ENERGY CONSERVATION PRINCIPLES

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Abstract

This paper discusses preliminary findings from energy audits conducted in cotton gins in six states, including the allocation of motor horsepower and energy consumption per bale (kWh). General inferences will be drawn from information collected at gin plants of various bale-per-hour capacity and annual throughput from various parts of the cotton belt. Practices common to gins that had particularly low energy per bale costs will be shared so that the industry, as a whole, may benefit by implementing ideas that will lead to energy (and cost) savings.

Cost of Ginning Survey

Periodically a cost of ginning survey is conducted with state, regional and National Cotton Ginners Associations (Valco et al., 2009). The 2007 survey indicated that there was a tremendous range in electrical energy consumed per unit processed, with some gins using nearly three times more electricity per bale than others. This finding prompted industry leaders to request a study by the USDA Ginning Labs to find out why there is such a large difference, in hopes that sharing findings so that every gin can implement best practices to reduce electricity costs industry-wide. These surveys also indicated that energy was the second greatest expense (after labor), accounting for nearly 20 % of the total cost of ginning, and that energy costs have risen more than all other costs. Surveys showed a trend of increasing energy cost, despite decreasing energy consumption.

Data from this survey was analyzed using *PROC PRINCOMP* (SAS 9.1, 2003, Cary, NC, SAS Institute Inc.), but there were no correlations between energy consumed per bale and other questions on the 2007 cost of ginning survey. Either the survey, in the interest of brevity, did not ask a question that captured differences in how electricity is used, or there was too much variance for a correlation to emerge. Several factors contributed to the high level of variance including weather, variety ginned, and facility layout. Some gins included the energy that they used to aerate seed and others did not. This survey and its predecessors indicated that electrical energy consumed per bale processed varies from year to year for a given gin and the average value varies from state to state as well as from year to year. Thus, electrical energy consumed per bale is influenced by many uncontrolled external variables and is more than just the result of a gin's design.

Energy Audits

Twenty US cotton gins participated in energy audits in 2009. They provided USDA-Agricultural Research Service personnel from Stoneville, MS and Mesilla Park, NM, access to their facilities and records. The USDA-ARS Southwestern Cotton Ginning Research Laboratory and USDA-ARS Cotton Ginning Research Unit cooperatively collected and analyzed this field data. Pre-season data collected included preparing a process flow diagram showing motor horsepower for each piece of machinery. Only a small percentage of data points were missing due to motor name plates that were obscured by paint or mounting position.

Data collected during the ginning season consisted of current measurements from each motor in the gin and its processing rate at the time of sampling. Two guidelines governed in-season data collection: don't get hurt and don't stop the gin. Current measurements must be made where each motor leg is independently accessible, usually at the motor control center. To safely measure current after opening the energized motor starter or disconnect housing, high-voltage protective gear including lineman's gloves and an arc shield affixed to a hard hat were used (Figure 1).

Care was exercised to minimize wire disturbance and the associated risk of breaking or shorting a circuit under load when placing the clamp-on ammeter. For smaller motors with disconnects located in boxes having little clearance, an ammeter with a fork-style sensing head was used (Figure 2). Multiple readings were recorded for motors with variable loads. Each current value was entered into a spread sheet for analysis. Motors were grouped into four categories: cleaning, ginning, bale packaging, and material handling. Motor center mains data included line to line voltages and, if available, power factor.

Figure 1. Tools used to measure motor current. The screwdriver was used to open motor disconnect or starter boxes. Then it went into a back pocket. Never stick a metal tool inside an energized electrical enclosure!

Figure 2. An ammeter with a fork-style sensing head was used to measure current when the disconnect box was too small to fit a clamp-on style ammeter. This minimized disturbing wires and reduced the risk of knocking a connection loose.

Energy Audit Results

For the gins participating in the 2009 audits, the average consumption per unit processed was 40.1 kWh/Bale for saw ginning and 64 kWh/Bale for roller ginning. The saw gin plant that used the most electrical energy (59 kWh/Bale) used 2.3 times more energy than the gin that used the least (26 kWh/Bale). For comparison, the national average electrical energy consumed per unit processed for the gins that participated in the 2007 survey was 42.4 kWh/Bale, with a range from 27 to 79 kWh/Bale.

