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ENGINEERING AND GINNING

Energy Utilization and Conservation in Cotton Gins

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ABSTRACT

Gins have become more energy efficient. However, energy costs account for 25% of the total variable costs of ginning, including seasonal labor, increasing from 15% in 1994. Recent studies found that average electricity use at gins is approximately 35 kWh per bale, down from 53 kWh per bale reported in 1980. However, gins must continue to increase efficiency to remain profitable and consumers are increasingly concerned with the sustainability of textile products. This paper reviews recent research on energy use and conservation in cotton gins and offers suggestions on ways for gin managers to reduce energy use based on this research. Gins should focus on maximizing their ginning rate and sustaining this rate as much as possible during the ginning season. Increased ginning rates will reduce per-bale costs of not only electricity and fuel, but labor as well. Maintaining consistent material flow through the gin, matching equipment capacities, and minimizing downtime allows gins to produce more bales per shift. More than half the electricity at gins is used for material handling, primarily by the large centrifugal fans used to convey materials. The cost of conveying materials should be considered when designing or updating gins. Gins should use only the volume of air necessary for consistent conveying and adequate drying and need to eliminate unnecessary friction losses in conveying systems. To reduce fuel use, dryer control systems should be used to avoid excessive drying of cotton. Insulating drying systems might be economically feasible, particularly from the burner to the mixpoint. Gins also should consider strategies to reduce the prices paid for electricity and fuel.

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Energy use and conservation continues to be a relevant topic as energy costs are a larger portion of total ginning costs. In a 2013 survey, energy use accounted for approximately 25% of the total variable cost, which included seasonal labor, bagging and ties, and repairs and maintenance (Valco et al., 2015). When "Energy utilization and conservation in cotton gins" was published in the 1994 Cotton Ginners Handbook, energy use was only 15% (Anthony and Eckley, 1994).

Surveys returned by cotton ginners following the 2013 season indicated that the average U.S. gin spent $4.44 per bale on electricity and $1.67 on dryer fuel, up from $3.79 and $1.39 for those sources of energy in 2010 (Valco et al., 2015). These increases likely were due to reduced production and shorter ginning seasons, although drying fuel consumption is partly affected by the weather. Lower cotton acreage is forecast for the near future in parts of the U.S.; consequently, gins need to reduce costs to stay profitable. Furthermore, cotton consumers are increasingly concerned with the sustainability of cotton goods. Minimizing the energy used in producing cotton goods is an important aspect of sustainability.

Energy audits and monitoring studies from 2009 through 2011 (Funk et al., 2013) found that saw gins consumed an average of 34.5 kWh of electrical energy per bale processed (Table 1). This amount is considerably less than the historic values of 47.4 to 52.9 kWh/bale reported by Watson, Griffin Jr., and Holder (1964), and Griffin Jr. (1980). Progress has been made in increasing electrical energy efficiency, but because there is a wide difference between individual gins, ranging from 25.6 to 46.7 kWh per bale based on measurements in 22 gins in 2009 through 2011, further efficiency gains are clearly possible.

Table 1. Saw gin energy consumption and connected power by gin function for region and U.S. average[z]; statistics from 2009 to 2011(Funk et al., 2013)

	West (kWh bale^{-1})	Southwest (kWh bale^{-1})	Mid-South & Southeast (kWh bale^{-1})	U.S. Average Consumption (kWh bale^{-1})	U.S. Average Connected Power (hp)
1) Seed Cotton Drying	7.22	4.94	5.54	5.53	452
2) Seed Cotton Cleaning	3.38	3.01	2.36	2.60	236
3) Ginning	5.94	6.79	6.52	6.38	529
4) Lint Cleaning	2.79	2.22	2.20	2.21	205
5) Bale Press	4.26	3.68	4.16	3.98	426
Value Added Total	*23.60*	*21.46*	*20.84*	*20.98*	*1848*
6) Seed Cotton Unloading	3.54	0.90	1.89	1.56	126
7) Seed Cotton Conveying	1.70	1.89	1.83	1.79	161
8) Lint Conveying	5.33	4.58	4.33	4.65	347
9) Seed Conveying	1.25	0.65	1.44	1.11	80
10) Trash Conveying	6.01	3.59	4.62	4.43	336
Materials Handling Total	*17.79*	*11.61*	*14.10*	*13.53*	*1049*
Total for Gin Facility	41.37	33.07	34.94	34.50	2897
Processing Rate (bale h^{-1})	26.7	50.6	39.1	44.2	44.2
Sample Size[1]	3	4	8	15	15

[z]Fifteen representative saw gins were sampled to estimate the US average.

INCREASING EFFICIENCY TO REDUCE COSTS

Historic Trends. During the past half century, the number of U.S. cotton gins has fallen from approximately 5,000 to under 600, while average annual U.S. production has increased from 11 to 17 million bales (USDA NASS, 2016). Small, inefficient gins have consolidated or been replaced by larger, more efficient ones. Because of increased automation and efficiencies of scale at larger gins, labor input is greatly reduced. Despite modern gins having additional energy-consuming equipment (e.g., dust cyclones, universal density presses, and bale strapping and handling equipment), greater efficiencies have decreased the energy used per bale. Funk et al. (2013) found that electrical energy consumed per unit of cotton processed decreased by 19 to 34% during the past 50 years as gin processing rates have increased three- to six-fold and as mechanization has made labor four to six times more productive.

