Impacts of automated single barrel bourbon processing on overall product quality and production rate

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The global market is experiencing a significant increase in demand for premium single barrel bourbon products. The need for separate manipulation of each barrel's contents exerts a significant technical strain on all processing operations from barrel emptying to the filling of the bottle. Each of the two blending steps where water is added to the spirit were particularly error prone, occupied large physical footprints, withdrew labor from other critical tasks, and were limiting to the overall single barrel production volume. In this study, we measured the impacts of converting the manual blending operations to an automated process at the Four Roses Warehouse and Bottling Facility from before the changeover in 2019 until the end of 2022. During this time, the use of automated blending enabled a 62% increase in overall production of single barrel cases while the total number of quality holds was reduced by 46%. The daily single barrel processing rate increased by 15% immediately after automation, and the daily production rate was more consistent after automation. This automated approach enabled a significant increase in throughput without additional process footprint.

INTRODUCTION

The processes between maturation and bottling for a premium whiskey are complex and technically demanding. The extractive and reactive processes of whiskey maturation create different expressions of aroma, flavor,[1, 2] color, and mouthfeel within each barrel.[3-7] These unique sensory profiles that support the premiumization of single barrel products[1] also result in differing amounts of evaporative and other losses in each barrel.[8] These losses change both the total volume of liquid yield after maturation and the alcohol concentration.[9] In many products, the concentration of alcohol is reduced from a barrel strength near 60% alcohol by volume to a more palatable and consistent level near 50% alcohol by volume.[10] As an additional processing challenge, alcohol dilution often reduces the solubility of trace compounds in the whiskey product at low temperature.[11] These precipitated compounds alter the visual appeal of the spirit and are frequently removed via chill filtration.[12].

In all, the path from barrel to bottle often involves a barrel dump where barrel carbon is screened out, a rough cut, chill filtration,[13] and a final cut (Figure 1). The rough cut is a preliminary dilution to a concentration just higher than the intended final alcohol content in the bottle. The rough cut allows haze-forming compounds to be removed during chill filtration. The procedure for the rough cut consists of measuring the alcohol content of the spirit, calculation of the water addition, mixing in the water, and verification of alcohol content. Each distiller's approach to chill filtration will vary. In general, the spirit is cooled to 0 °C, run through a depth filtration pad and warmed back up to near room temperature.[12] Then, the final cut involves measurement of the alcohol content, calculation of the water addition to achieve bottling alcohol content, mixing in the water, and verification of alcohol content.

In the United States, the concentration of alcohol in the container must be within 0.3 % alcohol by volume of the concentration stated on the label.[14] If the concentration is too high, the spirit may be reworked through the addition of more water. If the concentration is too low, it is not possible to add more alcohol and still be defined as a single barrel product. The over-diluted spirit must be incorporated into a future batch of a blended product.

