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

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Abstract

Cotton gins emit particulate and lint fiber into the atmosphere as a result of the ginning process. All the gins in Texas are required to install a minimum of Baseline Best Available Control Technology (BBACT) in order to obtain a permit to construct or operate. Gins that are located in densely populated areas or those which are in violation of the Texas Natural Resource Conservation Commission (TNRCC) regulations may be required to install additional controls to come into compliance. TNRCC permit engineers have the authority to require the installation of additional controls to reduce emission factors. The selection of the control strategies is the prerogative of the ginner. However, some control strategies may result in the cotton gin going out of business. The definition of BACT incorporates a phrase that requires consideration for economic reasonableness. It is the premise of this research that a cotton ginner will be able to utilize the requirement that a mandated BACT abatement system must include consideration of"economic reasonableness" to negotiate an appropriate abatement strategy.

Several additional air pollution abatement strategies using combinations of cyclones, rotary drum filters, and baffle type pre-separators have been defined. Procedures to estimate costs of equipment and emission factors for various abatement equipment are described in detail. Models to determine the costs of cyclones and to simulate the ginning volumes for cotton gins in Texas were developed. Two criterions (return on investment and cost per ton of reduced emissions) were proposed to define economic reasonableness.

Introduction

The principal function of a cotton gin is to process seed cotton by separating lint from seed. Cotton gins use pneumatic conveying systems to transport seed cotton, cotton seed, trash, and lint. Gins must also be equipped to remove foreign matter, moisture, and other contaminants that may significantly reduce the value of the ginned lint. Lint is packaged into 500 pound (lb) bales while seed is sold to oil mills or livestock operations. The gin trash removed and particulate entrained into the conveying air during the ginning process is passed through air pollution abatement equipment with a fraction of the particulate penetrating the abatement device and exhausted to the atmosphere. The particulate emitted from cotton gins consist of trash, dust, and lint fibers which are a potential source of air pollution. Air pollution is regulated by the Texas Natural Resource Conservation Commission (TNRCC), which is the State Air Pollution Regulatory Agency (SAPRA) in Texas. Cotton gins are required to install air pollution abatement equipment to comply with SAPRA rules and regulations.

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The Ginning Process

The two methods of harvesting cotton are machine picking and stripping. Most of the cotton produced and ginned in Texas is stripped in contrast to other states in the cotton belt where most of the cotton produced and ginned is picked. It was assumed in this research that a bale of picked or stripped seed cotton delivered to the cotton gin for processing will contain 500 pounds (lbs) of lint fiber and 800 lbs of cotton seed. Each bale of picked seed cotton contains 200 lbs of trash while a bale of stripped seed cotton will contain 900 lbs of trash. Hence, a bale of picked and stripped seed cotton will contain 1,500 lbs and 2,200 lbs of lint, seed, and trash, respectively. Cotton gins processing stripped cotton will contain more seed cotton cleaning equipment and will utilize more air for pneumatic conveying than gins processing picked cotton.

Centrifugal and axial-flow fans are used in the ginning process to move seed cotton from storage facilities, convey seed cotton through driers and cleaners, transport cotton from one processing point to another, supply air for doffing nozzles of air blast gins and move seed, lint, and trash. A flow diagram of a typical cotton ginning process is shown in Figure 1. Typically, 10-40 different fan/motor systems are used to move material in cotton gins and the quantity of air used is dependent on the type of cotton processed and the ginning capacity (bales per hour). Axial-flow fans operate at low pressure drops and move large quantities of air, while centrifugal fans move smaller quantities of air but can overcome high pressure losses.

The Regulatory Process

There are many emission points with varying emission rates in a typical cotton gin. The Environmental Protection Agency defined emission factors for cotton gins in pounds of particulate matter released into the air for each bale that is processed (lb/b). The total emission factor for a cotton gin is the sum of the emission factors from all the gin's process exhausts. The EPA AP-42 (1988) total emission factor for cotton gins was 2.24 lb/b. The emission factors for each process exhaust are shown in Table 1.