Increase the Average Ginning Rate. Some expenses, for example, bagging and ties, are the same per bale, independent of the number of bales ginned. Other expenses decrease with more bales ginned, such as the per-bale cost of repair season improvements, routine maintenance, and energy. Increasing the average ginning rate reduces the unit cost of energy and labor, which are the largest source of variable costs for gins. Ginning rate is the primary factor affecting electricity use per bale at a given gin (Hardin IV and Funk, 2012), and has a significant effect on fuel use per bale (Hardin IV and Funk, 2014).

The average ginning rate depends on both the actual ginning rate and the frequency and duration of downtime. Increasing the average ginning rate means more bales are ginned per hour, shift, day, and week. Simply increasing the maximum ginning rate will not increase the average ginning rate if the higher rate cannot be sustained because it results in choking the gin. Increasing the average ginning rate allows for a shorter gin season, so the customer can market their cotton sooner. It could result in one less monthly electrical demand charge.

Maintain a Constant Flow of Material Through the Gin. The average gin stand operating efficiency, the proportion of time each gin stand motor was running *and* ginning cotton, recently was found to exceed 91% at monitored gins (Hardin IV and Funk, 2012). However, efficiency varied widely and was always lowest at the final stand before the overflow. Installing automatic feed controls on the storage hopper (steady flow), the extractor-feeders, and the automatic overflow system can help keep all gin stands fully loaded as much as possible. These automatic feed controls were used to achieve a gin stand operating efficiency more than 95% at the most efficient gin in the monitoring study.

Match Equipment Capacities. The capacity of each subsystem in the gin—module feeding, drying, seed cotton cleaning, ginning, lint cleaning, packaging, and byproduct handling—needs to match so that no one subsystem is a bottleneck limiting the others. A recent study documented the effect of increasing bale packaging capacity by adding another bale press booster pump to match ginning capacity. The average ginning rate increased 13%, reducing per bale electricity use by 7%, despite the additional 56-kW (75-hp) motor (Hardin IV and Funk, 2014).

Minimize Downtime. Preventive maintenance is critical to maximizing machinery life, which will increase efficiency through reduced downtime. Machinery should be inspected regularly during operation for signs that components, such as belts and bearings, might fail soon. Scheduling downtime for replacement could save additional time compared to a failure during operation, where equipment could choke and component failure could cause collateral damage. Repair season decisions to replace or upgrade equipment and the care with which each machine is rebuilt and adjusted have a large impact on the average processing rate (Keilty, 1994), and thus the per-bale cost of energy (and labor). The most efficient gin in the monitoring study by Hardin IV and Funk (2012) had almost no downtime, with nearly all bales ginned near the maximum ginning rate, using only 27.7 kWh/bale during the season (compared to an industry average of 34.5). See Keilty (1994) for more information.

Shut Equipment Off Instead of Idling. Electricity and dryer fuel are consumed while the gin is idling (machinery on, but no cotton being processed). These costs can be avoided by shutting the gin down when an event occurs that requires the gin to stop processing cotton. However, additional time is required to restart the equipment. Determining the breakeven idle time requires consideration of hourly labor costs, energy use and costs, and the time required to restart. Energy monitoring data from four commercial gins and estimated average hourly labor and electricity costs were used to determine breakeven idle times; they ranged from 8 to 16 min., with an average of 12 min. (Hardin IV and Funk, 2012). This guideline is a useful starting point for gins. However, the factors involved in determining the breakeven idle time vary widely between gins. For example, gins that can restart quickly or have low hourly labor costs will have a shorter breakeven idle time.

REDUCING ELECTRICITY USE

The general recommendations mentioned above can reduce electricity use per bale with minimal capital investment. Additional, more specific changes can be made to the gin plant layout and to component equipment to make the gin plant intrinsically more energy efficient, reducing electricity use at any processing rate. Some of the following suggested modifications require a financial investment to pay over the long term through the savings realized from reduced energy consumption. Combining these modifications with other motivations, such as increasing capacity, replacing equipment that is worn out, or reducing emissions sources leverages the energy savings part of the expense and shortens the return on investment.

Why should gin managers consider investing in energy saving modifications? It is likely that there are some systems or components in the typical gin facility that use more energy than necessary. A wide variation exists among gins in the amount of electricity consumed per bale, with a recent audit of 22 facilities showing the least efficient saw gin using 46.7 kWh bale^{-1}, nearly twice as much as the most efficient one (25.6 kWh bale^{-1}). This variation in electricity use between gins was partly due to differences in installed equipment and plant layout (Hardin IV and Funk, 2012).