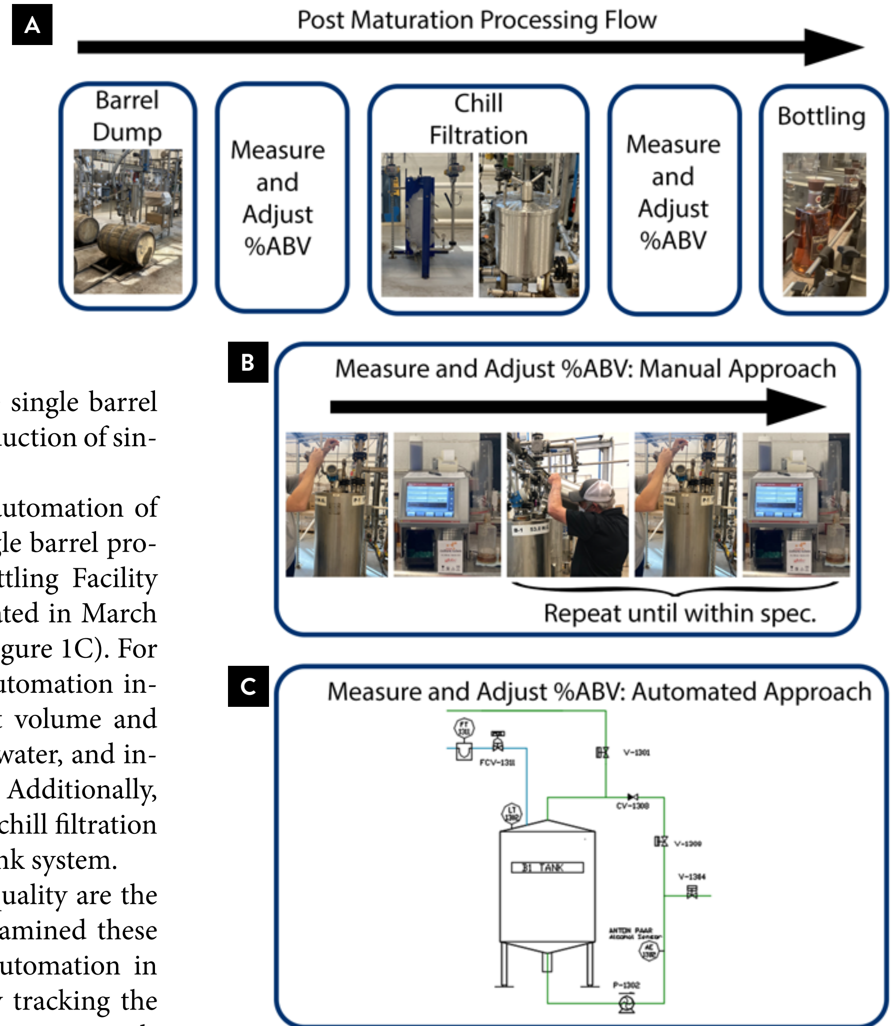


FIGURE 1 *Overview of single barrel processing.* **A:** Detailed progression of steps required to deliver a shelf-stable single barrel product at Four Roses Distillery. **B:** Manual approach to single barrel bourbon blending. **C:** Automated approach to single barrel bourbon blending.

The demand for single barrel products has increased dramatically, where some major single barrel products have recently surged by 47.5 percent in a year.[15] While the production volumes of single barrel products have increased, the production methods have not adapted to this change. The throughput of batched bourbons may be improved through an increase in batch size. The definition of a single barrel product precludes alteration of batch size. In the case of Four Roses, the single barrel processing was a rate limiting step in the production of single barrel products in 2019.

This manuscript evaluates the impact of automation of the dilution and filtration processing on single barrel production at Four Roses Warehouse and Bottling Facility in Cox's Creek, KY. The process was automated in March 2021 by JCS Process and Control Systems (Figure 1C). For each alcohol content adjustment step, the automation included the in-line measurement of product volume and alcohol concentration, automated dosing of water, and in-line confirmation of alcohol concentration. Additionally, the automation system included handling of chill filtration and batch transfers throughout the twelve-tank system.

The overall production rate and product quality are the expected impacts of automation, and we examined these from before automation in 2019 to after automation in 2022. The product quality was measured by tracking the total number of quality holds associated with incorrect alcohol concentration. We consider these metrics relative to an alternative strategy of increasing throughput through expansion of infrastructure for manual dilution. We contrast the impacts of a manual versus automated approach on the overall capital and operating expenditures. Major factors impacting capital expenditures included the real estate associated with overall process footprint and the costs of new process equipment. Major factors impacting operating expenditures included labor.

MATERIALS AND METHODS

DATA COLLECTION

All data described in this study was generated as a part of normal production operations at Four Roses Warehouse and Bottling Facility in Cox's Creek, KY between January 1, 2019 and December 31, 2022. Production data includes the date of production, the number of barrels processed in a given day, the number of production hours in a given day, and the number of quality holds each year. All data sets were recorded into batch records as a part of routine operation. The data presented was retrieved from production batch records on February 15, 2023, December 7,2023, and January 16, 2024. All cases of spirits are reported in equivalent 9 L cases. Alcohol content is expressed in percent alcohol by volume (%ABV).

