# ENGINEERING ANALYSIS AND ECONOMIC IMPACTS OF AIR POLLUTION ABATEMENT STRATEGIES FOR COTTON GINS

**Anantha R. Ramaiyer, Graduate Research Assistant**
**Calvin B. Parnell, Jr. Ph.D., P.E.**
**Roy Childers**
**Department of Agricultural Engineering**
**Stephen Fuller, Ph.D.**
**Melanie Gillis, Graduate Research Assistant**
**Department of Agricultural Economics**
**Texas A&M University**
**College Station, TX**

## Abstract

The implementation of the Federal Clean Air Act (FCAA) amendments have imposed more stringent air pollution controls from sources of air pollution. Cotton gins emit particulate as a result of their ginning process. All gins in Texas must install Baseline Best Available Control Technology (BBACT) to control emissions. Gins that are located in densely populated areas may be in violation of the nuisance hazard and may be required to install additional controls. In Texas, the permit engineers can define the additional controls that must be used to comply. These additional controls must be BACT which requires that the regulator consider "economic reasonableness". One method for defining economic reasonableness is to use cost per ton of reduced emissions (CPTRE). This paper defines four additional abatement strategies. The emission factors, the total mass of particulates released annually were estimated for each of these strategies. The cost of investing in each of these strategies and the cost per ton of reduced emissions when upgrading the pollution controls from BBACT to each of the additional abatement strategies were calculated.

## Introduction

Currently, there are about 440 gins in Texas. Only 150 of these gin plants have permits. As per Regulation VI, if a facility began operation after September 1, 1971 it must obtain a permit, unless the facility qualifies for an exemption. According to the Texas Natural Resource Conservation Commission (TNRCC), "Any person who plans to construct any new facility or engage in the modification of any existing facility of this state which may emit air contaminants into the air must obtain a permit to construct pursuant to" TNRCC Rule 116.111. A technical review is conducted by the State Air Pollution Regulatory Agency's (SAPRA) permit engineers before issuing a permit. The first part of the review verifies that all emission sources have been identified and the emission rates have been correctly calculated. After this, the permit engineer reviews the proposed control technology and the applicant may have to perform dispersion modeling on the proposed emissions from the facility. The SAPRA engineers have the authority to mandate that a gin install the abatement system that results in a minimum particulate emission rate.

Reprinted from the *Proceedings of the Beltwide Cotton Conference*
Volume 2:1619-1625 (1996)
National Cotton Council, Memphis TN

The process of establishing the appropriate air pollution abatement system for a specific cotton gin is not a simple process. In Texas, gins must install the Best Available Control Technology (BACT). By rule, BACT is the air pollution equipment that minimizes particulate emission with consideration for "economic reasonableness and technological practicability." Baseline Best Available Technology (BBACT) is the minimum level of control required for new gins, in order to obtain a permit. BBACT was defined in a policy document by the TNRCC with input from the Texas Cotton Ginners Association (TCGA). BBACT is defined as, 2D2D or 1D3D cyclones for centrifugal fan exhausts and covered condenser drums on axial-flow fan exhausts. This policy authorized regulators to require additional controls for gins that are problematic, i.e. (a) gins located in populated areas, (b) gins with a history of noncompliance, and (c) gins with a history of complaints from neighboring public. Cotton gins located in rural areas or those with a good history of compliance need only utilize BBACT to comply with the Texas Clean Air Act (TCAA). However, a gin using BBACT and complying with TCAA may be required to install additional controls as a result of any single violation. These additional controls will reduce the emissions of particulates from the cotton gins. Installing additional controls will require additional investments.

This study defines four abatement control strategies that will reduce the gins emission rate relative to BBACT. The TNRCC permit engineer has the authority to mandate the air pollution abatement strategy that must be installed by the ginner to achieve compliance. However, the ginner has the opportunity to use the "economic reasonableness" criteria to negotiate an abatement strategy that will allow him to operate at a profit. The determination of the economic impact on a cotton gin with mandated air pollution control equipment is a goal of this research. The results of this study may be used by regulatory personnel and cotton ginners to establish the appropriate air pollution abatement system for a specific gin, that will result in a minimum emission rate considering "economic reasonableness."

## Theory

Cotton gins in Texas have ginning capacities ranging from 6 bales per hour (bph) to 55 bph. Five gin plant categories were defined for this study: $\leq$10 bph, 10-15 bph, 15-25 bph, 25-35 bph, >35 bph. Table 1 shows the distribution of the gins in Texas for each category. The total and average ginning volumes for each category is presented in Table 2 and Table 3. Four air pollution control strategies were conceived, that would result in decreasing emission rates related to BBACT. These strategies were called Best Available Control Technology Design 0 (BACTD0), BACTD1, BACTD2, BACTD3. The associated investment costs for each of these strategies were estimated. In addition, the total particulate mass (total emissions) emitted by all five control systems (including BBACT) were calculated and the cost per ton of reduced emissions estimated. More specifically this section:

(1) Defines the air pollution control equipment for the five control technologies or systems (BBACT, BACTD0, BACTD1, BACTD2, and BACTD3).

(2) Estimates emission factors and total mass of particulate emitted each ginning season from plants processing picked and stripped cotton, using the five air pollution control technologies or systems.

(3) Estimates the cost of investment required to implement the five control systems and the associated cost per ton of reduced emissions.