Material handling, including seed cotton drying, accounts for more than half the electricity used at gins (Funk et al., 2013). Centrifugal fans used for pneumatic conveying of seed cotton, lint, and byproducts consume most of the electricity used for material handling. The design and layout of pneumatic conveying systems varies considerably between gins and accounts for much of the variation in electricity use. The power required by a fan is equal to the product of the volume of air moved and the resistance of the system to air flow (pressure drop), divided by the efficiency of the fan. Decreasing the volume of air flow, decreasing the pressure drop, or increasing the fan efficiency will reduce the electricity consumed by fans.

Reduce the Volume of Air Used. The minimum recommended conveying velocity for seed cotton is 17.8 m s^{-1} (3500 ft min^{-1}) and for lint is 7.6 m s^{-1} (1500 ft min^{-1}) (Baker et al., 1994). These values are based on many years of practical experience. Recent research led to the development of a model to predict the minimum conveying velocity of seed cotton based on the mass flow rate of seed cotton, pipe diameter, and air density (which varies inversely with temperature) (Hardin IV, 2014). According to this model, a 0.51-m (20-in.) pipe conveying 3.7 kg s^{-1} (8.2 lb s^{-1}, approximately 21 bales h^{-1}) of seed cotton in 93.3 °C (200 °F) air would require a minimum velocity of 14.9 m s^{-1} (2940 ft min^{-1}). The minimum conveying velocity increases with increasing seed cotton mass flow rate (ginning rate) and decreasing air density (higher temperatures). Seed cotton conveying systems should be operated above this minimum velocity because a sudden increase in the mass flow rate due to a large wad of cotton fed into the system or a wet region in the module would cause choking, which is quite costly to the gin. Therefore, gins need to use at least the minimum recommended conveying velocity. Ginners should be aware that the measured air velocity with no material in the conveying system will be higher than the actual air velocity at the same location when material is in the pipes, because centrifugal fan system static pressures increase and air flows decrease with loading. The actual air velocity when conveying material needs to be at least the minimum recommended velocity.

Increasing the velocity above that needed for trouble-free conveying increases electricity costs significantly. If the fan speed is increased, the volumetric air flow rate is increased by the same proportion. However, the increase in the system static pressure is equal to the ratio of fan speed increase squared, and the increase in power requirements is equal to this ratio cubed. Example fan curves are shown in Fig. 1. In the example, the fan currently operates at 2000 rpm, producing 2.12 m^3 s^{-1} (4500 cfm) against a system static pressure of 3.58 kPa (14.4 in. H_2O), requiring 16.1 kW (21.6 hp). If 20% greater air flow is needed, the fan speed can be increased by 20%. The resulting air flow rate is 2.55 m^3 s^{-1} (5400 cfm), but the system static pressure is 5.18 kPa (20.8 in H_2O), an increase of 44%. The fan now requires 27.9 kW (37.4 hp), an increase in power of 73%.

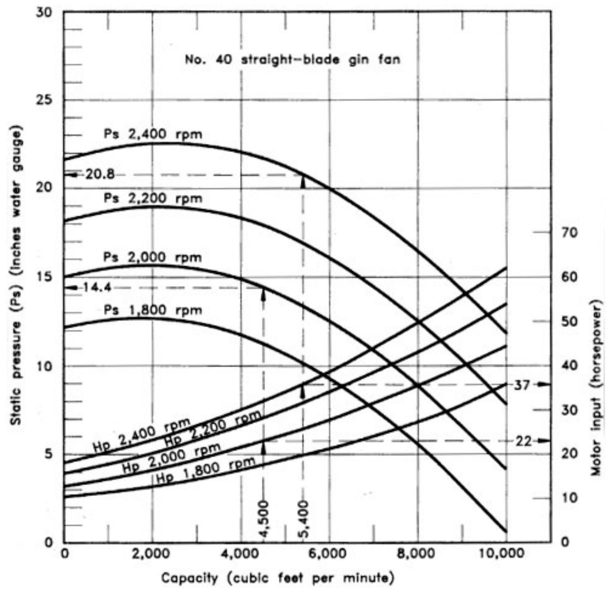

Figure 1. Fan curves at multiple speeds for radial-blade centrifugal fan.

One reason that air flow rates could be increased is to provide improved drying of seed cotton. However, the effect of higher air flow rates on drying is not well understood, as the exhausted air is still capable of drying cotton, and cotton gin dryers are inefficient (Funk et al., 2016). Research is currently underway to determine the effect of air flow rates on gin dryer efficiency and how to improve dryer efficiency. Ginners should be aware of the cost of producing additional air flow and consider the economics of alternatives such as increasing dryer temperatures (remaining below 177 °C [350 °F]) or reducing the processing rate slightly. See the section on moisture control (Hughs et al., 1994).