TNRCC regulations require all cotton gins in Texas that began operations after September 1, 1971, to obtain an operating permit unless the gin qualified for an exemption. All gins operating prior to September 1, 1971 are referred to as "grandfathered", and are allowed to operate without a permit, provided the gin has not increased its emissions in the interim. If a grandfathered gin's operations were modified such that its emission rate increased, the gin was required to obtain an operating permit. All grandfathered gins that have been modified and have not obtained an operating permit are in violation of Regulation VI (TNRCC, 1993) and are subject to fines and penalties. Also, "any person who plans to construct a new facility or engage in the modification of any existing facility in this state which may emit air contaminants into the air must obtain a permit to construct pursuant to TNRCC Rule 116.111", (TNRCC, 1993). Currently, there are about 393 gins in Texas, of which 180 have operating permits and 62 are grandfathered. The status of the remaining 151 are not known (Green, K. J. 1996a). Among those 151 gins whose status are unknown, some may be grandfathered and others may require an operating permit.

The Texas permitting process includes a technical review by permit engineers of the TNRCC. This review verifies that all emission sources have been correctly identified and that the emission rates have been correctly evaluated. After the emission sources and emission rates have been identified and evaluated, the gins must define the abatement strategy they propose to install. Once the ginner and the TNRCC agree on the controls required, the TNRCC permit engineers can request the applicant perform dispersion modeling and include these results in the permit application. The permitting process also includes a mandatory public notice period. During this period, anyone in the area impacted or likely to be impacted by the cotton gin's emissions may request a contested case hearing. If a valid request is submitted to the TNRCC during the notice period, a hearing will be scheduled and conducted with a TNRCC lawyer serving as an Administrative Law Judge. After all the technical issues and public notice issues have been resolved, the permit package is routed for approval.

One of the main hurdles in the permitting procedure is the process of establishing an appropriate air pollution abatement system or strategy for a specific cotton gin. In Texas, gins are required install the Best Available Control Technology (BACT) by rule. Increasing numbers of public complaints, interpretations by permit engineers that any new technology redefined BACT and no criterion for determining whether a mandated control strategy would meet the requirement on the SAPRA that consideration be given for “economic reasonableness” was a serious problem in 1993. It was apparent that small gins in rural locations may be required to install very expensive air pollution abatement systems because this system was perceived by the SAPRA as BACT. BACT was a moving target. In addition a number of grandfathered gins were subject to Reg. VI penalties because they had changed their system and increased their emission rates of particulates without obtaining a permit. In 1993, a Cotton Gin BACT Study Group consisting of representatives from the Texas Cotton Ginner’s Association, the National Cotton Council and TNRCC permit engineers was formed to develop guidelines for the determination of appropriate BACT levels for cotton gins.(In 1993, the SAPRA for Texas was the Texas Air Control Board (TACB)) By rule, BACT is the air pollution abatement equipment that minimizes particulate emissions with consideration for "economic reasonableness and technical practicability" (TNRCC, 1993).

The Study Group developed a policy that was adopted by the TACB that defined Baseline Best Available Control Technology (BBACT) as the minimum level of control required to obtain a permit in Texas. (See Figure 2.) BBACT was defined as 2D2D or 1D3D cyclones for all centrifugal fan exhausts and covered condenser drums for all axial fan exhausts. This policy allowed permit engineers the authority to impose more sophisticated controls on a cotton gin, if the gin had a bad compliance history or if the gin was located near densely populated areas, schools or in residential areas. Figure 2 illustrates the decision process used by TNRCC permit engineers to determine whether the gin will be allowed to use BBACT in their permit. This policy also established that a first time Reg. Vl violation was to be a zero dollar penalty replacing the mandatory fine that had been associated with this violation. It was assumed that many grandfathered small businesses might not be aware of the requirement to obtain a permit.