**Proposed Abatement Strategies**

Five alternative air pollution control systems (BBACT, BACTD0, BACTD1, BACTD2, and BACTD3) were defined. For each of the five gin plant categories, the associated investment costs resulting from the implementation of each air pollution control system were estimated. Each of these systems were developed on the basis that each system would achieve an associated level of air pollution control. This level of control (emission rate) depends upon the specific equipment included in each design. Each air pollution control system design is described below in detail:

Baseline Best Available Technology (BBACT) consists of either 2D2D or 1D3D cyclones on all the centrifugal exhausts and fine mash screens on the condenser drums of all axial flow exhausts. This design was defined in a policy document developed by the permit engineers and the industry engineers. This abatement strategy is assumed to have an emission factor of 2.24 lbs/bale . This number corresponds to 0.0373 grains /dry standard cubic foot (gr/dscf) for picker gins.

Best Available Control Technology Design 0 (BACTD0) is an abatement strategy that consists of 1D2D cyclones on the axial-fan exhausts in the place of the covered condenser drums used in BBACT. The centrifugal fan exhausts have 1D3D or 2D2D cyclones. The 1D2D cyclones can be used for the axial flow exhausts because they are designed to operate at low pressure (<1.5 inches w.g). This cyclone was designed and tested successfully for this specific purpose (Simpson et al., 1995). This cyclone was also more effective as a dust abatement device for lint cleaner exhausts when compared to 1D3D or 2D2D cyclones. Best Available Control Technology Design 1 (BACTD1) is defined to include the following specific controls: Axial fans are replaced by centrifugal fans, 1D3D or 2D2D cyclones are utilized for all the centrifugal fan exhausts. The covered condenser drums are replaced by 2D2D cyclones. Particulate emissions are expected to be lower than BBACT because of the higher efficiency of cyclones compared to covered condenser drums. This strategy is currently being used by some gins in Texas.

Best Available Control Technology Design 2 (BACTD2) is the fourth air pollution control system. It has a pre-separator/1D3D cyclone system on all of the fan exhausts. The axial flow fans are replaced with centrifugal fans.

Best Available Control Technology Design 3 (BACTD3) is a strategy being used by some cotton gins. This design strategy incorporates a rotary drum filter on the cyclone exhausts that are connected to the unloading fan, the two push pull fans, and the trash fan exhausts. The remaining exhausts have the same controls as in BACTD1 (the axial fans are replaced by centrifugal fans, all the centrifugal exhausts have 1D3D or 2D2D cyclones). The rotary drum filter/cyclone system is included in order to study the economic feasibility of using rotary drum filters as air pollution control devices for cotton gins.

**Emission Rates**

The rate at which each air pollution abatement strategies emit particulate matter or "dust" into the air can be called emission rate. EPA AP-42 defines the emission factor for cotton gins in terms of the pounds of particulate matter released into the air for each bale that is processed. The EPA AP-42 (1988) emission factor for cotton gins is 2.24 pounds of particulate per bale (lbs/b). If the total number of bales processed per season is known, the total mass of particulate emitted per year can be determined. This is useful in determining the associated cost of investment from adopting a specific air pollution control system. Several methods are available to estimate cotton gin emissions. One method is to utilize source sampling data. The results from using this method are influenced by many variables which include the type of cotton, ginning rate, and engineering design of the control system. Consequently, source sampling data are highly variable; therefore, the following alternative approach was selected:

(1) Emission rates were used to estimate emission concentrations based on a "standard" air flow rate from a gin. The air flow rate for gins processing picked cotton is 7000 cubic feet per minute (cfm) per bale per hour (bph) of capacity and 8000 cfm per bph of capacity for gins processing stripped cotton.

(2) The EPA AP-42 emission factor is 2.24 lbs/bale which is equivalent to an average emission concentration of 0.0373 grains per dry standard cubic feet (gr/dscf). Using the average emission concentration of 0.0373 gr/dscf, the emission factor for picker and stripper gins

are 2.24 lbs/bale and 2.56 lbs/bale respectively. This difference is observed because the air flow (8000 cfm per bph of capacity) for gins processing stripped cotton is larger than the air flow (7000 cfm per bph of capacity) for gins processing picked cotton. A larger air flow will result in more emissions. The following equation was used to determine the total volume rate of flow of air used by the gin:

$$\mathbf{Q_T = (Q_P \text{ or } Q_S) \times G_C} \qquad \textbf{(Eq. 1)}$$

where $Q_T$ = total air volume used by the gin (cfm);
$Q_P$ = 7,000 cfm per bph for picker gins
$Q_S$ = 8,000 cfm per bph for stripper gins; and
$G_C$ = ginning capacity (bph).

The conversion of the average emission concentration to an emission factor is demonstrated mathematically as follows:

(Picker cotton)
$0.0373$ gr/ft$^3$ × 7000 cfm/bph × 1 lb/7000 gr × 60 min/hr = 2.24 lbs/bale

(Stripper cotton)
$0.0373$ gr/ft$^3$ × 8000 cfm/bph × 1 lb/7000 gr × 60 min/hr = 2.56 lbs/bale

This is a more realistic estimate of the emission factor for stripped gins. The emission factor calculations for all the abatement strategies were calculated by converting the emission concentrations in gr/dscf to emission factors in lbs/bale. The emission concentration 0.0373 gr/dscf was used as the EPA AP-42 emission standard.

(3) Where emission rates were not available (for control technologies associated with BACTD0, BACTD1, BACTD2, and BACTD3), emission concentrations were estimated and the emission factors were developed using the "standard" air flow rate. For example, it was assumed that a gin plant under pre-control conditions had some air pollution control equipment with an emission factor of 4 lbs/bale. This emission rate is equivalent to an average concentration of 0.067 gr/dscf, based on a 7,000 cfm per bph capacity for picked cotton gins. The design for BBACT was assumed to have an EPA-AP 42 emission factor of 2.24 lbs/bale for gins processing picked cotton which is equivalent to an average emission concentration of 0.0373 gr/dscf. The equivalent emission factor for a stripper gin utilizing 8000 cfm per bph is 2.56 lbs/bale.