Table 1 summarizes the national average of energy use by process category both in terms of energy per unit processed and as a percentage of the total. The most important finding was that over half the electrical energy used in the average gin was used in material handling, primarily fans for pneumatic conveying, with a smaller amount used for vacuum droppers and conveyors. The other three categories, seed cotton and lint cleaning, fiber-seed separation (ginning), and bale packaging, each add value and therefore are not candidates for omission. On the other hand, material handling, though necessary, does not add value to the fiber or the seed. It is unlikely, therefore, that reducing this component of energy use would compromise the value of the end product (provided it is still dried to the proper moisture content). Thus, producer profitability could be maintained even as electricity use is decreased, if alternate methods of material handling were implemented or plant layouts were modified to minimize material handling requirements. If such changes can be made without negatively impacting gin plant operations, they have the potential to significantly reduce energy use. There is some evidence that this has already been taking place. Over the past thirteen years that data have been recorded, gins have reduced the electricity consumed per bale (from 52 to 42 kWh/Bale), in large part because they have reduced the amount of air that they use for conveyance (J. Kelley Green, Texas Cotton Ginners' Association, personal communication 01 Dec 2010).

Table 1. Electricity use by process category for a typical US cotton gin.

	kWh/Bale	%
Cleaning	5.67	13%
Ginning	6.92	15%
Lint Packaging	6.14	14%
Material Handling	25.9	58%
Total	**44.6**	**100%**

Can fans be eliminated? In many cases it is not possible; after all, fans are used because they are an economical means of conveying material from one stage of the process to another and pneumatic conveyance is generally trouble free. However, there are some cases where a pneumatic conveying system could be replaced by a belt or screw conveyor. For example, many gins have replaced a pneumatic gin trash handling system with a mechanical one to reduce their dust emissions. Eliminating a fan-cyclone system results in one less emissions point and not handling trash twice reduces both total dust emissions and connected horsepower.

Recommendations

The following general principles may in some cases be implemented with little expense or disruption and in other cases may only be appropriate when designing a gin from the ground up. Since fans account for about half of the electrical energy consumption in a gin, reducing their connected horsepower wherever possible is something to bear in mind during the design phase where it may be possible to locate machinery so that it feeds the next process by gravity rather than by pneumatic conveying, saving the expense of a fan system, the electricity it consumes over its lifetime, and the air emissions associated with that fan system's dust cyclone. For facilities that have already been built, a good starting point is to consider ways to reduce existing fan loads.

Minimize Fan Loads

The following recommendations were selected because they pertain to cotton gins. Most are from the sourcebook "Improving Fan System Performance" (DOE, 2003) whose authors observe, "A highly efficient fan system is not merely a system with an energy efficient motor. Overall system efficiency is the key to maximum cost savings." They recommend a systems approach to energy conservation that considers all the components of an air handling system, and their interactions, over their life-cycle.

Fan Size

System design begins with a considerable amount of guess work. Equipment selection is often conservative. Consequently, fans may be specified larger than actually necessary in the finished gin plant. An oversized fan pushes more air than the process requires, unlike a properly sized fan. An oversized fan may cost more to operate as well more to purchase. Indications that a fan is oversized include unstable or surging air flow, pulsating or excessive noise and vibration, and inlet vanes or dampers that are always in a restrictive position. Replacement with a properly sized fan may result in less electrical power consumption, less vibration, and less down time. A less expensive alternative to complete fan replacement is decreasing the fan speed by changing belt pulleys or possibly replacing the soft start with a Variable Frequency Drive (VFD). The VFD does not alter motor efficiency. There was no apparent difference in motor efficiency when various sizes and types of motors were tested with and without VFD (Burt et al., 2006). However, a VFD may be used to reduce air flow to the optimal rate. Reducing the excess portion of air mass flow may result in energy savings compared to when the motor is connected across-the-line. Because fan power consumption is a function of speed to the third power, a small decrease in speed will result in a large decrease in power required, a medium (second order) decrease in pressure, and a one-for-one decrease in airflow. A VFD allows one to match the fan speed to the minimum airflow requirement easily and precisely. When controlling a fan with a VFD that has a feedback input it may be possible to program the drive to maintain a constant motor RPM or a constant current, allowing the fan to automatically react to changes in static pressure. Although energy savings through VFD installation has not yet been documented in the literature, several gins have been pleased with the results of using current to control VFD to maintain a constant process air volume, attaining more consistent operation with fewer choke ups and better drying (John Fabian, Technical Services, Kimbell Gin Machinery Co., Personal Communication 10 December 2010.)