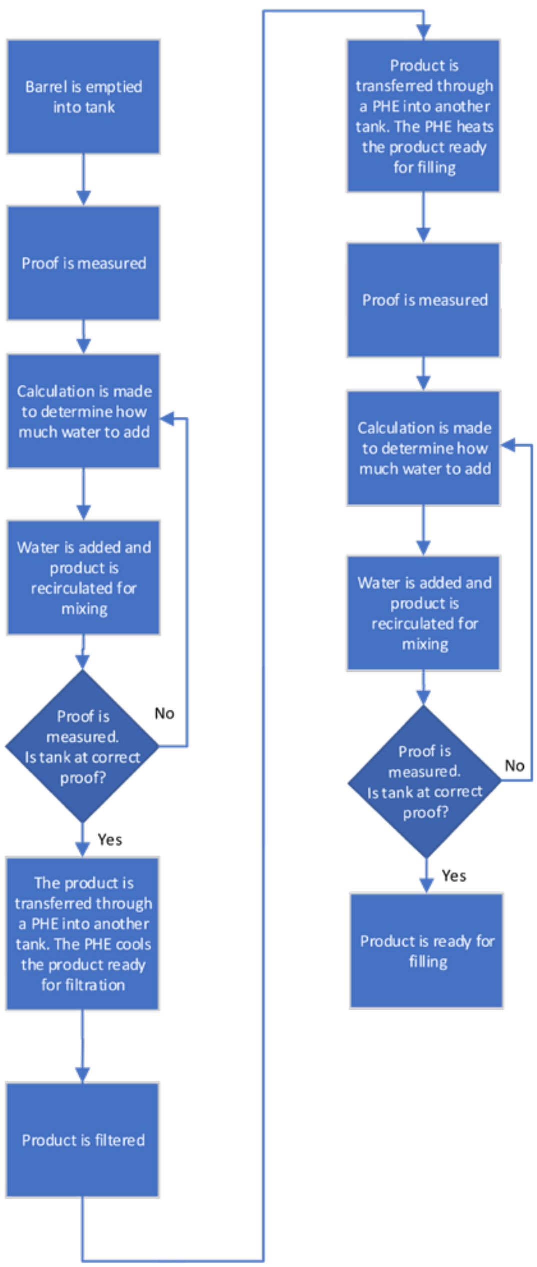
PRODUCTION OVERVIEW

The Warehouse and Bottling Facility receives new make spirit from Four Roses Distillery in Lawrenceburg, KY, stores the spirit in barrels, and processes the mature spirits into bottles for all Four Roses product lines. This study focuses on the effect of automation inclusive of emptying the barrel, blending to the correct alcohol content for chill filtration, chill filtration, and dilution to the correct alcohol content for bottling. The individual steps in this process are visually presented in Figure 2.

PRODUCTION METHODS BEFORE AUTOMATION

Production methods from immediately prior to the automation were retrieved from the SOPs in place during 2019 through April 2021.[16-21] Six operators were required to run the dilution and filtration operations, and the roles of each operator are summarized in Table 1.

FIGURE 2 Overview of single barrel processing between barrel evacuation and transfer to the bottling line.



PRODUCTION METHODS AFTER AUTOMATION

This study focuses on the effect of automation during product blending prior to bottling. Production methods from immediately after the automation were retrieved from the SOPs in place from May 2021 through December 2022.[16, 22, 23] Two operators were required to run the dilution and filtration operations, and the roles of each operator are summarized in Table 2.

AUTOMATION

Automation of the blending system was designed and implemented by JCS Process & Control Systems. In this system, the automated solution mimics manual operation except the system uses instrumentation to monitor and control flow rates, levels, temperatures and % ABV. Two processing trains were run in parallel with identical processing.

TABLE 1 Operator roles and responsibilities within the dilution and filtration processing operation prior to automation.

NUMBER / TITLE	DESCRIPTION
1 / Evacuator	Organizes, stages, and rolls barrels. Removes the bung and inserts evacuation tube. Responsible for handling the paperwork for each barrel.
2 / Head Proofer	Pulls sample at final bottling tank and checks / document the final %ABV, color, and clarity using the benchtop meters.
3 / Proofer 1	Proofer 1 is responsible for the rough cut and final cut on Train 1. The proofer pulls samples from the Train 1 rough cut and measures / adds the required water to cut the liquid to within 0.5 %ABV of the alcohol content listed on the label. The proofer pulls samples from the Train 1 bottling tank and measures / adds the required water to cut the liquid to within 0.3 %ABV of the alcohol content listed on the label.
4 / Proofer 2	Proofer 2 is responsible for the rough cut and final cut on Train 2. The proofer pulls samples from the Train 2 rough cut and measures / adds the required water to cut the liquid to within 0.5 %ABV of the alcohol content listed on the label. The proofer pulls samples from the Train 2 bottling tank and measures / adds the required water to cut the liquid to within 0.3 %ABV of the alcohol content listed on the label.
5 / Processor 1	Processor 1 is responsible for the liquid transfer on Train 1. Processer 1 throws hand valves at each step to move liquid, turns on pumps to transfer liquid from step to step, and changes the filter stack when filters need to be replaced.
6 / Processor 2	Processor 2 is responsible for the liquid transfer on Train 2. Processer 2 throws hand valves at each step to move liquid, turns on pumps to transfer liquid from step to step, and changes the filter stack when filters need to be replaced.