(4) The emission concentration from cyclones (1D2D, 1D3D, and, 2D2D) are assumed to be 0.03 gr/dscf. The emission concentrations from pre-separator cyclone systems were assumed to be 0.02 gr/dscf. There is little information on the emission concentrations from drum filters. Studies by Yarlagadda et al (1994), showed that the rotary drum filter had an efficiency of 80% for loading rates of 1 to 3 grams per cubic meter. Rotary drum filters were used in BACTD3, where the cyclone exhausts directly into the rotary drum filter. If the cyclone emission concentration is 0.03 gr/dscf, then the emission concentration from a rotary drum filter (at 80%efficiency or 20% penetration) connected to the cyclone exhaust would be:
0.03 gr/dscf × 0.20 = 0.006 gr/dscf

This is a rough estimate and is probably a lower emission concentration than what would really be achieved in practice. This can be illustrated by the fact that rotary drum filters (RDF) are comparable to bag filters. However, rotary drum filters operate at high filtering velocities [80-100 feet per minute (fpm) compared to less than 10 fpm for bag filters] and the RDFs do not have a dust cake formation like the bag filter. Bag filters can achieve an emission concentration of 0.01 gr/dscf provided a dust cake is formed. It is likely that the majority of particulates leaving the cyclones will be less than 10µm aerodynamic equivalent diameter (AED). The assumed emission concentration of 0.006 gr/dscf may be lower than what will occur in practice.

(5) The air used in pneumatic conveying in cotton gins is associated with centrifugal and axial flow fans. Using data from Shaw et al (1977), the centrifugal fan airflow were estimated to be 70% of the total air flow and the axial air flow were estimated to be 30% of the total air flow. The EPA AP-42 emission factor is the summation of emissions from all the individual centrifugal fan exhausts and the axial fan exhausts. For BBACT, BACTD0, and BACTD1 the emission concentrations from the cyclones associated with centrifugal fans were assumed to be 0.03 gr/dscf.

(6) The covered condenser drums associated with the dust control system of the axial flow fans in BBACT were replaced by 1D2D cyclones to attain BACTD0. The average emission concentration from 1D2D cyclones was assumed to be 0.03gr/dscf which is the same as that for the 1D3D or 2D2D cyclones. The emission concentration for all cyclone exhausts was assumed to be 0.03 gr/dscf. The corresponding emission factors for picker and stripper gins were calculated to be 1.8 and 2.06 lbs/bale, respectively.

(7) For BACTD1, the vane axial fans and the covered condenser drum in BBACT are replaced by centrifugal fans and 1D3D or 2D2D cyclones. The emission concentration was assumed to be 0.03 gr/dscf for BACTD1. The corresponding emission factors for

picker and stripper gins were calculated to be 1.8 and 2.06 lbs/bale, respectively.

(8) In BACTD2, all the exhausts have a pre-separator cyclone system, which was assumed to have an average emission concentration of 0.02 gr/dscf. The corresponding emission factor for picker and stripper gins were calculated to be 1.2 and 1.37 lbs/bale, respectively.

(9) For BACTD3, the unloading fan, push-pull fan, and the trash fans have 2D2D or 1D3D cyclones which is followed by a rotary drum filter. Based on data from Shaw et al (1977), the unloading fan, push-pull fan, and the trash fans accounted for 60% of the total air flow. The emission rate for the cyclone-rotary drum filter exhausts are assumed to be 0.006 gr/dscf (Yarlagadda, 1995). The remaining exhausts have 2D2D or 1D3D cyclones with an assumed average emission concentration of 0.03 gr/dscf. The corresponding emission factors for picker and stripper gins were calculated to be 0.94 and 1.07 lbs/bale, respectively. The calculated emission factors for the different abatement strategies are shown in Table 4 & 5.

**Total Mass of Particulate Emitted**

The total mass of particulate emitted per season by a gin with a particular control system is dependent on its ginning capacity and utilization rate. As previously noted, five gin plant sizes were defined and analyzed for this study. The total number of bales ginned each season by gins of different capacities were based on an assumed "standard" ginning season of 1000 hours. For example, a 10 bph plant operating at 75 percent utilization will process 7,500 bales per season (10 bales/hr. × 1,000 hours/season × 0.75). Table 6 shows the bales ginned per season by the different categories of gins for different utilization rates. The total mass of particulate emitted each season was calculated based on the number of bales processed and their respective emission rates. The total mass of particulates released was calculated using the following equation:

$$\mathbf{MT = EF \times G_C \times 1000\ hrs./season \times U} \qquad \textbf{(Eq. 2)}$$

where

MT = total mass of particulates emitted per season (lbs/season);

EF = emission factor (lbs/bale);

$G_C$ = ginning capacity (bph); and

U = percent utilization;

For example, a 10 bph picker cotton gin at 100% utilization with the BBACT control system has an emission factor of 2.24 lbs/bale. Thus the total emission from this gin would be 22,400 pounds/season or 11.2 tons/season (2.24 lbs/bale × 10 bph × 1000 hrs./season × 1.0). The total mass of particulate emitted each season for other gin plant sizes were similarly estimated. The total mass of particulate emitted per season were estimated for different capacity (bph) gins, operating at 100, 75, and 50 percent utilization levels (See Tables 7-12).

**Cost of Equipment**

The air pollution control equipment that are used in the various abatement strategies defined in this study are 1D2D, 1D3D, and 2D2D cyclones, covered condenser drums, rotary drum filters, and pre-separators. BACTD1, BACTD2, and BACTD3 required that the axial fans be replaced by centrifugal fans. The cost of covered condenser drums and pre-separators were developed using estimates made by Parnell (1993). The cost of covered condenser drums was assumed to be \$0.1/cfm. The cost of pre-separators was assumed to be \$0.3/cfm. The cost of rotary drum filters (\$2.5/cfm) were estimated using a price quotation of Continental Conveyor & Equipment Company (1993), Yarlagadda et al (1994.)