This new policy solved the problem of inappropriately requiring small rural gins to install expensive controls and the moving target associated with the SAPRA definition of BACT. However, the permit engineers retained the authority to mandate more sophisticated controls on problematic gins; i.e. (a) gins located in populated areas; (b) gins with a history of complaints from the public; and (c) gins with a history of non-compliance (TNRCC, 1994). Cotton gins located in rural areas, isolated areas or those with a good compliance history, need only utilize BBACT to comply with the Texas Clean Air Act (TCAA). However, a gin using BBACT and complying with the TCAA may be required to install additional controls as a result of any single violation.

The policy outlined in Figure 2 places no limitations or specifications of mandated controls that can be imposed by a TNRCC permit engineer other than the definition of BBACT. The only criterion specified that could limit the level of mandated control is the definition of BACT which requires that SAPRA engineers give due consideration for economic reasonableness and technical practicability. If a mandated strategy exceeded this criterion, it could be argued that the mandated control level was the next level above BACT which is Maximum Acheivable Control Technology (MACT). MACT has no requirement for consideration of economic reasonableness. (MACT can be required by SAPRAs in non-attainment areas.) It was assumed in this research that if an objective criteria could be developed which could demonstrate that a particular air pollution abatement strategy were economically unreasonable, cotton ginners could negotiate a less costly abatement strategy.

Objectives

The goal of this research was to minimize the cost of cotton gin compliance with air pollution regulations in Texas. The objectives were as follows:

1. Propose air pollution abatement strategies for cotton gins that are required to install additional controls.

2. Develop a standard procedure to calculate the emissions factors and cost factors for these air pollution abatement strategies.

3. Define a criterion for determining "economic reasonableness" associated with the installation of additional air pollution abatement equipment on cotton gins to reduce particulate emission rates and hence define a methodology that can be used by the ginning industry and SAPRAs to negotiate an abatement strategy that meets the requirements of BACT.

Methodology and Procedures

Estimating Emission Concentrations and Emission Factors

There are several methods that can be used to estimate cotton gin emission concentrations and/or emission factors. One method utilizes source sampling data. Source sampling data are measures of emission concentrations from process exhausts. If the volumetric air flow rates (Qs) are known, it is possible to calculate the process exhaust emission factors. The total Q from each process exhaust must be measured so that the measured emission concentrations can be converted into emission factors. (Care must be taken to use the total Q of a process if the emission factor for that process is to be calculated. Partial Qs will result in erroneous estimates of emission factors.) The results from this method are influenced by many variables including foreign matter content of cotton, ginning rate, and air pollution abatement system. Source sampling is an elaborate and time consuming process and the data obtained are highly variable.

Emission concentrations can be estimated using emission factors, processing rates, abatement equipment efficiencies and volumetric air flow rates. For example, the EPA AP-42 emission factor for the number one lint cleaner process exhaust is 0.81 lb/b. The BBACT abatement device required for this exhaust is fine mesh screen on the condenser drums. Fine mesh screens are assumed to have an efficiency of 50% (Yarlagadda et al. 1994). Therefore, the inlet loading for this exhaust is $0.81 \times 1/0.5 = 1.62$ lb/b. If the fine mesh screen were replaced with cyclones having an efficiency of 90%, then the emission factor would be 1.62 lb/b$\times$ (1-0.9) =0.16 lb/b. If the efficiency of an abatement system or device and the inlet loading rate are known, then it is possible to calculate the emission factor from that emission point using simple arithmetic. The emission factor can then be converted to an emission concentration if the volumetric flow rate of air from the emission point is known. However, the efficiency of an abatement system is a function of the particle size distribution (PSD) and the magnitude of the inlet loading. Cyclones will have lower efficiencies if the inlet loadings have a greater fraction of small particles when compared to a loading with a lower fraction of small particles. In addition, the exit concentrations of a cyclone increase with increases in total inlet concentrations of trash and fine dust. (Mihalski et al., 1994) Yarlagadda et al. (1994) reported that measured emission rates differed from the emission rates that were calculated using efficiency. The efficiency approach tended to underestimate the emission rates.

