FUEL USE PATTERNS IN COTTON GINS

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Abstract

Thirty commercial gins across the U.S. cotton belt cooperated with the USDA-ARS ginning research labs in Stoneville, MS and Mesilla Park, NM, allowing scientists to measure fuel use efficiency during an interval of approximately one hour, representing 30 to 60 bales. Airflow and temperature change were measured to estimate burner fuel consumption. Seed cotton samples before and after each drying system were collected to measure change in moisture content. Fuel use efficiency was calculated as the ratio of moisture evaporated to fuel consumed (both quantities expressed in kilowatts). Substantial variability in initial moisture content and ambient conditions (temperature and humidity) made it difficult to separate the effect of different drying system designs and operating strategies. Fuel consumption can be reduced by locating the burner close to the mix point, insulating the pipe from the burner to the mix point, and idling burners when the moisture content of incoming cotton is less than 7%.

Introduction

The cost of fuel for cotton gin drying system and moisture restoration system burners has increased and currently is between 6.5% and 8.5% of the total cost of ginning (Valco et al., 2015). Fossil fuel costs have been volatile, with the average price for propane doubling over the past ten years, and natural gas increasing as well. Not only are fuel prices unpredictable, the amount of fuel needed depends on the moisture content of seed cotton arriving at the gin, and moisture content is determined by weather conditions. Because these factors are uncontrolled, improving fuel use efficiency is the only means ginners have to manage drying costs.

The first phase of this research program consisted of performing audits in 30 commercial gins across the U.S. cotton belt during the 2016 and 2017 harvest season. The audits attempted to estimate fuel use efficiency for a variety of drying systems in a variety of weather and operating conditions. Fuel use efficiency for this study was defined as the energy used to evaporate water from seed cotton divided by the energy consumed by the drying system burner(s). Because it would be disruptive to shut off the fuel supply during gin operations, and prohibitively expensive to install a dedicated fuel meter on every burner in each participating gin, a surrogate for measuring fuel flow was used.

Materials and Methods

Pitot tubes and thermocouples were installed in drying system ducts where no cotton flow was present. The pitot tube sensed velocity pressure. The temperature was used to estimate air density. Air velocity was calculated from the density and velocity pressure. Duct size was recorded to determine volumetric flow rate, and air mass flow rate was calculated from the volumetric flow rate and air density. Thermal power is the product of air mass flow rate, temperature change, and air's specific heat capacity. Burner power was estimated by dividing the thermal power by burner efficiency:

$$P_{in} = \left(\rho \pi r^2 0.92 \sqrt{\frac{2p_v}{\rho}} \right) C_p \, \Delta T \, \eta^{-1}$$

Where: P_{in} = burner power; ρ = air density; π = pi; r = duct radius; 0.92 = centerline to average correction; p_v = velocity pressure, c_p = specific heat capacity of air; ΔT = temperature increase through burner; and η = burner efficiency.

Thirty seed cotton samples were taken, usually one per bale processed, to find the moisture content before and after each drying system. The product of processing rate times bale weight, divided by turnout, yields seed cotton mass flow rate. Water evaporated is the change in moisture content multiplied by seed cotton mass flow rate. Drying power was estimated by:

$$P_{out} = \left(\dot{m} \cdot \Delta mc \cdot \Delta H_{vap}\right)$$

Where: P_{out} = drying power; $\dot{m}$ = bale weight times bales per hour divided by turnout (percent of seed cotton that is baled lint); Δmc = change in moisture content; and ΔH_{vap} = enthalpy of vaporization for water.

In this study fuel use efficiency, $\eta_{fuel} = P_{out} / P_{in}$.