The cost of cyclones had been previously estimated using the procedures outlined by Cooper and Alley (1992). There were some questions as to the accuracy of these estimates, especially for large air flows where a series or a bank of cyclones were needed. The cost factors given in Cooper and Alley did not lay out procedures for calculating the costs of cyclone banks. Another source for estimating the cost of air pollution abatement systems was published by Vatavuk (1990). The formula given by Vatavuk for calculating costs is:

$$\mathbf{Price\ (\$) = 6520\ (A^{0.903})} \qquad \textbf{(Eq. 3)}$$

where

$0.200\ ft^2 \leq A \geq 2.64\ ft^2$.

This procedure included the cost of cyclone, fan, motor, supports, and hoppers/drums. From our initial calculations using various inlet areas, the Vatavuk method yielded costs that were relatively high for gins used in the cotton gin industry. The Vatavuk model was developed for cyclones used in the chemical processing industry where the metal used for construction of the cyclone, must possess high strength and chemical resistance. Most of the cyclones used by cotton gins are constructed with sheet metal which costs less than the metal used in chemical industries. The cost factor also includes the cost of engineering design. However, the engineering design work that goes into designing cyclones for chemical industries is more complex and hence more expensive than for the cyclones used in cotton gins.

Based on past experience and interactions with the cotton ginning industry, the cost of cyclones is approximately \$1/cfm. This is exclusive of the fan costs. In order to arrive at a more reasonable estimate which would also be conservative, the formula given by Vatavuk was modified:

$$\textbf{Price (\$)} = 5500\ (A^{0.9}) \qquad \textbf{(Eq. 4)}$$

where

A = total inlet area of the cyclones used ($ft^2$).

An assumption was made that the gins would use 42 inch cyclones with an inlet area of 1.56 $ft^2$ for an airflow of 5000 cfm. For example, if the airflow is 76,000 cfm, then the inlet area is calculated as:

inlet area (A) = (76,000 cfm/5000 cfm) × 1.56 $ft^2$ = 23.712 $ft^2$

The modified Vatavuk procedure was compared to the Cooper and Alley procedure. The results of this comparison suggested that this new procedure was more appropriate. The suppliers of cyclones will be surveyed in the near future to improve this model. The current abatement equipment costs are conservative.

The cost of fans are included in the Vatavuk procedure. Fan costs are not included in the capital equipment for abatement strategies BBACT and BACTD0. In both these strategies, the axial fans are not replaced by centrifugal fans. In some strategies, the centrifugal fans already exist and they should not be included when calculating costs. The axial fans are replaced by centrifugal fans in the case of BACTD1, BACTD2, and BACTD3. Using data from cotton ginners, the cost of centrifugal fans was estimated to be $0.3/cfm. The fan costs were added or deleted, as required when calculating costs for different abatement strategies. The costs ($/cfm) for each abatement strategy for both picked and stripped cotton is given in Tables 13 & 14.

The capital cost invested in air pollution abatement systems was calculated using the following equation:

$$\mathbf{C = C_i \times Q_T} \qquad \textbf{(Eq. 5)}$$

where

- C = capital cost required for implementation of BBACT, BACTD0, BACTD2, and BACTD3 ($);
- $C_i$ = cost per cfm associated with the selected abatement system ($/cfm); and
- $Q_T$ = total air volume used by the gin (cfm) (Eq. 2).

The initial investment for each abatement strategy in dollars, is shown in Table 15 for picker gins and Table 16 for stripper gins. The air flow rates used for calculations were the "standard" airflow rate of 7000 cfm per bph for picked gins and 8000 cfm per bph for stripped gins. The centrifugal exhausts were estimated to be 70% and the axial exhausts were estimated to be 30% of the total airflow.

**Cost per ton of reduced emissions**

The cost per ton of reduced emission is a factor used by SAPRA engineers to determine the feasibility of using a particular abatement strategy. If cotton gins are in "tight" locations and are required to install additional controls, these additional controls will reduce the emission rate but the permit engineer must consider "economic reasonableness". One of tools to decide on economic reasonableness is the cost per ton of reduced emissions. As the name specifies, it is the additional cost of investment involved per ton of reduced emissions resulting from the upgrading of the pollution control system. The cost per ton of reduced emissions was calculated using the following equation:

$$\mathbf{CPTRE = [(C_{BACT+} - C_{BBACT}) \times (Q_P \text{ or } Q_S)] \div [(EF_{BBACT} - EF_{BACT+}) \times U \times 0.5\,]} \qquad \textbf{(Eq. 6)}$$

where

- CPTRE = cost per ton of reduced emissions;
- $C_{BACT+}$ = capital investment required in order to implement BACT+, which could be BACTD0, BACTD1, BACTD2, and BACTD3 ($);
- $C_{BBACT}$ = capital cost required to implement BBACT ($);
- $EF_{BBACT}$ = emission rate of BBACT (lbs/bale);
- $EF_{BACT+}$ = emission factor of BACT+ (lbs/bale);
- U = percent utilization; and
- 0.5 = conversion factor (1000 h/season × 1 ton/2000 bales)

The cost per ton of reduced emissions for gins processing both picked and stripped cotton is shown in Tables 17-22.

