ENERGY MONITORING IN GINS- 2013 UPDATE

Robert G. Hardin IV
USDA-ARS Cotton Ginning Research Unit
Stoneville, MS
Paul A. Funk
USDA-ARS Southwestern Cotton Ginning Research Unit
Las Cruces, NM

Abstract

Energy, comprised of electricity and fuel, is the second largest source of variable costs for cotton gins, after labor. Few studies of gin energy use have been conducted recently and none have monitored energy use continuously throughout the ginning season. More detailed information is needed to identify management strategies and design systems that can reduce energy use. Electricity use was monitored continuously throughout the 2010-2012 ginning seasons at two gins, and fuel use was also calculated from air flow and temperature measurements during the 2011 and 2012 ginning seasons. Electricity use averaged 32.0 kWh bale^{-1} and 26.2 kWh bale^{-1} in 2012, similar to results from 2010 and 2011. LPG use was 1.57 L bale^{-1} (0.41 gal bale^{-1}) and 4.04 L bale^{-1} (1.07 gal bale^{-1}). Greater variation was observed in fuel use, both within a ginning season and between years. Cultivar had a significant effect on processing rate, electricity use, and agitator tube motor current. Further research is needed to identify the optimum process rate for different cultivars and develop improved gin stand control systems. Higher processing rates reduced electricity and fuel use per bale for all years at both gins. To reduce energy costs, gins should be operated at maximum capacity as often as possible and equipment should not be left idling during significant downtime.

Introduction

Electricity and fuel account for 25% of a cotton gin's variable costs and are the second largest component of variable costs, after seasonal labor (Valco et al., 2012). A significant opportunity exists to improve gin profitability by reducing energy use. Since 2000, the average nominal electricity costs for U.S. industrial consumers have increased 44% and propane prices have increased 74% (USDOE–EIA, 2014). While natural gas prices are currently similar to 2000, prices have been quite volatile, with a peak price in 2008, more than twice the current cost. Higher energy costs emphasize the importance of increased energy efficiency at gins and increase the economic benefit of implementing conservation measures.

Recent research has shown that the average gin electricity use has decreased from a historical average of near 50 kWh bale^{-1} to 40 kWh bale^{-1} (Funk and Hardin, 2012; Hardin and Funk, 2012a). Fuel use has declined over time as control systems and burner designs have improved (Holder and McCaskill, 1963; Griffin, 1980; Anthony, 1988). A more recent study found that gins used an average of 2.3 m^3 bale^{-1} (81 ft^3 bale^{-1}) of natural gas or 4.0 L bale^{-1} (1.1 gal bale^{-1}) of LPG (Ismail et al., 2011). However, this study was conducted in Australia, which typically experiences drier weather than some cotton producing regions of the U.S. A survey of U.S. gins' costs for the 2010 ginning season found that fuel use averaged 150 MJ bale^{-1} (142 000 Btu bale^{-1}; T.D. Valco, unpublished data). The quantity of fuel corresponding to this energy content is 4.0 m^3 (142 ft^3) natural gas or 5.9 L (1.6 gal) LPG. Fuel use varied widely across regions of the U.S., from 85 MJ bale^{-1} (81 000 Btu bale^{-1}) in the Mid-South to 312 MJ bale^{-1} (296 000 Btu bale^{-1}) in the West, due to differences in weather during the ginning season. Hardin and Funk (2012b) determined fuel use for several systems at two gins. First stage drying systems required 1.25 and 1.45 L bale^{-1} (0.33 and 0.38 gal bale^{-1}; the second stage drying system was only used at one gin, requiring 0.32 L bale^{-1} (0.08 gal bale^{-1}); and the burner evaporating the moisture added to lint used 0.89 and 0.38 L bale^{-1} (0.23 and 0.10 gal bale^{-1}). Fuel use by the burner heating air added at the lint slide was not measured.