Repair-season site visits were made to cooperating commercial gins from California to Georgia to install flanges that would hold pitot tubes (Series 160, Dwyer Instruments, Inc., Michigan City, IN) and type J thermocouples (Omega Engineering, Norwalk, CT) during the ginning season audits. During the ginning season site visit, pitot tubes, velocity pressure transmitters (Dwyer 607D-05), thermocouples, and temperature transmitters (ProSense XTD-0500F-J, Automation Direct, Cumming, GA) were installed. Independent, synchronized data loggers (Onset Computer Corporation, Bourne, MA) were used to record ambient temperature and relative humidity (UX100-011), analog current signals from pressure and temperature transmitters (UX120-006M), and standalone thermocouples (UX100-014M). Seed cotton samples of at least 50 g were collected and placed in air-tight containers and the moisture content determined gravimetrically at USDA-ARS Cotton Ginning Research laboratories in Stoneville, MS and Mesilla Park, NM (Shepherd, 1972). Data logger records of velocity pressures and air temperatures, moisture content results, and other gin information was processed using spreadsheets (Microsoft Excel) with the above equations. Greater detail is available elsewhere (Funk and Hardin, 2017).

Results and Discussion

Seed cotton moisture content varied from less than 5% to more than 12% in each region, for each season. During audits some gin burners were idling or off, while a few others were unable to provide adequate drying. Variability in system configuration was substantial, too. There were drying systems that were fully insulated, systems with insulation before the mix point or insulation only after the mix point, and systems with no insulation at all. No two gins were alike – there were tower dryers, jet dryers, fountain dryers, collider dryers, vertical flow dryers, pipe dryers, and various combinations. There was a range of stages, from one to three, and some gins used reclaimed air from the first stage to convey material, accomplishing a second stage of drying without an additional burner. There were even systems that removed moisture from seed cotton using unheated ambient air. Figures 1 and 2 illustrate the drying accomplished by a two-stage system with separate burners and a system using reclaimed warm air. In the two-stage system with individual burners (Figure 1), the first stage removed an average of 0.8% moisture, and the second stage removed 0.9% moisture. In the system using reclaimed air (Figure 2), the first stage removed 1% moisture by mass from the seed cotton, and the second stage removed 0.4% without additional fuel energy. Both systems dried seed cotton more than recommended for best quality (corresponding fiber moisture content is less than 5%), although the lower moisture levels may have been necessary for foreign matter removal or with roller ginning (Mayfield et al., 1994). We did not test a system that reheated reclaimed air.

At this point in the analysis, the data supports the following generalizations:

- Drying system fuel use efficiency is as much a function of weather as it is system design
- Locating the burner close to the point where cotton is picked up (the mix point) reduces heat loss
- Insulating pipes before the mix point improves performance more than insulating them after the mix point
- The first stage tends to make better use of fuel than the second, probably because there is a greater vapor differential when the material is wetter
- Drying systems can add moisture to cotton when the ambient air is humid and the cotton is dry

The planned multivariate analysis awaits processing of large data files and compiling results from recent on-site sampling.