In order to demonstrate the procedures used to calculate the cost per ton of reduced emissions, consider the following example: A 20 bale per hour (bph) cotton gin processing picked cotton with a utilization of 75%. Since we are assuming that a normal season is 1000 bales, this gin will be processing 15,000 bales per season (0.75 × 20,000 bales/season). The emission factors for this gin (which falls in the 15-25 b/h category) if it installed the different abatement strategies is given in Table 3. The total mass of particulate emitted per season (1000 hours) if the gin uses BBACT can be calculated from equation 2:

**2.24 lbs/b × 15,000 bales/season = 33,600 lbs/season**

The capital cost involved in BBACT for example can be calculated from equation 4 and equation 1:

**$0.67/cfm × 7000 cfm/bph × 20 bph = $93800**

The cost per ton of reduced emission if the abatement strategy was upgraded from BBACT to BACTD0 can be calculated from equation 5:

**[$/cfm(0.95 - 0.67) × (7000 cfm)] ÷ [lbs/b(2.24 - 1.8) × 0.75 × 0.5] = $11,879**

The cost per ton of reduced emissions and the cost of initial investment for other abatement strategies for this particular gin are given in Table 23.

## Results and Discussions

The emission factors used for BBACT were 2.24 lbs/bale and 2.56 lbs/bale for gins processing picked and stripped cotton, respectively. The emission factors for BACTD0 and BACTD1 were the same, i.e. 1.8 lbs/bale and 2.06 lbs/bale for gins processing picked and stripped cotton, respectively. BACTD2 had a lower emission factor than BACTD0 but was higher than BACTD3. The emission factors for BACTD2 were 1.2 lbs/bale and 1.37 lbs/bale for gins processing picked and stripped cotton, respectively. BACTD3 had emission factors of 0.94 and 1.07 for gins processing picked and stripped cotton, respectively.

A general trend for the cost of investments was observed. The cost of investment increased from one abatement strategy to the next higher strategy i.e. BBACT< BACTD0< BACTD1< BACTD2< BACTD3. BACTD3 was to be the costliest abatement strategy with cost factors ranging from $2.09/cfm to $2.26/cfm. The cost factors for , BACTD1, and BACTD2 ranged from $0.96/cfm to $1.13/cfm and $1.26/cfm to 1.43/cfm, respectively. BBACT and BACTD0 had cost factors ranging from $0.62/cfm to $0.74/cfm and $0.87/cfm to $1.04/cfm respectively.
The costs per ton of reduced emissions were calculated for all the additional control technologies. These results were the ratio of additional costs required to install upgraded controls and the reduced emissions after replacing BBACT with BACTD+. BACTD0 and BACTD2 had a lower cost per ton of reduced emissions than BACTD1 and BACTD3. The cost per ton of reduced emissions ranged from $4773 to $14000 for BACTD0 and from $4644 to $15077 for BACTD2 at 100% utilization rates. BACTD1 had a larger cost per ton of reduced emissions (ranging from $6205 to $19040 at 100% utilization rates) than BACTD0 and BACTD2. BACTD3 had the cost per ton of reduced emission (ranging from $8185 to $27704 at 100% utilization rates) and had higher values than any other abatement strategy.

In order to demonstrate the usefulness of all these factors (the emission rate, the initial investment, and the cost per ton of reduced emission), a 20 bph (75% utilization) picker gin was used. Table 23 presents the initial cost of investment for different abatement strategies, the extra cost of investment when compared to BBACT, and the cost per ton of reduced emissions when compared to BBACT. The data in Table 23 can be used to illustrate as to which of the additional abatement strategies would meet the "economic reasonableness" criteria.

Looking at Table 23, the cost per ton of reduced emissions is least for BACTD0 ($11879), followed by BACTD2 ($12025) and BACTD1 ($15697) and BACTD3 ($21539). These data suggest that BACTD0 or BACTD2 would be less than $12,500 per ton of reduced emissions. It is likely that the permit engineer will require the gin to install BACTD2, since this abatement strategy reduces the emission factor reduces the emission factor to 1.2 lb/b instead of BACTD0 which has an emission factor of 1.8 lb/b. However, BACTD2 requires an additional investment of $94,000 compared to only $39,000 for the initial investment of BACTD0. It is likely that the ginner can successfully argue that BACTD3, which requires an additional investment of $210,000 does not meet the economic reasonableness criteria.

## Conclusions

1) A procedure was developed to calculate emission factors based upon the emission concentrations that would be expected from different levels of air pollution abatement control equipment.

2) There are times when a gin may be required to reduce its particulate emission rate and hence will be required to install additional controls. A procedure was presented that will allow the manager/owner of the cotton gin and the regulator to quantify the cost per ton of reduced emissions and negotiate a strategy that will address "economic reasonableness".

3) Achievable average emission concentrations for cotton gins will be in the range of 0.03 gr/dscf for pollution control equipment meeting the criteria of "economic reasonableness".

4) The emission factor for a cotton gin should not be less than 1 lb/bale. In order to comply with emission factors lower than 1 lb/bale, the gin will have to invest in abatement equipment that will not meet the criteria of "economic reasonableness".

5) Rotary drum filters will not meet the test of "economic reasonableness" for cotton gins.

6) The utilization of 1D2D cyclones is a new abatement strategy. These cyclones can be retrofitted on axial fan exhausts and this strategy will significantly reduce emissions from a cotton gin.

## Future Research

Using the results of this study and a business model developed by The Department of Agricultural Economics, Texas A&M University, it is possible to determine the fraction of gins that will go out of business if they invest in a particular abatement strategy. Future work will concentrate on developing a model that can be used to determine the criteria for economic reasonableness. This will incorporate a simulation model of the annual ginning volumes for the gins in Texas. It will be possible to use the procedures in this model to similarly determine the consequence of mandated air pollution controls for all the states in the Cotton Belt.

## Acknowledgements

We would like to acknowledge Cotton Incorporated, Cotton Foundation, and Texas Cotton Ginners Association for their support towards this research.

## References

Cooper, David C. and F.C. Alley. *Air Pollution Control.* Waveland Press, Inc, Illinois, Second Edition., pp 16-22,605-644, 1994.