The goal of this research was to gain a greater understanding of electricity and fuel use in cotton gins. Greater knowledge of energy use patterns should result in improved management strategies and new technologies that improve energy efficiency. This research project was started during the 2010 ginning season, with monitoring of gin electricity consumption and individual motor loads. Measurements of fuel use were also made beginning in 2011. The specific objectives of this research were:

- Monitor individual motor loads and total gin electricity consumption
- Measure air flow and burner temperatures to estimate fuel use

- Identify factors significantly affecting electricity and fuel use
- Quantify potential energy savings from implementing improved management strategies

Materials and Methods

Energy monitoring systems were installed in two saw-type gins, located in the Mid-South and Southeast, during the 2010-2013 ginning seasons. Motor loads were monitored for motors larger than 11 kW (15 hp) and power and power factor were measured at each motor control center. Data was recorded at 2.5 s intervals at the Mid-South gin and at 2 s intervals in the Southeast gin. A more complete description of the gins, electrical energy monitoring components, and data acquisition system can be found in Hardin and Funk (2012a).

Fuel (LPG) used by the seed cotton dryers and the burner used to supply heated air to the lint slide in both gins was estimated based on heat transfer to the conveying air. Ambient temperature and humidity, the heated air temperature, and the air flow through the burner were measured to calculate fuel use. Similar measurements were made with the humid air moisture restoration systems at each gin; however, the heated air was assumed to be saturated to determine fuel use. These measurements were taken at the same intervals as the electricity measurements. Additional details of these components and installation are provided in Hardin and Funk (2012b, 2012c).

Sensor data were analyzed to provide summary data for each gin and identify factors that significantly affected energy use. Data from the 2010-2012 ginning seasons has been analyzed. Total power demand and the fuel use by each burner were calculated for each record (2 or 2.5 s interval) in the data. A local maximum in the bale press pump motor current data indicated that a bale had been pressed. The total electricity and fuel used for each bale was calculated by integrating the instantaneous power demand over the length of time required to process the bale. All bales were used to calculate average energy use; consequently, the effect of gin downtime was included in this calculation of energy use. The number of lint cleaners used for each bale was determined from lint cleaner motor current data. Average gin stand and agitator tube motor currents and the average ambient temperature were calculated for each bale. Correlations between fuel use, processing rate, power demand, electricity use, and ambient temperature were examined at both gins (*PROC CORR*, SAS 9.2, SAS Institute, Inc., Cary, N.C.).

Management of the Southeast gin provided USDA–AMS classing data and bale weights for all monitored bales, as well as the cultivar for nearly 70% of the monitored bales. For the Southeast gin, an analysis of variance (*PROC MIXED*) was performed on the variables listed in Table 1 to identify differences between cultivars. Only bales that were ginned at 30 bale hr^{-1} or faster (near the maximum ginning rate) were used in this analysis. This condition was imposed to exclude factors other than cultivar that can affect energy use, such as machinery breakdowns or extremely wet seed cotton. When analyzing data from multiple seasons, the year was added as a random effect in the mixed model.

Table 1. Variables used in statistical analysis of Southeast gin data.

Dependent Variable	Independent Variables	Covariates
Electricity used	Cultivar, Stages of lint cleaning	Bale weights, Ambient temperature
Processing rate	Cultivar, Stages of lint cleaning	Bale weights, Ambient temperature
Average power demand	Cultivar, Stages of lint cleaning	Bale weights, Ambient temperature, Processing rate
Average gin stand motor current	Cultivar	Ambient temperature, Processing rate
Average agitator tube motor current	Cultivar	Ambient temperature, Processing rate

Results and Discussion

Electricity use for 2010-2012, is shown in Table 2, along with the number of bales with data for that parameter. Electricity used per bale was similar in both 2010 and 2011, at the Mid-South gin, and increased slightly in 2012. Additional seed cotton cleaning machinery was installed prior to the 2012 ginning season, likely increasing the electricity used per bale. The average processing rate at the Mid-South gin increased slightly, from 34 bale hr^{-1} in 2011 to 35 bale hr^{-1} in 2012. The Southeast gin reduced electricity consumption by nearly 2 kWh bale^{-1} from 2010 to 2011. Before the 2011 ginning season, the bale press was modified, increasing the average processing rate for the monitored bales from 39 bale hr^{-1} in 2010 to 44 bale hr^{-1} in 2011. Electricity use increased slightly from 2011 to 2012, as the processing rate decreased to 41 bale hr^{-1}. Electricity use was found to be inversely related to processing rate at both gins for all three years.

Table 2. Electricity use for 2010-2012 ginning seasons.