Fan Style

The workhorse of the industry has always been the radial-blade centrifugal fan. It is simple in design and easy to make, durable, and its flat blades can handle gin trash. They can overcome higher static pressure and are self-cleaning, resulting in less gin down time. But it does not have the highest efficiency. Radial-tip fans have backward-curved blades resulting in lower turbulence and higher efficiencies, up to 75%. They can only survive in airstreams that have a moderate loading of small particles. Even more efficient (up to 85%) are backward-inclined and airfoil centrifugal fans, though they are recommended for clean air or push fan service only.

Pipe Layout

Most of the energy a fan consumes is due to air friction inside the pipes it is connected to. This air friction can be reduced by the following: Short pipe runs (locating processing machinery close to the next machine in sequence and locating fans close to the machinery they serve); Straight pipe runs (minimizing elbows to reduce losses); Smooth pipe runs (dents, bends, misalignment and internal surface roughness cause air friction losses); Gradual or sweep elbows (reducing losses where pipe must change direction by using low-turbulence fittings); Fan connections that minimize swirling and turbulence (by having a straight pipe run of at least three pipe diameters on the inlet and outlet sides of the fan or by installing flow straightening vanes if there is no material flowing in the elbow); and Downstream elbow directions that compliment rather than reverse the direction air moves out of the fan housing.

Leakage

It is a mistake to think that air is free- the money spent on power to pump or compress air is significant. If system airflow must increase 5% to make up for leaks, the fan speed must increase 5%. Assuming there is no change in the system curve, this 5% increase in fan speed will result in a 16% increase in power because of the fan law relationship governing fan speed and power. A seed line pipe system can be leak tested during the off season by pressurizing it up to its rated pressure and measuring the airflow required to maintain this pressure. Not only will sealing leaks save energy, it will result in a cleaner gin during the operating season. In gins where compressed air is used to sweep the floor, consider purchasing large dust mops. They can take less time cover a given surface area and they do not expose personnel to dust or air noise that can damage hearing.

Fan Preventative Maintenance

Predictive maintenance through continuous monitoring of critical machinery may be a few years away for the typical cotton gin. However, equipment is available today that is affordable and that might make sense in the context of cotton gin preventative maintenance, especially if the equipment is owned by a contractor who provides this as a service. The typical system is an instrument that records and processes high rates of frequency data coupled with an accelerometer that has a magnetic base and a laser tachometer. The accelerometer is mounted on a pre-determined location on each fan housing (marked with paint or permanent marker) following a set route. After establishing a baseline data set, a regular check up is performed (daily or weekly) during normal operation. The accelerometer is attached to its usual place and the instrument 'listens' for any abnormalities that may indicate eminent failure of a shaft bearing or imbalance in the fan wheel. A portable analyzer with appropriate sensors may cost from $15,000 to $20,000. Cotton gins may find rental or hiring a service provider to be the most cost effective way to benefit from this capability. Vibration analysis has been used successfully in other industries to schedule repairs before catastrophic failure, preventing costly unplanned downtime and collateral damage.

Table 2. Full load motor efficiencies at 1800 rpm (Burt et al., 2006).

Size (HP)	Pre-1992	EPA Act*	NEMA Premium
5	0.833	0.875	0.895
7.5	0.855	0.895	0.917
10	0.857	0.895	0.917
15	0.866	0.910	0.924
20	0.885	0.910	0.930
25	0.893	0.924	0.936
30	0.896	0.924	0.936
40	0.902	0.930	0.941
50	0.913	0.930	0.945
60	0.918	0.936	0.950
75	0.917	0.941	0.954
100	0.923	0.945	0.954
125	0.922	0.945	0.954
150	0.930	0.950	0.958
200	0.935	0.950	0.962

*The US Energy Policy Act of 1992 specified nominal full load efficiency standards for polyphase induction motors.

Match Motor HP to Load

Energy savings may be realized by matching each load to the right sized motor. Early in the design process there are many uncertainties and motors may be specified to meet loads that end up being smaller than anticipated (designers prefer to err on the side of caution). Additionally, motors may have been installed that are larger than necessary to allow for future expansion. Once a system is operating it is possible to measure the current that each motor draws (and to record this value for trouble shooting and future planning). The measured current value can be used to calculate the actual load on each motor:

$$\text{Current} \times \text{Voltage} \times \text{Motor Efficiency} \times \text{Power Factor} \times 1.732 \times 0.001341 = \text{Load}$$

...where 1.732 is the square root of three (for three phase motors) and 0.001341 is the conversion factor from W to HP. If power factor cannot be measured, 0.85 may be substituted as a reasonable initial estimate. Motor efficiency based on the age and size of the motor can be found in Table 2.