An alternative approach (which was used in this research) is to calculate emission factors based on the air flow through each exhaust and the emission concentration from each abatement device. In order to estimate emission factors from gins, the emission concentrations for typical air pollution abatement equipment (used by gins) have to be defined. Emission concentrations of air pollution abatement equipment such as cyclones in series, and a cyclone-Rotary Drum Filters (RDF) in series were tested to determine typical emission concentrations for varying loading rates.

Emission factors can be estimated from emission concentrations by using the "standard" air flow from a gin. The standard air flow rate for gins processing picked and stripped cotton are 7000 cfm per bale per hour (cfm/bph) and 8000 cfm/bph, respectively. If different abatement strategies are used for abating air pollution from axial and centrifugal fan exhausts, then the average emission concentrations from these exhausts will vary. The emission factors from the axial fan (lint cleaners and battery condenser) and centrifugal fan exhausts were determined separately by using the results of Shaw's (1977) data. The following equation was used to calculate the emission factors for each process fan exhaust:

$$EF = EC \times Q \times 60\ \text{min/h} \times GC \times CF \qquad (1)$$

where:

EF = emission factor in kg/b (lb/b)
EC = average emission concentration in mg/m^3 (gr/dscf)
Q = volume of air moved by the process fan in m^3/min (cfm)
GC = ginning capacity (bales per hour)
CF = conversion factor of 1 kg/10^6 mg (1 lb/7000 gr)

The EPA AP-42 emission factor of 2.24 lb/b is equivalent to an average emission concentration of 86 mg/m^3 (0.0373 gr/dscf) based on 7,000 cfm/bph of air flow for picker gins (Eq. 1). The AP-42 emission factor for stripper gins was not listed which suggested that it was the same as picker gins (2.24 lb/b.) For this work, it was assumed that EPA made an error and that the picker gins and stripper gins would have different emission factors. Stripper cotton contains more trash and would be expected to have a higher emission factor. In order to estimate a more accurate emission factor for stripper gins, we assumed that the average emission concentration of particulate emitted by stripper gins would be equal to that of picker gins (86 mg/m^3). The corresponding emission factor for a stripper gin using 8,000 cfm/bph and 86 mg/m^3 was calculated to be 2.56 lb/b . It was assumed that a more accurate emission factor for stripper gins would be 2.56 lb/b.

It was assumed that the AP-42 emission factors for gins processing picked and stripped cottons would correspond to the emission factors for picker and stripper gins with BBACT. In order to calculate the individual process exhaust emission factors, the volume rate of flow (Q_i) of each exhaust was needed.

Cotton Gin Air Flow Model

Emission concentrations can be converted into emission factors for various process exhausts and vice versa only if the volumetric air flow from each process exhaust is known. The inital step in formulating a cotton gin air flow model was to establish that a typical gin would have 10 process exhausts defined by the AP-42. (See Table 1 and Figure 1.) An estimate of the ratio of the volume rate of flow for centrifugal and axial-flow fans was established for picker and stripper gins using data reported by Shaw et al. (1977) and a minimum of 20 cubic feet of air per pound (ft^3/lb) of seed cotton, seed, lint or trash (Baker et al.,1994).