Year	**Mid-South Gin**		**Southeast Gin**	
	# Bales[a]	**Electricity (kWh bale^{-1})**	**# Bales**	**Electricity (kWh bale^{-1})**
2010	16774	31.5	5968	27.7
2011	30379	31.4	24591	25.8
2012	26207	32.0	26020	26.2

[a]The "# Bales" column refers to the number of bales with data available, because some instrumentation did not function properly throughout the entire season.

Fuel use for 2011 and 2012, is shown in Table 3. The total fuel use was only calculated for 2012, and only includes bales with data for all systems. Seed cotton dryer fuel use was slightly lower at the Mid-South gin in 2012, than 2011; however, both seasons were generally dry. Less fuel was also used by the moisture restoration system. The ginning season started earlier at the Mid-South gin in 2011, and the average ambient temperature (measured near the 1st stage dryer inlet) while ginning the monitored bales was 9°C (16°F) warmer in 2011. More moisture may have been required in 2011, to produce bales with desirable final moisture contents. Adding additional moisture increases fuel use.

Table 3. Fuel use for 2011-2012 ginning seasons.

System	**Mid-South Gin**		**Southeast Gin**	
	2011	**2012**	**2011**	**2012**
	L bale^{-1} (gal bale^{-1})			
1st stage drying	1.25 (0.33)	0.87 (0.23)	1.45 (0.38)	1.63 (0.43)
2nd stage drying	Not used	0.09 (0.02)	0.32 (0.08)	0.24 (0.06)
Moisture restoration	0.89 (0.23)	0.44 (0.12)	0.75 (0.20)	1.73 (0.46)
Heated air at lint slide	Not measured	0.19 (0.05)	Not measured	0.47 (0.12)
Total	-	1.57 (0.41)	-	4.04 (1.07)

Slightly more fuel was used by the Southeast gin for seed cotton drying in 2012; however, significantly more fuel was used for moisture restoration. No weather-related explanations for this difference have been identified. This result may be due to the small number of bales (1432) with moisture restoration system fuel use data collected in 2011, not being representative of the entire ginning season. At both gins, a significant proportion of the fuel was used to add moisture to the lint. In 2012, the moisture restoration system burner (for heating the air to evaporate the water) and the burner used to heat air added at the lint slide (to prevent condensation and lint sticking to surfaces) accounted for 40% of fuel used at the Mid-South gin and 54% of fuel used at the Southeast gin.

The relationship between fuel use per bale and processing rate was similar to the electricity-processing rate model (Hardin and Funk, 2012a); however, there was significantly more variation in the fuel use data (Figure 1). Much of the variation in fuel use was likely due to varying weather conditions and seed cotton moisture content.