Due to changing ginning rates, drying air temperatures, and possibly air requirements for drying, controlling the air flow rate produced by the fan might reduce the total energy used by conveying fans, while providing the necessary air flow when ginning at maximum rates. As mentioned previously, air velocities in the conveying system are highest when the system static pressure is lowest, that is, when no material is being conveyed. Consequently, power requirements by centrifugal fans used for conveying are highest when no material is conveyed. One control strategy used by a commercially available system for conveying seed cotton is to use a variable frequency drive (VFD) to change fan speed to maintain a constant current (and power) used by the fan motor. This system would typically slow down the fan when little or no seed cotton is conveyed, saving energy, and increase the fan speed to provide more air flow at maximum ginning rates. Consideration should also be given to controlling the overflow system fan. Although smaller than other gin fans, the overflow fan might convey a more variable amount of material. Although constant current control offers benefits over a system without fan speed control, the work by Hardin (2014) indicated that the optimum motor current should decrease with decreasing seed cotton flow rates. Research is ongoing to develop improved control systems for pneumatic conveying systems' fan speed control.

Although the cost of installing VFDs on fans might not be justified on energy savings alone, there are some additional benefits to using VFDs. Some utilities require soft starters on motors above a certain size, and a VFD can be used instead of a soft starter. Another reason to replace conventional motor starters with VFDs is to control air flow without using gate valves. Closing gate valves to reduce air flow is inefficient, because the system static pressure is increased. A test of a small-scale conveying system at the USDA-ARS Cotton Ginning Research Unit in Stoneville, MS showed that closing a gate valve to reduce air flow 10% and 20% only reduced power requirements 8% and 13%, respectively. Slowing the fan down to achieve the same air flow rates using a VFD reduced power requirements 24% and 49%, amounts that would be expected based on fan laws and power losses in the VFD. Furthermore, gate valves are difficult to adjust accurately and they do not always hold their position.

Another strategy for reducing the volume of air used is to eliminate leaks in the conveying system, so that the air moved by the fan is used for its intended purposes: drying and conveying material. Duct work should be inspected for leaks because joints can work loose as the sheet metal expands and contracts with temperature, and jointscan get knocked loose in various ways. Access doors should be checked on air-fed and air-line cylinder cleaners, separators, droppers, and dryers to make sure they are sealing properly. Gaskets should be replaced when they no longer hold air. Flashings on separators and flights on vacuum droppers should be inspected frequently and replaced when worn. Properly maintaining separators and droppers will greatly reduce the downtime from choking, as well as reducing fan energy use. In a pull-through seed cotton drying system, a significant amount of air can leak in to the conveying system at the cylinder cleaner dropper, due to the large negative static pressure at this point in the system. The air that leaks in at this point serves no useful purpose to the gin, but requires energy and emissions controls. Although some leakage is unavoidable, proper maintenance of the dropper flights will minimize leakage. For more detailed information, see Baker et al., (1994).

Reduce Conveying Systems Friction Losses. Friction losses (measured by static pressure) in pneumatic conveying ducts are proportional to the duct length. Locating equipment and planning duct runs to minimize length saves energy year after year. Elbows have significantly greater air flow resistance than a straight pipe of equal length, requiring additional energy. These losses can be reduced by eliminating elbows where possible, and by replacing short-radius elbows (centerline radius equals nominal pipe diameter) with long-radius elbows (centerline radius greater than 1.5 times nominal pipe diameter); friction loss through a long radius elbow is about two-thirds as much as friction loss through a standard elbow. Elbows located immediately before fan inlets create turbulence where airflow enters fan blades, contributing to energy losses, and should be avoided. Air discharged by a fan should enter a long duct before changing direction to reduce energy losses. If there is not space for this, the elbow should be oriented to complement the direction of rotation of the fan to minimize losses (Fig. 2). Additional fan and duct recommendations are available from AMCA (2007). The USDA-ARS Cotton Production and Processing Unit in Lubbock, TX made modifications to the unloading system in their gin to reduce friction losses, such as eliminating elbows and replacing undersized pipe. These modifications resulted in a 19% increase in velocity while using 37% less power (Holt et al., 2001).

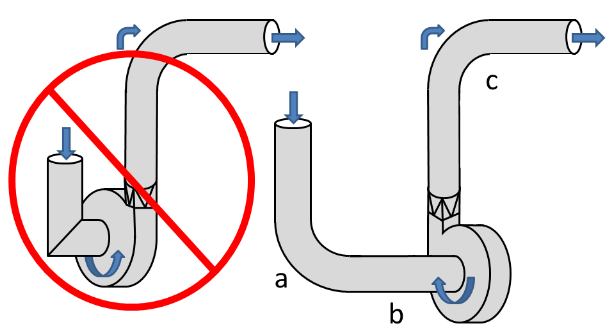

Figure 2. To save energy, a) replace sharp elbows with long radius elbows and eliminate elbows where possible; b) provide evenly distributed air to the fan inlet with long straight sections, and; c) if an elbow must be close to a fan outlet, arrange the fan's discharge, rotation and ducts so that changes in airflow direction compliment fan rotation direction.