TABLE 2 Operator roles and responsibilities within the dilution and filtration processing operation after automation.

NUMBER / TITLE	DESCRIPTION
1 / Processor	1. Manages the organization of barrels, removing the bung, inserting evacuation tube, and evacuating liquid into the system.
2 / Processor	2. Monitors the automatic transfer of the liquid in the system from step to step concluding with the automatic transfer from the final bottling tank to the filler hopper. 3. Changes the filter stack when filters are spent and need to be replaced. 4. Pull samples in the final bottling tank to check for color and clarity using benchtop meters and a retained sample. 5. Documents all transfers and testing information on the batch form.

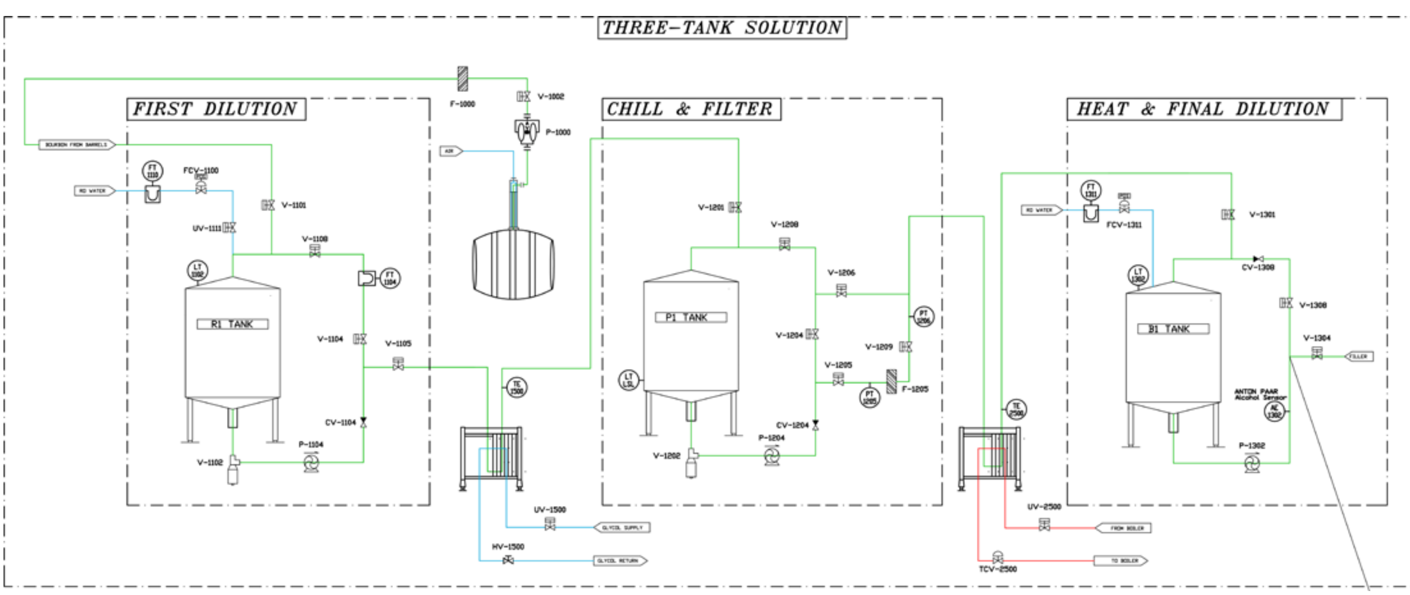
The measurement and adjustment of alcohol content was critical to this process. Alcohol content and temperature prior to chill filtration (rough cut) were measured using a mass flow meter and the internal temperature sensor from the meter. The total amount of liquid in the rough-cut tank was measured via a tank mounted level transmitter. Dilution calculations were performed within the PLC to achieve a spirit of approximately 50.5% alcohol by volume, with the limiting factor being the accuracy of the mass meter used to determine concentration. The TTB Gauging Manual [24] was used to design the calculations for water addition in the PLC. The temperature of the spirit was accounted for in these calculations. For the dilution operation, the bourbon is recirculated in the mixing tank by pumping from the bottom of the tank past the temperature and alcohol sensor and into the top of the tank. The calculated amount of water is fed past a mass flow meter at a low rate into the top of the mixing tank. After passing through filtration, the alcohol content of the liquid received in the final dilution tank was measured using an Anton-Paar inline alcohol meter. The total amount of liquid in the final dilution tank was measured using a tank mounted level transmitter. Dilution calculations were performed as before to achieve a spirit 50.0 ± 0.3 % alcohol by volume.[14] After dilution was complete, final product strength was verified and recorded using the inline alcohol meter before sending to the filling line. This inline alcohol meter is approved by the TTB for use for the determination of the alcohol content of spirits,[25] and these spirits may be sent directly to bottling without off line determination of alcohol content.