Mihalski K., P.F., Kaspar., and C.B. Parnell, Jr., 1993, Design of Pre-Collectors for Cyclone Collectors, Transactions of ASAE, Paper No. 934058.

Shaw, D.L., O.A. Cleaveland, Jr., and J.L., Ghetti., 1977, Economic Models for Cotton GInning, College of Agricultural Sciences Publication No. 934058.

Simpson, S. and C.B. Parnell, Jr., 1995, Performance Characteristics of a New Low Pressure Cyclone for Cotton Gin Emissions, American Society of Agricultural Engineers Paper No. 951652, Chicago, Illinois.

Texas Natural Resource Conservation Commission (TNRCC) 1994, Technical Guidance Package for Agricultural Sources, TNRCC, Austin, Texas.

Vatavuk, W., 1990, *Estimating Costs of Air Pollution Controls*. Lewis Publishers, MIchigan.

Yarlagadda, S., 1995, Engineering and Economic Analyses for Cotton Gin Compliance with Air Pollution Regulations, Unpublished M.S. Thesis, Department of Agricultural Engineering, Texas A&M University, College Station, Texas.

Table 1. Distribution of cotton gins in Texas - Category-wise.

| Category | Number of gins | % of total gins in Texas |
|---|---|---|
| ≤10 | 56 | 12.7 |
| 10-15 | 148 | 33.6 |
| 15-25 | 162 | 36.7 |
| 25-35 | 57 | 12.9 |
| >35 | 18 | 4.1 |
| TOTAL | 441 | 100 |

Table 2. Ginning volumes (bales) from 1990 to 1994 for cotton gins in Texas.

| Category | 1990 | 1991 | 1992 | 1993 | 1994 | Average |
|---|---|---|---|---|---|---|
| ≤10 | 116891 | 99158 | 40298 | 61390 | 93791 | 82306 |
| 10-15 | 609617 | 496603 | 384786 | 486684 | 617853 | 519109 |
| 15-25 | 1486976 | 1383938 | 1062434 | 1602980 | 1653723 | 1438010 |
| 25-35 | 807885 | 850414 | 574212 | 1284046 | 1358147 | 974941 |
| >35 | 472815 | 511729 | 363860 | 596216 | 647378 | 518400 |
| TOTAL (millions) | 3.49 | 3.34 | 2.43 | 4.03 | 4.37 | 3.53 |

Table 3. Average ginning volumes (bales) from 1990 to 1994 for cotton gin in Texas.

| Category | 1990 | 1991 | 1992 | 1993 | 1994 | Average |
|---|---|---|---|---|---|---|
| ≤10 | 2087 | 1771 | 720 | 1096 | 1675 | 1470 |
| 10-15 | 4119 | 3355 | 2600 | 3288 | 4175 | 3507 |
| 15-25 | 9179 | 8543 | 6558 | 9895 | 10208 | 8877 |
| 25-35 | 14173 | 14920 | 10074 | 22527 | 23827 | 17104 |
| >35 | 26268 | 28429 | 20214 | 33123 | 35965 | 28800 |

Table 4. Emission factors and emission concentrations from gins with different abatement strategies, processing picked cotton.

| Abatement Strategy | Emission Factor (lbs/bale) | Emission Concentration (gr/dscf) |
|---|---|---|
| BBACT | 2.24 | 0.0373 |
| BACTD0 | 1.80 | 0.030 |
| BACTD1 | 1.80 | 0.030 |
| BACTD2 | 1.20 | 0.020 |
| BACTD3 | 0.94 | 0.0156 |

Table 5. Emission factors and emission concentrations from gins with different abatement strategies, processing stripped cotton.

| Abatement Strategy | Emission Factor (lbs/bale) | Emission Concentration (gr/dscf) |
|---|---|---|
| BBACT | 2.56 | 0.0373 |
| BACTD0 | 2.06 | 0.030 |
| BACTD1 | 2.06 | 0.030 |
| BACTD2 | 1.37 | 0.020 |
| BACTD3 | 1.07 | 0.0156 |

Table 6. Bales Ginned for Different Percent Utilizations

| Ginning Rate (bales/h) | Typical Gin (bales/h) | 100% (bales/season) | 75% (bales/season) | 50% (bales/season) |
|---|---|---|---|---|
| ≤10 | 10 | 10000 | 7500 | 5000 |
| 10-15 | 12.5 | 12500 | 9375 | 6250 |
| 15-25 | 20 | 20000 | 15000 | 10000 |
| 25-35 | 30 | 30000 | 22500 | 15000 |
| >35 | 35 | 35000 | 26250 | 17500 |

Table 7. Total mass of particulates (in pounds) emitted each season, from gins with different abatement strategies, processing picked cotton at 100% utilization.

| Capacity (bales/h) | Pre-BBACT | BBACT | BACTD0 | BACTD1 | BACTD2 | BACTD3 |
|---|---|---|---|---|---|---|
| ≤10 | 40000 | 22400 | 18000 | 18000 | 12000 | 9400 |
| 10-15 | 50000 | 28000 | 22500 | 22500 | 15000 | 11750 |
| 15-25 | 80000 | 44800 | 36000 | 36000 | 24000 | 18800 |
| 25-35 | 120000 | 67200 | 54000 | 54000 | 36000 | 28200 |
| >35 | 140000 | 78400 | 63000 | 63000 | 42000 | 32900 |

Table 8. Total mass of particulates (in pounds) emitted each season, from gins with different abatement strategies, processing picked cotton at 75% utilization.