Comparing the actual load to the rated name plate power, indicates the percent of full load. In most industrial applications, the objective is to select a motor such that the load is 95% of the motor's rating for steady loads and 75% of the motor's rating for variable loads (a variable load can be calculated by taking the root mean square of its value over a typical operating cycle). If the measured current indicates that the motor is lightly loaded, especially if it is below 50%, the motor is operating inefficiently (see Figure 3).

The efficiency of that system may be improved by replacing the existing motor with a motor that is the right size. A typical gin may have several motors that were accidentally oversized or undersized (a few may have been replaced during the season with whatever was handy). Overloaded motors are also inefficient (as well as likely to trip their circuit breaker and are prone to failure). Replacing an overloaded motor with one that is the right size will also result in operating costs savings. At the same time, it will reduce the likelihood of costly unplanned downtime because of motor failure.

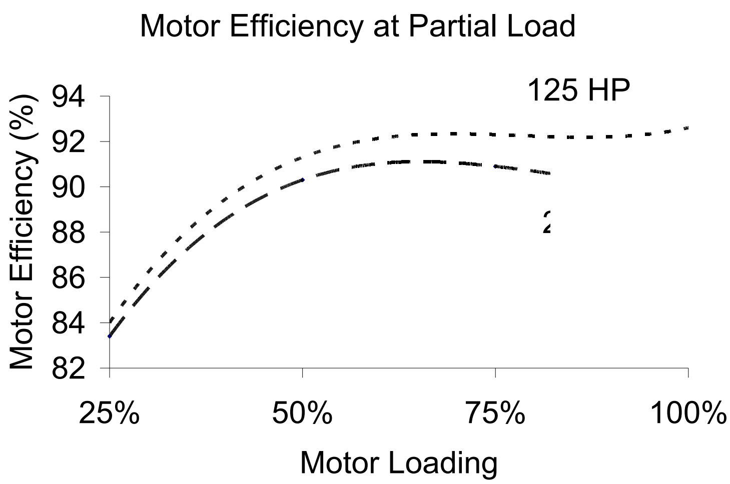

Figure 3. Motor efficiency as a function of percent of rated load. Efficiency drops significantly when motors are lightly loaded (DOE, Undated).

Table 3. Hypothetical benefit from motor replacement in a typical cotton gin assuming season is 2,250 hours per year and electricity costs $0.14 per kWh. A 25 HP motor was overloaded to the point that it will need to be replaced soon . In most cases replacement motors save money only because new motors are more efficient.

Current (Amps)	Old HP	Rated Eff.	% Load	Actual Eff.	New HP	Rated Eff.	% Load	Motor Cost	Svgs/ year	Yrs ROI
4.0	3	0.814	101%	81%	**5**	0.875	65%	$450	$53	9
4.6	7.5	0.855	49%	85%	**5**	0.875	75%	$450	$28	16
11.0	10	0.857	87%	86%	10	0.895	91%	$600	$91	7
5.0	15	0.866	**27%**	81%	**5**	0.875	81%	$450	$66	7
9.6	15	0.866	51%	86%	**10**	0.895	80%	$600	$78	8
15.6	15	0.866	84%	87%	15	0.910	88%	$750	$149	5
7.8	20	0.885	**32%**	84%	**7.5**	0.895	86%	$500	$92	5
10.0	20	0.885	41%	86%	**10**	0.895	83%	$600	$79	8
15.0	20	0.885	62%	89%	**15**	0.910	84%	$750	$81	9
29.0	25	0.893	96%	89%	**30**	0.924	83%	$1,500	$195	8
43.0	25	0.893	**143%**	89%	**40**	0.930	93%	$1,875	$345	5
16.0	30	0.896	44%	88%	**15**	0.910	90%	$750	$111	7
18.0	30	0.896	50%	89%	**20**	0.910	76%	$900	$90	10
23.0	30	0.896	64%	90%	**25**	0.924	79%	$1,200	$140	9
31.0	30	0.896	86%	90%	30	0.924	89%	$1,500	$188	8
33.0	40	0.902	69%	90%	40	0.930	71%	$1,875	$200	9
37.0	40	0.902	77%	90%	40	0.930	80%	$1,875	$225	8
43.3	40	0.902	91%	90%	40	0.930	93%	$1,875	$263	7
28.8	60	0.918	41%	89%	**30**	0.924	82%	$1,500	$209	7
39.0	60	0.918	55%	91%	**40**	0.930	84%	$1,875	$140	13
46.0	60	0.918	65%	92%	**50**	0.930	79%	$2,200	$120	18
39.0	75	0.917	44%	90%	**40**	0.930	84%	$1,875	$265	7
75.0	75	0.917	85%	92%	75	0.941	87%	$3,000	$390	8
89.7	75	0.917	102%	92%	100	0.941	78%	$4,400	$467	9
80.0	100	0.923	69%	92%	100	0.945	70%	$4,400	$381	12
99.0	100	0.923	85%	92%	100	0.945	87%	$4,400	$472	9