Batch integrity is especially challenging for the simultaneous processing of many single barrel batches at a time. For the automated processing, the control system does automated tracking of each batch from barrel to filling. In addition, compressed air is automatically cycled after each transfer to clear all transfer lines between batches.

RESULTS AND DISCUSSION

In this study, we measure the impact of process automation on single barrel dilution and filtration. To our knowledge, this was the first project in Kentucky automating the labor-intensive steps where the alcohol concentration of a

FIGURE 3 Overview of the single barrel processing train 1 at Four Roses Warehouse and Bottling Facility after automation.



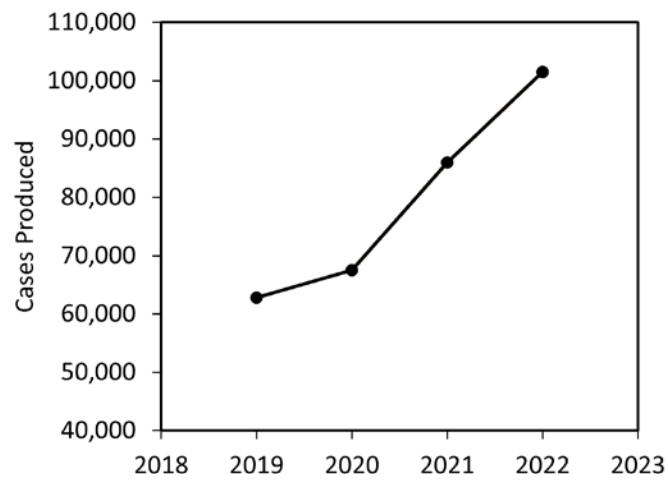
single barrel whiskey product is lowered. The automation approach developed by JCS Process & Controls is based on multiple automated measurements of the spirit %ABV and the automated addition of water. After evacuating the barrel, one automated dilution step brings the spirit to 50.5 %ABV, and following chill filtration, another dilution step brings the spirit down to the target bottling concentration of 50 %ABV. This automation approach was implemented in the filtration and dilution operations at Four Roses Warehouse and Bottling Facility in Cox's Creek, KY in March of 2021. We then evaluated the effects of automation on daily and annual production volumes and accuracy of dilution.

EFFECT OF AUTOMATION ON OVERALL PRODUCTION OF SINGLE BARREL PRODUCTS

With the recent surge in bourbon demand, production volume is the highest priority for most Kentucky distillers. Fermentation and distillery production capacity is frequently highlighted in the media.[26-29] Fermentation and distilling expansions must be later matched with additional processing and bottling capacity.[30] Capacity expansion of the single barrel product lines may also offer the benefit of diverting liquid to higher value products. The current retail price of Four Roses Single Barrel is 38% higher than that of the Four Roses Small Batch product.

The automation of the single barrel dilution and filtration system in March of 2021 supported a significant increase in the annual production volumes of the single barrel product lines. For the net impact of this intervention on sales, we must consider production of single barrels cases each year. In this work, we primarily compare data annual production data from 2019 and 2022 (Figure 4). While 2020 data is available, the effect of the COVID pandemic[31, 32] prevents a direct comparison to 2020 production data. When considering cases of Single Barrel produced annually, Four Roses processed 62,824 cases in 2019. The production of cases rose 61.6% to 101,513 over the following three years.

FIGURE 4 Annual production of Four Roses Single barrel products measured cases.