| Capacity (bales/h) | Pre-BBACT | BBACT | BACTD0 | BACTD1 | BACTD2 | BACTD3 |
|---|---|---|---|---|---|---|
| ≤10 | 30000 | 16800 | 13500 | 13500 | 9000 | 7050 |
| 10-15 | 37500 | 21000 | 16875 | 16875 | 11250 | 8813 |
| 15-25 | 60000 | 33600 | 27000 | 27000 | 18000 | 14100 |
| 25-35 | 90000 | 50400 | 40500 | 40500 | 27000 | 21150 |
| >35 | 105000 | 58800 | 47250 | 47250 | 31500 | 24675 |

Table 9. Total mass of particulates (in pounds) emitted each season, from gins with different abatement strategies, processing picked cotton at 50% utilization.

| Capacity (bales/h) | Pre-BBACT | BBACT | BACTD0 | BACTD1 | BACTD2 | BACTD3 |
|---|---|---|---|---|---|---|
| ≤10 | 20000 | 11200 | 9000 | 9000 | 6000 | 4700 |
| 10-15 | 25000 | 14000 | 11250 | 11250 | 7500 | 5875 |
| 15-25 | 40000 | 22400 | 18000 | 18000 | 12000 | 9400 |
| 25-35 | 60000 | 33600 | 27000 | 27000 | 18000 | 14100 |
| >35 | 70000 | 39200 | 31500 | 31500 | 21000 | 16450 |

Table 10. Total mass of particulates (in pounds) emitted each season, from gins with different abatement strategies, processing stripped cotton at 100% utilization.

| Capacity (bales/h) | Pre-BBACT | BBACT | BACTD0 | BACTD1 | BACTD2 | BACTD3 |
|---|---|---|---|---|---|---|
| ≤10 | 45700 | 25600 | 20600 | 20600 | 13700 | 10700 |
| 10-15 | 57125 | 32000 | 25750 | 25750 | 17125 | 13375 |
| 15-25 | 91400 | 51200 | 41200 | 41200 | 27400 | 21400 |
| 25-35 | 137100 | 76800 | 61800 | 61800 | 41100 | 32100 |
| >35 | 159950 | 89600 | 72100 | 72100 | 47950 | 37450 |

Table 11. Total mass of particulates (in pounds) emitted each season, from gins with different abatement strategies, processing stripped cotton at 75% utilization.

| Capacity (bales/h) | Pre-BBACT | BBACT | BACTD0 | BACTD1 | BACTD2 | BACTD3 |
|---|---|---|---|---|---|---|
| ≤10 | 34275 | 19200 | 15450 | 15450 | 10275 | 8025 |
| 10-15 | 42844 | 24000 | 19313 | 19313 | 12844 | 10031 |
| 15-25 | 68550 | 38400 | 30900 | 30900 | 20550 | 16050 |
| 25-35 | 102825 | 57600 | 46350 | 46350 | 30825 | 24075 |
| >35 | 119963 | 67200 | 54075 | 54075 | 35963 | 28088 |

Table 12. Total mass of particulates (in pounds) emitted each season, from gins with different abatement strategies, processing stripped cotton at 50% utilization.

| Capacity (bales/h) | Pre-BBACT | BBACT | BACTD0 | BACTD1 | BACTD2 | BACTD3 |
|---|---|---|---|---|---|---|
| ≤10 | 22850 | 12800 | 10300 | 10300 | 6850 | 5350 |
| 10-15 | 28563 | 16000 | 12875 | 12875 | 8563 | 6688 |
| 15-25 | 45700 | 25600 | 20600 | 20600 | 13700 | 10700 |
| 25-35 | 68550 | 38400 | 30900 | 30900 | 20550 | 16050 |
| >35 | 79975 | 44800 | 36050 | 36050 | 23975 | 18725 |

Table 13. Unit cost of installation ($/cfm) for different abatement strategies processing picked cotton.

| Capacity (bales/hour) | BBACT | BACTD0 | BACTD1 | BACTD2 | BACTD3 |
|---|---|---|---|---|---|
| ≤10 | 0.74 | 1.04 | 1.13 | 1.43 | 2.26 |
| 10-15 | 0.72 | 1.01 | 1.10 | 1.40 | 2.23 |
| 15-25 | 0.67 | 0.95 | 1.04 | 1.34 | 2.17 |
| 25-35 | 0.64 | 0.90 | 0.99 | 1.29 | 2.12 |
| >35 | 0.63 | 0.88 | 0.97 | 1.27 | 2.10 |

Table 14. Unit cost of installation ($/cfm) for different abatement strategies processing stripped cotton.

| Capacity (bales/hour) | BBACT | BACTD0 | BACTD1 | BACTD2 | BACTD3 |
|---|---|---|---|---|---|
| ≤10 | 0.72 | 1.02 | 1.11 | 1.41 | 2.24 |
| 10-15 | 0.70 | 0.99 | 1.08 | 1.38 | 2.21 |
| 15-25 | 0.66 | 0.93 | 1.02 | 1.32 | 2.15 |
| 25-35 | 0.63 | 0.88 | 0.97 | 1.27 | 2.10 |
| >35 | 0.62 | 0.87 | 0.96 | 1.26 | 2.09 |

Table 15. Initial investment ($) for different abatement strategies processing picked cotton.

| Capacity (bales/hour) | BBACT | BACTD0 | BACTD1 | BACTD2 | BACTD3 |
|---|---|---|---|---|---|
| ≤10 | 51800 | 72800 | 79100 | 100100 | 158200 |
| 10-15 | 63000 | 88375 | 96250 | 122500 | 195125 |
| 15-25 | 93800 | 133000 | 145600 | 187600 | 303800 |
| 25-35 | 134400 | 189000 | 207900 | 270900 | 445200 |
| >35 | 154350 | 215600 | 237650 | 311150 | 514500 |

Table 16. Initial investment ($) for different abatement strategies processing stripped cotton.