Cyclone pressure drop increases with the square of inlet velocity. In a study that measured cyclone emissions from pneumatically conveyed cotton gin trash, lower inlet velocities reduced pressure drop but had no effect on emissions (Funk et al., 2015). Where dust cyclone inlet velocity is above that required to comply with state regulations or the gin's operating permit, energy use can be reduced by meeting, but not exceeding, the minimum inlet velocity (typically 16.26 ± 2.03 m s^{-1} [3200 ± 400 fpm]). Cyclone pressure drop also can be reduced by up to 11.9% by including an expanding flow section (evasé) on the cyclone discharge in jurisdictions where this is permitted (Funk, 2015). Figure 3 illustrates a radial evasé.

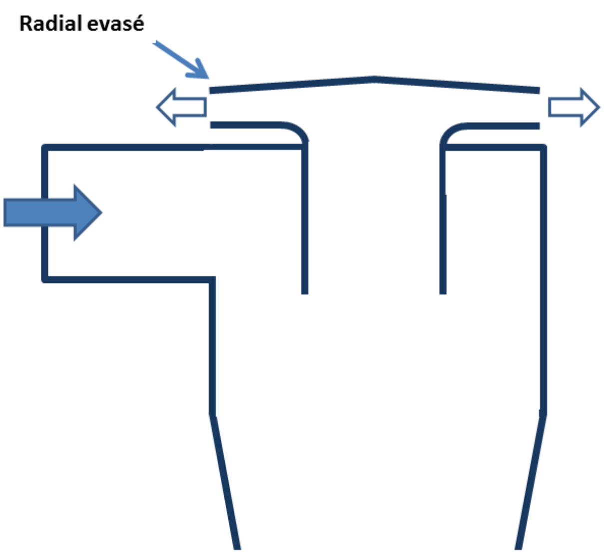

Figure 3. Cyclone pressure drop can be reduced by 11.9% by including a radial expanding flow section (evasé) on the cyclone discharge in jurisdictions where this is permitted (Funk, 2015).

Alternative Conveying Methods. Some gins have replaced pneumatic conveying systems not used for seed cotton drying with belt or screw conveyors. Mechanical conveyors use significantly less power, typically 7.5 to 15 kW (10-20 hp) to move the same amount of material as pneumatic conveying systems, which typically use 75 to 112 kW (100-150 hp). This change also can eliminate a cyclone and associated particulate emissions source. The gin using the least electricity per bale in the monitoring study by Hardin and Funk (2012) achieved this level of efficiency by having the most efficient material handling systems. This gin used screw conveyors to handle trash; consequently, electricity use per bale for material handling was reduced by more than one-third compared to the other gins in the study.

Wherever feasible, this course of action should be investigated. Considerations include:

1. Can the conveyed material be moved by belt or screw conveyor without spilling or choking?
2. Will the mechanical conveyor's location block access or create safety hazards?
3. Does the existing location of machinery and building layout minimize construction costs?

Gravity should never be overlooked as a reliable and inexpensive means of conveyance. It is common to see stacked seed cotton cleaning equipment. Many gins have eliminated a fan by locating the steady flow feed hopper in a pit beneath the module feeder, as opposed to setting the storage hopper at a separate location at ground level (Funk and Wanjura, 2017). Although construction costs are higher and retrofitting an existing gin might not be possible, by eliminating a stage of pneumatic conveying this configuration could reduce energy use and particulate emissions.

Consider Electric Motor Efficiency. Whereas old motors can be replaced with newer, more efficient ones to save energy, return-on-investment decisions are different in the cotton ginning industry compared to many other industries because the typical cotton ginning season can be less than 90 days. In this case it is rarely cost effective to replace a less efficient electric motor unless the existing motor is at the end of its useful life and needs to be replaced anyway. Rewinding motors might not be cost effective for smaller motors, and should be considered carefully for larger motors. Motors can have damage that affects efficiency after rewinding, or their design can limit the efficiency. In such cases purchase of a new, more efficient motor would be indicated. One situation where replacing a motor before it is worn out might make sense is when the motor is oversized or undersized by a factor of two or more. Even then, the return on investment could take five to seven years (Funk and Hardin IV, 2012). To determine if a motor is properly sized, it is necessary to measure its current under normal load. This should be done by a licensed electrician trained and equipped to safely work on live high voltage equipment. The working power of a 3-phase motor can be calculated using the equation:

$$\text{Hp} = \text{Volts} * \text{Amps} * \text{PowerFactor} * \text{Motor Efficiency} * 0.00232$$

where typical power factor values ranged from 0.753 to 0.830, with a mean value of 0.791 in monitored cotton gins (Hardin IV and Funk, 2012). The power factor for large, fully loaded motors such as gin stands and fans will be higher and the power factor for small or lightly loaded motors such as the press hydraulic pumps (except when forming a bale) will be lower. Compare the calculated horse power to the name plate value to see if the motor is properly sized. Maximum efficiency is usually near 75% of rated load (DOE, 1997). Remember that press pump motors are sized for the maximum load at the end of the bale forming cycle. While the electrician is measuring motor voltages and currents, take the time to write them down for future reference (assuming the gin is running smoothly).