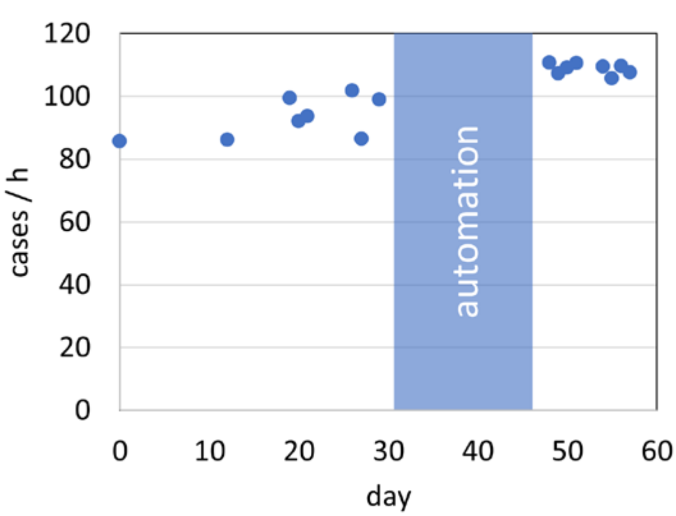


Since single barrel product operations are performed on a per-barrel basis, the number of single barrels processed is the most significant production metric to this study. Four Roses processed 3,609 barrels of single barrel products in 2019. In 2022 that number rose to 5,751 barrels which is a 59.4% increase in barrel throughput. The number of cases produced from each barrel vary significantly on a single-barrel basis. These barrel yield differences originate from the variable impact of the angels' share (liquid losses during maturation) on a barrel's liquid volume and %ABV.[8] It is also possible that the minor discrepancies between barrel- and case-level production are attributable to less loss of product in 2022 during barrel processing.

Across both barrel-level and case-level production, there was an increase in single barrel production of ~60%. The implementation of the process automation in March of 2021 results in a gradual increase in annual single barrel production totals across 2019 to 2022. This enhanced dilution and filtration production velocity eliminated a critical bottle neck and made bottle filling the rate-limiting single barrel production operation. When considering the maximum hourly production for a given day, the single barrel production was limited to 101 cases per hour in 2019. With additional investment, the bottling line was upgraded to support a production rate of 116 cases per hour in 2022.

To remove the influence of other changes to the system, we isolated data for the eight production days before and after commissioning of the automation system. The single

FIGURE 5 Mean daily production rate for the eight production days prior to automation and the eight production days following automation. Days without data are indicative of no single barrel production on the given day. One day of single barrel production during commissioning of the automation was omitted.

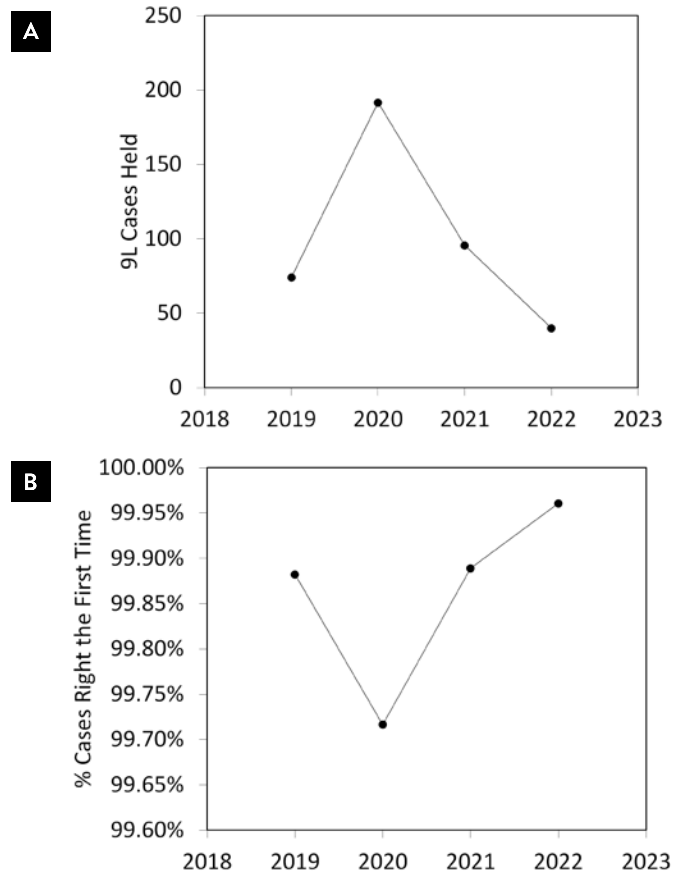


barrel production line produced 93.0 cases per hour before automation compared to an average of 108.7 cases per hour after automation (Figure 5).

Beyond the increase in average production rate, the variability in production rates is lower after automation. The standard deviation of production rate before automation was 6.3 cases/h, while immediately after automation the standard deviation of the production rate was 1.8 cases/h. This significant improvement in production rate consistency enables greater confidence in production planning and economic forecasting.