| Capacity (bales/hour) | BBACT | BACTD0 | BACTD1 | BACTD2 | BACTD3 |
|---|---|---|---|---|---|
| ≤10 | 57600 | 81600 | 88800 | 112800 | 179200 |
| 10-15 | 70000 | 99000 | 108000 | 138000 | 221000 |
| 15-25 | 105600 | 148800 | 163200 | 211200 | 344000 |
| 25-35 | 151200 | 211200 | 232800 | 304800 | 504000 |
| >35 | 173600 | 243600 | 268800 | 352800 | 585200 |

Table 17. Cost per ton ($/ton) of reduced emissions for different abatement strategies when compared to BBACT for 100% utilization - Picker Gins

| Capacity (bales/hour) | Average Annual Ginning (bales) | BACTD0 | BACTD1 | BACTD2 | BACTD 3 |
|---|---|---|---|---|---|
| ≤10 | 10000 | 4773 | 6205 | 4644 | 8185 |
| 10-15 | 12500 | 5767 | 7557 | 5721 | 10163 |
| 15-25 | 20000 | 8909 | 11773 | 9019 | 16154 |
| 25-35 | 30000 | 12409 | 16705 | 13125 | 23908 |
| >35 | 35000 | 13920 | 18932 | 15077 | 27704 |

Table 18. Cost per ton ($/ton) of reduced emissions for different abatement strategies when compared to BBACT for 75% utilization - Picker Gins

| Capacity (bales/hour) | Average Annual Ginning (bales) | BACTD0 | BACTD1 | BACTD2 | BACTD 3 |
|---|---|---|---|---|---|
| ≤10 | 7500 | 6364 | 8273 | 6192 | 10913 |
| 10-15 | 9375 | 7689 | 10076 | 7628 | 13551 |
| 15-25 | 15000 | 11879 | 15697 | 12025 | 21539 |
| 25-35 | 22500 | 16545 | 22273 | 17500 | 31877 |
| >35 | 26250 | 18560 | 25243 | 20103 | 36939 |

Table 19. Cost per ton ($/ton) of reduced emissions for different abatement strategies when compared to BBACT for 50% utilization - Picker Gins

| Capacity (bales/hour) | Average Annual Ginning (bales) | BACTD0 | BACTD1 | BACTD2 | BACTD3 |
|---|---|---|---|---|---|
| ≤10 | 5000 | 9546 | 12410 | 9288 | 16370 |
| 10-15 | 6250 | 11534 | 15114 | 11442 | 20326 |
| 15-25 | 10000 | 17818 | 23546 | 18038 | 32308 |
| 25-35 | 15000 | 24818 | 33410 | 26250 | 47816 |
| 0>35 | 17500 | 27840 | 37864 | 30154 | 55408 |

Table 20. Cost per ton ($/ton) of reduced emissions for different abatement strategies when compared to BBACT for 100% utilization - Stripper Gins

| Capacity (bales/hour) | Average Annual Ginning (bales) | BACTD0 | BACTD1 | BACTD2 | BACTD3 |
|---|---|---|---|---|---|
| ≤10 | 10000 | 4800 | 6240 | 4639 | 8161 |
| 10-15 | 12500 | 5800 | 7600 | 5714 | 10134 |
| 15-25 | 20000 | 8640 | 11520 | 8874 | 16000 |
| 25-35 | 30000 | 12000 | 16320 | 12908 | 23678 |
| >35 | 35000 | 14000 | 19040 | 15059 | 27624 |

Table 21. Cost per ton ($/ton) of reduced emissions for different abatement strategies when compared to BBACT for 75% utilization - Stripper Gins

| Capacity (bales/hour) | Average Annual Ginning (bales) | BACTD0 | BACTD1 | BACTD2 | BACTD3 |
|---|---|---|---|---|---|
| ≤10 | 7500 | 6400 | 8320 | 6185 | 10881 |
| 10-15 | 9375 | 7733 | 10133 | 7618 | 13512 |
| 15-25 | 15000 | 11520 | 15360 | 11832 | 21333 |
| 25-35 | 22500 | 16000 | 21760 | 17211 | 31571 |
| >35 | 26250 | 18667 | 25387 | 20079 | 36832 |

Table 22. Cost per ton ($/ton) of reduced emissions for different abatement strategies when compared to BBACT for 50% utilization - Stripper Gins

| Capacity (bales/hour) | Average Annual Ginning (bales) | BACTD0 | BACTD1 | BACTD2 | BACTD3 |
|---|---|---|---|---|---|
| ≤10 | 5000 | 9600 | 12480 | 9278 | 16322 |
| 10-15 | 6250 | 11600 | 15200 | 11428 | 20268 |
| 15-25 | 10000 | 17280 | 23040 | 17748 | 32000 |
| 25-35 | 15000 | 24000 | 32640 | 25816 | 47356 |
| >35 | 17500 | 28000 | 38080 | 30118 | 55248 |

Table 23. A 20 b/h gin, processing picked cotton at an annual average of 15000 bales over a period of 5 years (75% Utilization)

| Abatement Strategy | Emission Factor (lb/bale) | Cost Factor ($/cfm) | Investment Costs ($) | Extra Investment Compared to BBACT ($) | Cost per Ton of Reduced Emissions ($) |
|---|---|---|---|---|---|
| BBACT | 2.24 | 0.67 | 93800 | - | - |
| BACTD0 | 1.8 | 0.95 | 133000 | 39200 | 11879 |
| BACTD1 | 1.8 | 1.04 | 145600 | 51800 | 15679 |
| BACTD2 | 1.2 | 1.34 | 187600 | 93800 | 12025 |
| BACTD3 | 0.94 | 2.17 | 303800 | 210000 | 21539 |