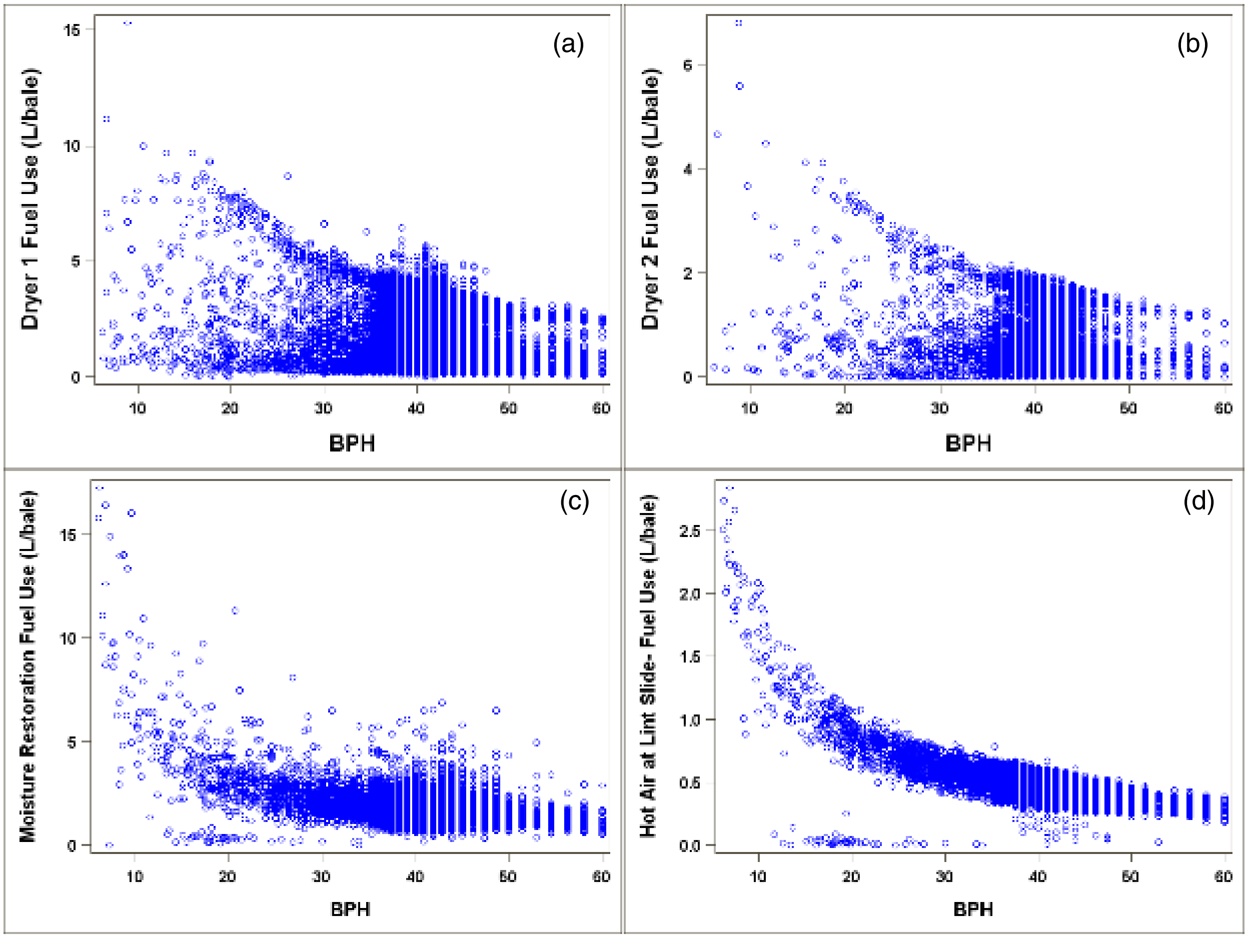

Figure 1. Fuel use by each burner at Southeast gin, 2012.

Fuel use had significant correlation with both processing rate and ambient temperature and results were similar in 2011 and 2012 (Table 4). Higher processing rates resulted in lower fuel use per bale by all systems. Lower temperatures required additional fuel to heat the air for seed cotton drying. Additionally, cooler weather in both regions during the ginning season tends to correspond to wetter weather and incoming seed cotton, which requires more fuel for drying. Correlation between the fuel used for moisture restoration and temperature ranged from slightly negative to slightly positive. Since most of the fuel energy was used to evaporate water instead of heating the air, the air temperature only had a small effect on the fuel used by the moisture restoration system.

Table 4. Correlations between fuel use per bale, processing rate, and temperature.

System	Mid-South Gin				Southeast Gin			
	Processing Rate		Temperature		Processing Rate		Temperature	
	2011	2012	2011	2012	2011	2012	2011	2012
1st stage drying	-0.40	-0.40	-0.61	-0.38	-0.22	-0.22	-0.21	-0.14
2nd stage drying	Not used	-0.18	Not used	-0.14	-0.18	-0.13	-0.07	-0.05
Moisture restoration	-0.46	-0.19	0.14	0	-0.48	-0.49	-0.06	-0.08
Heated air at lint slide	N/A	-0.03	N/A	-0.42	N/A	-0.70	N/A	-0.39

Cultivar affected the processing rate and energy used per bale at the Southeast gin (Table 5). All cultivar data presented is from the Southeast gin, since the Mid-South gin did not provide this information. PHY 375 WRF used the least energy in 2012, and ST 4145 LLB2 required the most energy. The average processing rate varied inversely with energy use, with PHY 375 WRF ginning the fastest at 43.4 bale hr^{-1} and ST 4145 LLB2 having the lowest processing rate at 38.6 bale hr^{-1}. Small differences in average power demand were observed; however, most variation in electricity use was due to the differences in processing rate. The gin stand feed rate at this gin was controlled to maintain a constant load on the gin stand motor. While there were differences in average gin stand current between cultivars, no relationship was observed between energy use or processing rate and gin stand current for different cultivars. While the same gin stand control settings were used throughout the season, differences in properties between cultivars likely affects the response of the control system and the resulting actual average motor current.