The discrepancy between the 60% increase in annual production and the 15% increase in hourly production is also tied to the number of days the single barrel processing was in operation. The 15% value of improvement is the clearest direct comparison of production rates with manual and automated dilution technologies. Prior to automation, the facility was unable to staff both the single barrel products and other product runs. The pre-automation approach required six operators to run single barrel processing (Table 1). Following automation, only two operators were required (Table 2). As a result, there was sufficient staffing to more frequently operate both Four Roses processing lines simultaneously.

FIGURE 6 *Impact of dilution and filtration automation on production quality.* **A:** Annual volume of single barrel product held for inaccurate alcohol content from 2019-2022. **B:** Percent cases right the first time from 2019-2022. Percent right the first time defined as the number of cases each year that are accurately diluted divided by the total annual production in cases times 100%.



EFFECT OF AUTOMATION ON QUALITY HOLDS IN SINGLE BARREL PRODUCTION

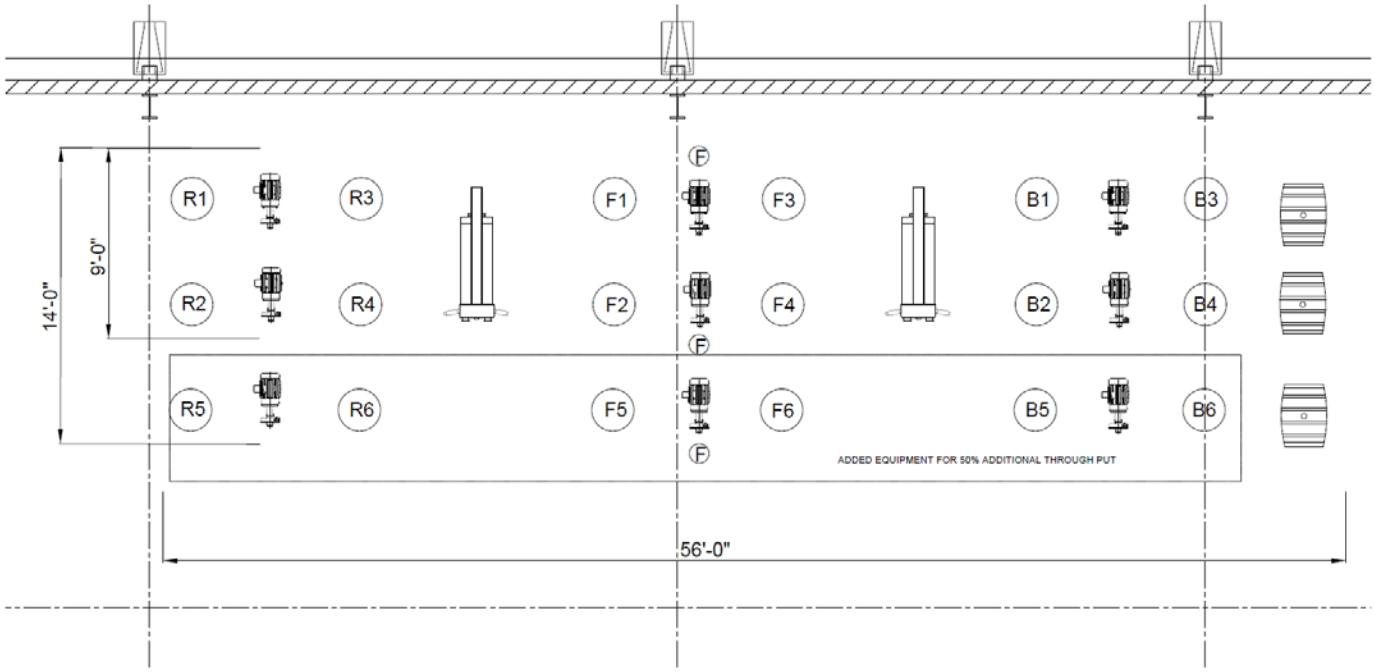
For US markets, the alcohol content of the final bottled product must be within 0.3 percent alcohol by volume of the value listed on the label.[14] Inaccurate dilution leads to a hold on the product, isolation of the goods, root cause analysis of the hold, and potential rework of the spirit. The rework process takes bourbon intended for Four Roses Single Barrel and blends it into Four Roses Bourbon retailing for a significantly lower price. Additionally, all corrugate, bottles, corks and labels from the packaging are lost. In all, inaccurate dilution increases the production costs per case of goods sold while also decreasing the value of the goods sold.