Table 3 lists loads that may be found in a typical cotton gin, indicates their load and efficiency based on current measurements, and predicts annual savings (based on operating hours and electricity cost) for each load if the motor is replaced with a new high-efficiency motor more closely matched to the load. Note that "When working above relative loads of 40%, the inherent efficiency of the motor itself is more important than the variation in efficiency due to changing loads (Burt et al., 2006)." NEMA Premium Efficiency motors typically cost 10 to 15% more than energy-efficient motors, but they can be cost effective where operations exceed 2,000 hours per year and electrical rates are high (DOE, 2005).

Capacity Matching and Attainment

Just as matching loads and motors results in more efficient operation, matching the capacity of each step of the ginning process to all the others results in a more efficient and smooth running plant. It is much easier to attain the rated capacity of a gin if each component has the same rating. Keeping the gin operating close to its maximum capacity day in and day out results in lower energy (and labor) costs over the season (J. Kelley Green, Texas Cotton Ginners' Association, Personal Communication, 01 December 2010). A typical cotton gin may have been designed for future expansion or may have had several modifications over the years, so it is not unusual for a cotton gin to have, for example, a 40 BPH set of gin stands and a 30 BPH overhead or bale press, or vice verse. In such a case part of the ginning system is underutilized and therefore operating less efficiently (or part is overloaded and prone to choke-up and break down). Once the capacities of each system - seed cotton cleaning and drying, ginning, lint cleaning and bale packaging - are matched, significant efficiencies may be realized by operating near to that capacity.

Seed Cotton Supply

During the energy audits a frequent observation was that the last gin stand was underfed, at times processing half as much cotton as the gin stand next to it. There may be various reasons for this including bale press capacity or seed cotton cleaning system size or automatic overflow system problems. Whatever the explanation, if feed rate adjustments or capacity matching improvements can be made that would keep the last gin stand running full, it would probably make better use of the investment that machine represents as well as the electricity it consumes.

Minimize Downtime

Typical cotton gin operating costs are several thousands of dollars per hour; downtime is the enemy of every gin, and no ginner tries to shut down. When an unfortunate event occurs, the decision must quickly be made whether to let the gin idle or shut it down. Restarting takes time, and one way to reduce energy use is to minimize restart times through training. A well trained crew can get a gin back on line in a short time. When the ginner is confident that the system can be brought back on line quickly, he will be less reluctant to shut it down for a minor event. The energy savings add up in two ways. First, if the gin is shut down, less gas and electricity will be consumed while the problem is getting resolved. Second, less energy is used in the process of bringing the gin back on-line if it can be brought on-line quickly. When at idle the electrical energy consumed by a gin is typically a bit more than 75% of the power used at full capacity; in half a minute at idle the gin has used as much electricity as it uses starting up. One minute of running time consumes more energy than a motor starting event (DOE, 2008).

Keep Good Records

Downtime and repair records are a potential gold mine when looking for problems or making repair and replacement decisions. In the long run, good record keeping leads to less downtime, and less downtime leads to less energy consumed per bale processed.

Summary

Following industry best practices when designing, upgrading, maintaining and operating a cotton gin results in many benefits, including energy savings. An efficiently operated gin makes the best use of all the resources entrusted to it - including employee time, capital resources, and the customer's cotton. The number of bales ginned at the end of the day has the biggest impact on all measures of efficiency. Measuring the current drawn by each motor during normal operations gives gin management a good idea how well each motor is matched to its load. The DOE fact sheet "Determining Electric Motor Load and Efficiency" discusses load estimation techniques. Organizing this information into value added and material handling categories may reveal areas of potential energy savings. As electricity costs rise more rapidly than other inputs, modifications that save energy can pay for themselves.

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