While the gin stand motor current controlled the feed rate at this gin plant, other plants use the agitator tube motor current as the controller input. The theory of operation behind both systems is that the motor current provides an indication of seed roll density. Excessive gin stand processing rates and seed roll density have been shown to reduce fiber quality (Bennett and Gerdes, 1936; Mangialardi et al., 1988). However, Table 5 illustrates significant differences in the agitator tube motor current with a gin stand control system based on the gin stand motor current. Additionally, there is no clear relationship between electricity use or processing rate and agitator tube motor current. For instance, DP 1028 B2RF had the lowest agitator tube motor current of all cultivars. ST 4288 B2F had a significantly higher agitator tube motor current, but the electricity used per bale for each cultivar was not significantly different.

Table 5. Least squares means for electrical energy parameters by cultivar in 2012.[a]

Cultivar	# Bales	Electricity (kWh bale^{-1})	Processing Rate (bale hr^{-1})	Power (kW)	Gin Stand Current (A)	Agitator Current (A)
PHY 375 WRF	1941	24.2a	43.4a	1040ce	199.6bc	6.96cd
FM 1740 B2R	480	24.3a	43.2ab	1041cde	208.5gh	7.17f
ST 4288 B2F	218	24.7bc	42.6bc	1040bcef	201.1bcd	7.27g
PHY 367 WRF	585	24.7b	42.6c	1042e	204.5ef	7.14f
NITRO 44 B2RF	126	24.7bcd	42.4cde	1040bcef	206.1efg	6.91bc
DP 1028 B2RF	2324	24.8bc	41.3fg	1012a	200.3bc	6.79a
PHY 499 WRF	3341	24.8bc	42.1d	1037b	204.0e	6.91b
AM 1550 B2RF	286	25.0cef	42.1cde	1045ef	206.2f	7.28g
DG 2570 B2RF	3350	25.1de	41.7e	1037b	202.8d	6.98d
DP 0912 B2RF	419	25.3fg	41.6ef	1047f	199.1b	7.05e
ST 4498 B2R	1146	25.4g	41.2g	1037bd	197.1a	6.95cd
DP 1219 B2RF	154	26.0h	40.1h	1041bcef	209.9h	7.38h
FM 1944 GLB2	712	26.4h	39.5h	1037bc	208.7h	7.80j
ST 4145 LLB2	71	27.5i	38.6i	1048ef	202.7cde	7.51i

[a]Means in a column followed by the same letter were not significantly different at the 5% level.

Similar trends were observed for cultivars that were also ginned in 2010 (Hardin and Funk, 2012a) and 2011 (Hardin and Funk, 2012b). Table 6 shows the least squares means for electricity use over 2011 and 2012, and a ranking of cultivars ginned in both 2011 and 2012, by electricity use per bale, from lowest to highest. While some differences in cultivar electricity use were observed from 2011 to 2012, cultivars that were low or high electricity users in 2011, generally remained the same in 2012.

Table 6. Ranking of cultivar electricity use per bale for 2011-2012 (from lowest to highest) and least squares means for electricity use over both years[a].

Cultivar	2011	2012	Electricity (kWh bale^{-1})
PHY 375 WRF	5	1	24.0a
FM 1740 B2R	4	2	24.2b
PHY 367 WRF	2	4	24.2b
AM 1550 B2RF	1	6	24.4bc
DG 2570 B2RF	3	7	24.5c
DP 1028 B2RF	7	5	24.6d
ST 4288 B2RF	8	3	24.9e
DP 0912 B2RF	6	8	25.0e
ST 4498 B2R	9	9	25.4f

[a]Means in a column followed by the same letter were not significantly different at the 5% level.

The average agitator tube motor current for each cultivar was also consistent from 2011 to 2012 (Table 7). The combined results over both years also illustrate the lack of an obvious relationship between electricity use, processing rate, and agitator tube motor current. DP 1028 B2RF had the lowest agitator tube motor current in both 2011 and 2012. ST 4288 B2RF had the highest agitator tube motor current in 2011, and was not significantly different from the highest cultivar (among the nine ginned in both seasons) in 2012. Both of these cultivars had intermediate average electricity use over both seasons.

