control.

Summary

A whiskey distiller had severe problems with the DDG moisture controls. Problems included off-spec product and system blockages. At times the moisture control system went unstable and operators had to intervene. The DDG moisture was also drastically upset by changes in syrup flow rate.

A three-step solution was proposed and implemented. First the DDG moisture controller was tuned based on the process' true dynamic characteristics obtained from step test data. The new controller settings stabilized the control loop, but changes in syrup flow were still causing large deviations in DDG moisture.

Then a feedforward controller was implemented to change the fuel flow rate based on changes in syrup flow rate. This addition had a very significant positive effect on control performance. The DDG moisture remained within acceptable limits after syrup flow rate changes.

Finally, the syrup tank level controller was tuned. After this the controller could be left running in automatic control mode.

As a result of the three corrective actions, DDG moisture control was no longer a problem, DDG profits improved, and operators could focus their time on the more valuable whiskey-making process.