REDUCING ELECTRICITY COSTS

Monetary savings unrelated to energy consumption can be realized through decisions that impact the price paid for electricity. Each state and utility will have different rules, and they change with time. The general idea is to negotiate with the vendor providing electricity, express willingness to help them meet their needs, and ask for a monetary reward in return. For example, some utilities award a discount to customers who are willing to have their operations interrupted during a peak demand event, such as hot summer afternoons when their grid is overloaded. Because many gins operate during the fall, the risk of having operations interrupted might be low. Typical contracts specify a limit on the length of time and number of times service will be interrupted. Time-of-use (time-of-day) is a related option some gins have used to lower energy costs. In areas where this is available, the gin chooses to cease operations when demand is highest, for example between noon and six pm on weekdays. Some utilities even allow commercial customers to bid for power in real time; this works as a hybrid of the above two options, a gin would elect to stop operating if the price incentive were high enough. With capacity or demand bidding programs there is advanced notice of 4 to 24 hours and the flexibility to continue operations if desired (unlike an interruption contract). Because any one of these options might lengthen the ginning season, there are other factors to consider as well.

Peak electricity demand is normally established over a 15 to 60 minute period, but the demand charge is applied for the entire month. The most common strategy to minimize this cost is to start operating the gin the day after the meter is read. Thus the demand charge is spread over more days of operation, and hence, more bales of cotton.

Power factor charges are rare in the ginning industry. Utilities assess a power factor charge in some cases because a low power factor increases their energy losses in the distribution grid and limits their power generation capacity. If a power factor charge is included in a gin's utility bill, the solution is to hire a registered electrical engineer to design a properly sized and cost-effective correction. This is normally accomplished by adding a circuit that has capacitors.

With solar (and possibly wind) energy generation and net metering, the primary benefit is avoided cost. In most cases, the gin is buying electricity at retail and selling it back to the utility at wholesale (perhaps 25% of retail price). Thus electricity generated at the time it is consumed is more valuable to the gin than electricity generated the other 8 to 10 months of the year. Renewable energy generation credits are no longer valuable, typically 0.5 to 2.5 cents per kWh (NREL, 2015). One other possible benefit for installing solar generation might be tax credits, if available.

REDUCING FUEL USE

The general recommendations for increasing processing efficiency also will reduce fuel use per bale. Likewise, equipment and process changes that reduce air flow in seed cotton drying systems could save drying fuel if adequate drying can still be accomplished, because a smaller volume of air needs to be heated. Additional management strategies and equipment selection can further reduce fuel use.

Avoid Excessive Drying. The most significant operating decision related to fuel consumption is dryer control. The optimum fiber moisture content for ginning is within the 6 to 8% range (Childers and Baker, 1978). Ginning at lint moisture content levels of 6 to 7% is recommended to preserve fiber length, length uniformity, and strength (see Mayfield et al., [1994]). Low humidity is not uncommon during harvest in many areas and seed cotton can arrive at the gin with a lint moisture content below 6% (Hughs, 1985). This cotton does not need to be dried if acceptable leaf grades can be obtained. However, seed cotton cleaning efficiency increases with decreasing moisture content, so some drying might be necessary. In addition to reducing fuel use by seed cotton dryers and better preserving fiber quality, ginning at higher moisture levels can alleviate static problems and reduce the need for moisture restoration by humid air at the lint slide, saving additional fuel. Moisture restoration before the gin stand should be considered if cotton is frequently ginned at low moisture levels. Water spray systems, which use no fuel, can be used before the gin stand effectively to increase lint moisture (Byler, 2008) . Moisture application at this location in the gin is self-limiting due to the ginning problems that would result from excessive moisture addition. Whether using water droplets or water vapor, an automatic system must be included that stops the seed cotton moisturizing system when it senses that cotton flow is interrupted. This automation is required on each gin stand because one stand might kick out independently of the others. For more information, see Hughs et al., (1994).

Maintain Burners. Burner maintenance is just as important as maintenance on any other gin system. To avoid unnecessary fuel consumption, keep burners adjusted, clean, and working properly. For more information, see Hughs et al., (1994).

Use Dryer Control Systems. Drying systems traditionally responded to changes in temperature after the hot air–seed cotton mixpoint. Newer systems anticipate drying requirements by measuring the moisture content of incoming seed cotton. A drying system that automatically responds to changes in incoming seed cotton moisture as it occurs will use only as much fuel as the situation requires and will supply the pre-cleaning system with seed cotton at a more consistent moisture level, maximizing ginning rate and reducing downtime due to choking the gin. The benefits are reduced fuel expense, more bales per shift, and higher fiber value for customers.

Control systems have fallen in price even as they have become increasingly sophisticated, and they offer energy savings through drying optimization. Basic gin drying systems have a high limit temperature sensor in the heated air not more than 3 m (10 ft) before the seed cotton mixpoint to ensure that drying air is not more than 177 °C (350 °F), and a primary control temperature sensor after the mixpoint (ASABE, 2012). It is important that the sensors are working properly, and for the control sensor to be located shortly after the mixpoint, usually at the top of the tower dryer, where it can more quickly respond to temperature changes caused by the amount of moisture as well as the amount of cotton being dried. More sophisticated moisture control systems will also have sensors that estimate the moisture content of seed cotton, seed, and lint. If any of the sensors in the control system are not working properly, there is a risk of excess fuel consumption and fiber damage. For more information, see Hughs et al., (1994).