In 2019, there were 74 cases of single barrel products held for inaccurate alcohol content. Based on the annual production of cases in Figure 3, there are approximately 158 L of product per single barrel processed. For a target product concentration of 50% alcohol by volume and these batch volumes, less than a liter too much water would result in an uncorrectable quality hold. It is reasonable to see how this magnitude of inaccuracy could result from manual operations (Figure 1B) with several tanks being processed in parallel.

Following automation of the dilution and filtration system, there were only 40 single barrel cases held for dilution issues in 2022. It is important to consider this 46% reduction in total number of cases held occurred in unison with a 62% increase in cases produced. This represents a 66% decrease in the fraction of cases held for incorrect alcohol content from 2019 to 2022. When framed around the percentage of cases accurately diluted the first time, 99.88% of cases produced in 2019 were "right the first time". In 2022, the proportion of cases that met quality standards increased to over 99.96%. In all, these metrics are indicative of a significant increase in the repeatability of the dilution process and a progression towards increased product consistency.

The decrease in holds for inaccurate alcohol content following automation is expected based on the precision of liquid addition and an expected lower error rate of calculation for the automated system. Similar quality and productivity improvements have been seen with automation in the automotive industry.[33] Additionally, the decrease in holds is likely attributable to the decreased complexity of an operator's role in the dilution and filtration system.

FIGURE 7 *Relationship between automation and required production space.* Actual floorplans of Four Roses's dilution and filtration processing area in 2019 using manual processing is the same as in 2022 using automated processing. The box in this figure indicates the hypothetical addition of a processing line for a 50% increase in annual production capacity.



Previous studies have shown that an increase in manufacturing complexity is associated with a decrease in quality,[34] and the complexity of the operator role significantly decreased following automation. Prior to automation, operators spent up to six weeks training on six standard operating procedures. Key training tasks for manual operation include learning the correct sequence for process flow, familiarization with tank and value numbers. With many valves and tanks on each processing train, even fully trained processors were prone to manipulating the wrong valve leading to a quality hold.

Following automation, operators spent two weeks training on three standard operating procedures. The post-automation training primarily covered the control system interface and tracking the progression of each batch on the screen. Because the operator is no longer responsible for tracking process flow or manually adjusting valves, the training is faster and more efficient. Additionally, the decreased complexity of the operator roles is supportive of a lower hold rate.

CHALLENGES OF FACILITY EXPANSION

In this case study, an effective automation strategy allowed for more efficient use of space. Following an automation intervention, the single barrel production volumes at Four Roses increased 60% from 2019 to 2022 (Figure 2) while the footprint of the single barrel processing operation remained constant (Figure 7).

Many facilities have opted for an expansion of their physical processing space to increase their annual production volume.[35-37] The box in Figure 7 shows the impact of adding additional tanks for the manual process to increase throughput instead of automating the line. This expansion requires significant capital expenditures owing to the addition of six tanks, chill filtration modules, and all associated piping and instrumentation. This also requires additional production space for a 50% expansion in dilution and filtration capacity totaling 280 square feet. In contrast, the automated blending and filtration system required no additional space. Finally, the acquisition of new land by distillers is increasingly political,[38, 39] and additional legal and public relations costs are tangible.[40]

Beyond capital expenditures, physical expansion of manual operations would also incur ongoing operating expenditures associated with the labor-intensive approach to processing. Based on roles described in Table 1, an additional processing train would require three additional operators for dilution and filtration to achieve a comparable 50% increase in annual productivity.

CONCLUSIONS

The production of single barrel requires the meticulous dilution and filtration of spirits in low volume batches, and these batches are commonly processed manually. To determine the impact of transitioning the single barrel processing space from manual to automated, the production data before and after the automation of the single barrel dilution and filtration lines was analyzed at Four Roses' Warehouse and Bottling Facility in Cox's Creek, KY in March of 2021. Automation supported a 60% increase in annual and a 46% decrease in total number of quality holds for inaccurate alcohol content from the 2019 to 2022 production years. Together these trends resulted in a decrease in the percent of cases that were held for alcohol content quality issues. Additionally, the automated approach prevented the installation of a third single barrel processing line required for expansion of manual operations. This third processing line would have significantly increased both capital expenses associated with real estate, tanks, filtration, piping, and instrumentation. Additionally, the third production line would have required an additional three operators to dilute and filter single barrel product. Instead of an increase in staffing, the automated operations allowed four of the existing single barrel operators to be allocated to alternate positions at the Warehouse and Bottling Facility.

ACKNOWLEDGMENTS AND ETHICAL COMPLIANCE STATEMENT

All authors contributed to the data collection, analysis, and writing of the manuscript. The authors declare no conflict of interest.

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