Table 7. Ranking of cultivars by average agitator tube motor current for 2011-2012 (from lowest to highest) and least squares means for agitator tube motor current over both years[a].

Cultivar	2011	2012	Agitator Current (A)
DP 1028 B2RF	1	1	6.91a
PHY 375 WRF	3	3	7.01b
DG 2570 B2RF	4	4	7.07c
FM 1740 B2R	5	7	7.19d
DP 0912 B2RF	8	5	7.23e
PHY 367 WRF	6	6	7.29f
ST 4498 B2R	7	2	7.32g
AM 1550 B2RF	2	9	7.33g
ST 4288 B2RF	9	8	7.75h

[a]Means in a column followed by the same letter were not significantly different at the 5% level.

Although processing rate and seed roll density obviously affect these motor loads, other factors, such as seed roll–gin stand friction and the fiber–seed attachment force influence the current drawn by the gin stand and agitator motor differently. Current gin stand feed rate controls likely do not provide optimal results for all cultivars- ginning some more slowly than optimum, while possibly ginning other cultivars too fast, resulting in fiber damage. More research is needed to develop a greater understanding of the factors affecting gin stand and agitator tube motor current, identify optimum ginning rates for different cultivars, and design improved control algorithms.

Conclusions

The two monitored gins used 32.0 kWh bale^{-1} and 26.2 kWh bale^{-1} of electricity in 2012, similar to values from 2010 and 2011. At both gins, electricity use per bale decreased with processing rate. Average fuel consumption at the Mid-South gin was 1.57 L bale^{-1} (0.41 gal bale^{-1}) in 2012, with the first stage seed cotton dryer using the largest quantity of fuel, 0.87 L bale^{-1} (0.23 gal bale^{-1}). The Mid-South gin used less fuel in both the first stage seed cotton dryer and the moisture restoration system in 2012 than 2011. The Southeast gin used 4.04 L bale^{-1} (1.07 gal bale^{-1})

of LPG. Similar amounts of fuel were used by the first stage seed cotton dryer, 1.63 L $bale^{-1}$ (0.43 gal $bale^{-1}$), and the moisture restoration system, 1.73 L $bale^{-1}$ (0.46 gal $bale^{-1}$). The Southeast gin used more fuel for seed cotton drying and moisture restoration in 2012 than 2011.

Fuel use per bale was inversely related to processing rate; however, there was significant variation in the amount of LPG required at a given processing rate, particularly with the seed cotton dryers. This variation was likely due to differences in seed cotton moisture content and weather conditions. Correlations between fuel use and processing rate or ambient temperature were similar in 2011 and 2012. Ambient temperature was negatively correlated with fuel used by seed cotton dryers and the burner heating the air added at the lint slide.

The cotton cultivar was a significant factor affecting processing rate and electricity use. The fastest ginning cultivar, PHY 375 WRF, had a ginning rate 4.8 bale hr^{-1} faster and used 3.3 less kWh $bale^{-1}$ than the slowest ginning cultivar, ST 4145 LLB2. Cultivar electricity use was consistent from 2011 to 2012. Agitator tube motor current varied significantly among cultivars when ginning rate control was based on gin stand motor current. There did not appear to be a relationship between the average agitator tube motor current for a cultivar and ginning rate or energy use. Similar results for agitator tube motor current were observed in 2011 and 2012, as DP 1028 B2RF had the lowest average current, while ST 4288 B2RF had the highest. More research is needed to understand the sources of this variability and determine optimum ginning rates to minimize energy use.

Operating all equipment at maximum capacity as often as possible is crucial in reducing both electricity and fuel use at the gin. To maximize processing rate and minimize fuel use, seed cotton must be properly stored so that cotton enters the gin at a suitable moisture content.

Acknowledgements

The authors would like to thank Cotton Incorporated for their financial support of this project under Cooperative Agreement No. 13-740. Tommy Valco, USDA-ARS Office of Technology Transfer, has provided in-depth survey data and suggestions to enhance this research. The authors would also like to thank the cooperating gins for their assistance.

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