Insulate Drying Systems. Drying systems lose heat to the gin environment, which represents wasted fuel. Locating burners to minimize pipe length is one solution. Additionally, insulation can be applied to pipes and other system components to minimize heat loss and reduce fuel use. The largest savings will be achieved by insulating pipes from the burner to the seed cotton mixpoint. Larger pipes often are used before the mixpoint to reduce velocity and friction losses; however, this increases heat losses. After the mixpoint, heat is rapidly transferred to the seed cotton, so the air temperature, and therefore, heat losses, in the pipe are much lower. However, in some cases, insulating dryers also can be economical. Although the air temperature will be lower, the greater surface area will increase heat losses and installation costs might be lower due to the shape and location of dryers. The payback period would be longer for insulating pipes after the mixpoint due to the lower temperature of pipe surfaces conveying seed cotton.

Several factors affect heat loss from the drying system—drying temperature, ambient temperature, air velocity, and pipe and dryer dimensions. If the difference in drying temperature and ambient temperature is small for much of the ginning season, adding insulation might not have a reasonable payback period. To calculate the heat loss over a section of pipe, temperatures need to be measured at the entrance and exit of the section and the air velocity measured to calculate mass flow rate:

$$q = \dot{m}c_p\left(t_{entrance} - t_{exit}\right)$$

where:

q = heat loss (kW or Btu h^{-1})
$\dot{m}$ = mass flow rate of air (kg s^{-1} or lb_m h^{-1})
c_p = specific heat of air (1.007 kJ kg^{-1}°K^{-1} or 0.241 Btu $lb_m^{-1}F^{-1}$)
$t_{entrance}$ = temperature at entrance of pipe section (°C or °F)
t_{exit} = temperature at exit of pipe section (°C or °F)

When determining the temperature drop from the burner to the mixpoint, the entrance temperature needs to be measured at least five diameters downstream from the burner to allow for full development of the temperature profile in the pipe. The procedure for predicting temperature drop involves a number of variables and equations (ASHRAE, 2013). An online calculator available from the National Institute of Building Sciences (2014) can be used to estimate temperature drop. An example using this calculator for estimating temperature drop is shown in Fig. 4 for conditions representative of a 40-bale h^{-1}cotton gin (the duct perimeter listed is for a 0.762-m [30-in] diameter round pipe).

Input Information	
1. Entering air temperature, °F	250
2. Ambient temperature, °F	70
3. Flow rate of air, cfm	15000
4. Length of run, ft	100
5. Outside perimeter of duct, in	94.248
6. R-value of duct insulation, (h ft^2 °F)/Btu	0
Results	
Temperature drop, °F	10
Leaving air temperature, °F	240

Figure 4. Online temperature drop calculator (National Institute of Building Sciences, 2014).

Note that the calculator includes a field for the R-value of the insulation (when estimating the temperature drop in an uninsulated pipe, enter zero). The R-value is the thermal resistance of the insulating material, °K m^2 W^{-1}(customarily in IP units: h ft^2 °F Btu^{-1}); higher R-values indicate that the insulating material better prevents heat loss. The mass flow rate of air with the volumetric flow rate and temperature specified in Fig. 4 is 6.311 kg s^{-1} (834.8 lb min^{-1}) and 121 °C (250 °F) inside the pipe and 21 °C (70 °F) surrounding the pipe. From Equation 1, the total heat loss corresponding to this mass flow rate and the temperature drop of 5.6 °C (10 °F) is 35.31 kJ s^{-1} (120,500 Btu hr^{-1}). Changing the R-value in the online calculator to 4, which would be typical for 3.8-cm (1.5-in) thick fiberglass, reduces the temperature drop to 1 °C (1.8 °F). This temperature drop represents a heat loss of 6.36 kJ s^{-1} (21,700 Btu hr^{-1}). Therefore, at these operating conditions, the insulation reduces heat loss by 28.95 kJ s^{-1} (98,800 Btu hr^{-1}).

The volume of fuel saved per hour is equal to the difference in heat loss per hour divided by the product of the heating value of the fuel and the burner efficiency, assuming the control system is capable of regulating fuel flow under the new conditions. The total energy savings per hour due to insulation of 28.95 kW (98,800 Btu h^{-1}) is equivalent to 104.2 MJ h^{-1} (98,800 Btu). The heating value of propane is 25.48 MJ L^{-1} (91,420 Btu gal^{-1}). If the burner efficiency is 95%, fuel savings are 4.30 L h^{-1} (1.14 gal h^{-1}). With a propane price of \$0.53 L^{-1} (\$2.00 gal^{-1}) and 1000 h of operation at those conditions, the total savings per year would be \$2,280. These savings would need to be compared to the costs of materials and installation to determine the potential payback. Because natural gas is less than half the cost of propane, potential annual savings would be less than half this amount in facilities that use natural gas.