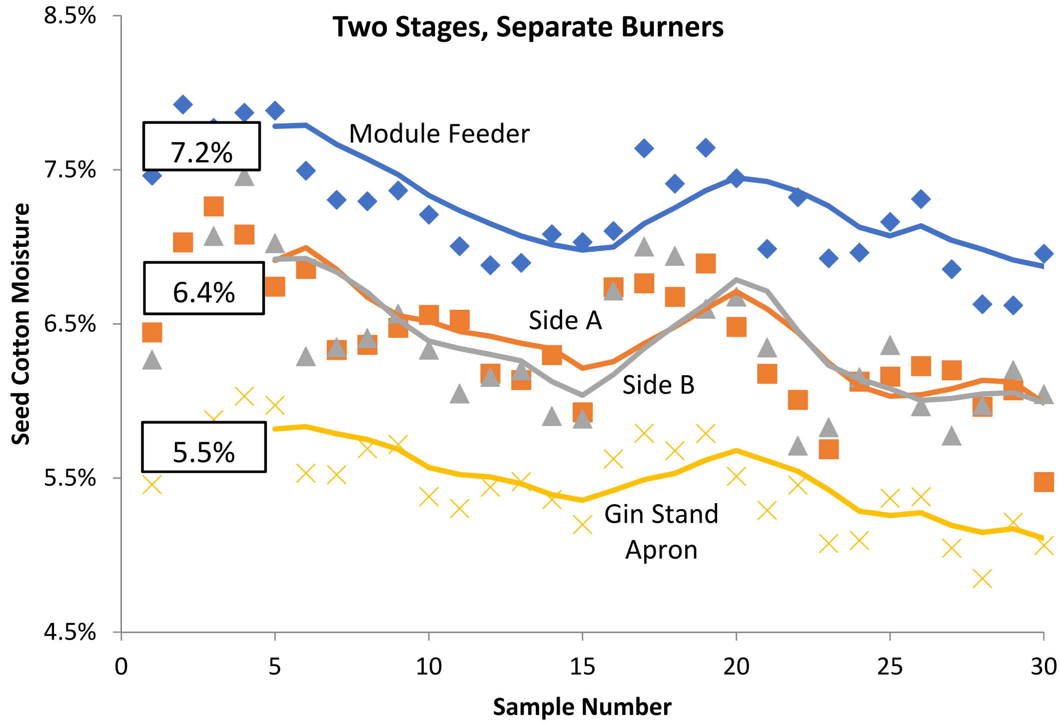

Figure 1. An example of a true two-stage system where the first stage removed an average of 0.8% moisture, and the second stage removed an average of 0.9% moisture during the 30 bales sampled.

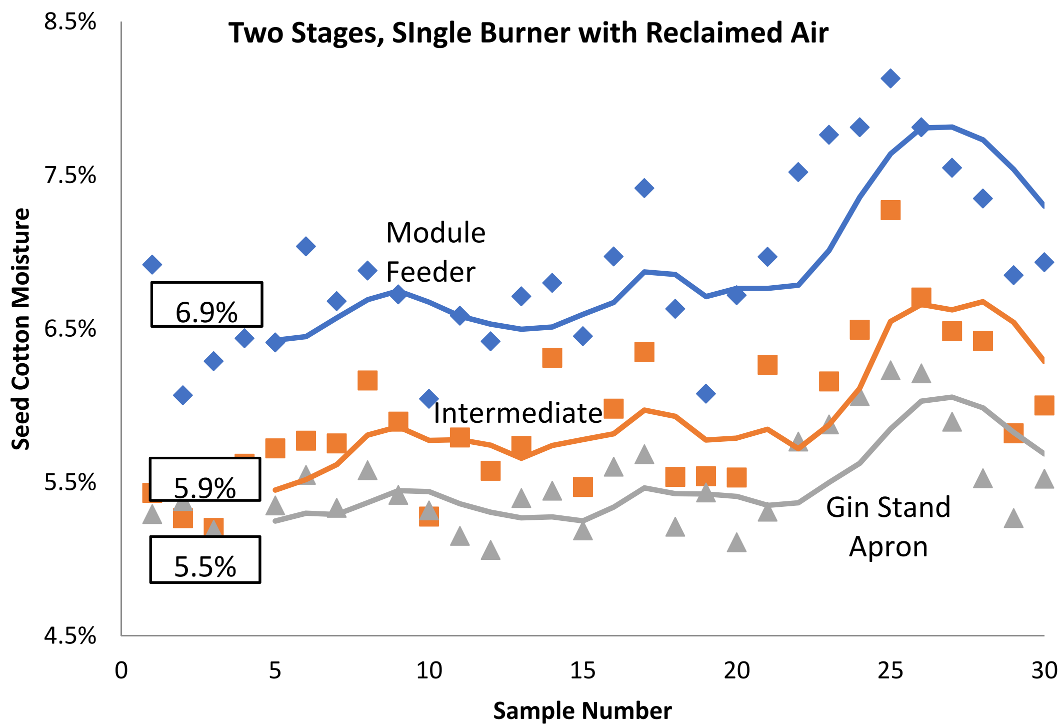

Figure 2. An example of a two-stage system with a single burner, using reclaimed air in the second stage. The first stage removed an average of 1.0% moisture, and the second stage removed an average of 0.4% moisture.

Summary

Substantial variability in initial moisture content and ambient conditions (temperature and humidity) made it difficult to separate the effect of different drying system designs and operating strategies. Fuel consumption can be reduced by locating the burner close to the mix point, insulating the pipe from the burner to the mix point, and idling burners when the moisture content of incoming cotton is less than 7%.

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Disclaimer

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