Several important points should be kept in mind when considering insulating pipes. If the gin only rarely uses temperatures as high as in the above example, potential savings would be much lower, and adding insulation might not be economically advisable. Also, the location of the pipes can significantly increase the temperature drop beyond the online calculator prediction in Fig. 4. The calculator assumes that pipes are located in an indoor environment with negligible air movement. If pipes are located outside or in a drafty area of the gin and subjected to wind, convective heat transfer from the pipe will increase significantly. Pipes located outside also can be subjected to precipitation, which would further increase heat loss. Insulation can protect the pipe from moisture that could cause corrosion. Finally, although energy savings are one motivation for insulating drying system components, personnel protection from high temperature surfaces is also important where people might come into contact with those surfaces.

REDUCING FUEL COSTS

Monetary savings unrelated to energy consumption can be realized through decisions that impact the price paid for dryer fuel. The biggest decision is fuel type, because natural gas is less expensive than LPG (propane). Two-thirds of U.S. gins use natural gas; it is more common in the southwest and less common in the southeast (Valco et al., 2015). Not all locations have access to natural gas, but the price difference between the two fuels is significant, and savings could potentially pay for the cost of burner conversion and connecting to a natural gas line. Using first quarter 2016 prices for commercial natural gas (\$6.87 1000 ft^{-3}) and residential propane (\$2.02 gal^{-1}) (EIA, 2016), and the heating value of each fuel, propane costs \$0.0811 kWh (\$23.78 Btu^{-6}), and natural gas costs \$0.0247 kWh (\$7.23 Btu^{-6}). As an example, if the propane bill for a typical ginning season is \$50,000, the expected bill after conversion to natural gas would be approximately \$15,200, resulting in an annual savings of \$34,800.

This estimate needs to be recalculated using actual prices paid, as propane delivered to commercial accounts is usually cheaper than residential propane (but is not tracked by EIA).

Purchasing fuel during times of low demand (early summer) is another strategy to save money. Filling tanks when prices are lowest could reduce a portion of the total drying fuel bill. During the past 25 years, May and June propane prices have averaged 7% less than September and October prices (EIA, 2016). The cost of tanks with sufficient capacity to store dryer fuel for an entire season might not be recovered by the potential savings, but some gins have justified large capacity on-site storage by including LPG retail as part of their business.

SUMMARY

Gins have become more energy efficient; however, energy costs account for 25% of gins' total variable costs. Reduced cotton acreage in recent years has driven gins to seek even greater efficiency, and consumers are increasingly concerned with the sustainability of textile products. Gins should maximize their average ginning rate to reduce the electricity and fuel used per bale. Increasing the ginning rate also utilizes labor more efficiently. A key point is that the gin needs to maintain this maximum ginning rate as much as possible, so that more bales are ginned per shift.

Material handling accounts for more than half of the electricity used at gins, as pneumatic conveying requires significant energy. The energy used for material handling varies widely between gins due to different equipment and gin layouts, indicating that additional reduction in electricity use is often possible. Reducing air volume and friction losses can save significant energy. Although factors affecting dryer efficiency are not controlled easily, dryer fuel use can be minimized by avoiding excessive drying through the use of properly designed control systems. Insulating components of the seed cotton drying system will save fuel, but gins need to evaluate the economics of installing insulation based on their gin layout and drying needs. The following specific recommendations can reduce energy use:

- Use automatic feed controls to maintain a constant flow of cotton
- Match equipment capacities
- Minimize downtime through an effective preventive maintenance program
- Shut off equipment instead of idling for long periods
- Use only the volume of air needed for consistent conveying and adequate drying
- Consider using VFD's to control fan speeds
- Eliminate leaks in the conveying system
- Consider conveying energy requirements when designing new gins or installing new equipment
- Eliminate elbows where possible, or use long-radius elbows
- Properly design ductwork at fan inlets and outlets
- Install evasés (diffusers) on cyclone exhausts, if permissible
- Use the minimum cyclone inlet velocity allowed by regulations
- Consider replacing pneumatic conveying systems with mechanical conveyors or gravity-fed systems
- Consider electric motor efficiency and choose the right size when replacing motors
- Avoid excessive drying: 6-7 percent target moisture content for ginning
- Properly maintain burners
- Use a dryer control system
- Consider insulating pipes in drying systems, particularly before the seed cotton mixpoint.

Besides reducing energy use, gins potentially can save money by reducing their costs for electricity and fuel. Start ginning soon after the electricity meter is read to avoid demand charges for a partial month of ginning. In some areas, gins can shut down when notified by their utility or avoid operating at certain hours to receive a discount on their bill. Gins often have land where solar or wind generation could be installed, and the excess energy sold back to the utility. If gins have access to natural gas, they should consider connecting to the line, because natural gas is less expensive than propane. If propane is used, gins can purchase propane during the summer when it is less expensive and store it until the ginning season.

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