The following assumptions were made to develop an air flow model:

1. A bale of stripped cotton contains 2200 lb of seed cotton consisting of 500 lb of lint, 800 lb of seed, and 900 lb of trash.
2. Each bale of picked cotton contains 1500 lb of seed cotton consisting of 500 lb of lint, 800 lb of seed and 200 lb of trash.
3. The first and second push pull fan systems will remove all but 50 lb of trash. Approximately 550 lb of lint and trash will be contained in the cotton entering the first stage lint cleaning system from both stripped and picked cotton.
4. Of the trash removed by the two push pull fans, one half is removed by each.
5. All of the trash is conveyed by the trash fans to the hopper.
6. The separator system following the second push pull designated as separator must move 1350 lb/b.
7. The overflow fan system must be capable of conveying 1350 lb/b.
8. The unloading system was designed with a minimum conveying rate of 30 ft^3/lb. Seed cotton entering the ginning system will typically have a higher moisture content.
9. All the other fan systems will have a conveying rate of at least 25 ft^3/lb.
10. Since trash fans convey only about 200 and 900 lb/b for picked and stripped cottons, respectively, the estimates of air flow rates using 25 ft^3/lb would have underestimated the conveying rate. Hence, the amount of air flow for trash fans was found after estimating all the rest of the process air flows and subtracting them from the total centrifugal air flow.
11. The individual process exhaust air flows were then estimated as a percentage of the total air flow.

Defining Abatement Strategies

Alternative air pollution control strategies were defined by specifying air pollution control equipment for each process exhaust. These abatement strategies were required to reduce the overall emission factor to below 2.24 lb/b for picker gins and 2.56 lb/b for stripper gins which corresponded to the AP-42 emission factors for cotton gins.

The newly developed 1D2D cyclone (Simpson, 1994) and a new "barrel" cyclone which is in its design and testing stage were incorporated in the proposed additional abatement strategies that might be considered by the cotton ginning industry. The barrel cyclone was developed and tested at Texas A&M University and was found to have efficiencies and emission concentrations that are comparable to the 1D2D cyclone. By using a vortex inverter in the barrel cyclone, it is possible to prevent the recycling effect of lint. Other abatement equipment that was used to define additional controls included a baffle type pre-separator reported by Mihalski et al. (1994).

Comparison performance tests were conducted with a 2D2D cyclone-Rotary Drum Filter (RDF) system with a series cyclone system to determine if a series cyclone system can be used to achieve results similar to the more expensive cyclone/RDF system.

Estimating Cost Factors

The cost factors for fans and RDFs were obtained from an air pollution control equipment manufacturer. The cost of fans (both axial and centrifugal type) were estimated to be approximately \$0.25/cfm while RDFs cost approximately \$2.0/cfm. The cost factors for baffle type pre-separators and fine mesh screens were estimated to be \$0.30/cfm.

Yarlagadda et al. (1994) used the method outlined in Cooper and Alley (1992) to estimate the cost factors for cyclones. However, this procedure was considered less accurate for a bank of cyclones or for cyclones that require large air flows. In order to develop a cost estimate for cyclones, a survey of sheet metal shops that manufacture cyclones was conducted. Using this data, the cost of a cyclone was represented as a function of the diameter or inlet area of the cyclone or as a function of the volumetric air flow through the cyclone.

Every gin has an auger system which is used to convey trash collected by the cyclones or other abatement devices. It is common for gins to group most of their cyclones in a bank and then have an auger system convey the collected trash to the trash conveying system. The average length of an auger system used by gins was assumed to be 20 ft and cost approximately $7000. Burr hoppers cost $24,000 each and it was assumed that gins with large ginning capacities (>35 b/h) would use two burr hoppers.

Transitions are used at each cyclone inlet and were estimated to cost approximately $450 each. In order to simplify calculations, it was assumed that standard sized cyclones are used in gins. The cyclone diameters were assumed to be 52 inches for smaller gins (<10, 10-15, 15-25 b/h) and 62 inches for the larger gins (25-35 and >35 b/h). The 52" and 62" 1D3D cyclones abate 7500 and 10,600 cfm, respectively at their design velocity. The number of cyclones required were determined by dividing the process exhaust air flow by the amount of air treated by an individual cyclone.

Simulation of Ginning Volumes for Texas Representative Gins

Gins were categorized into five main categories ($\leq$10 b/h, 10-15 b/h, 15-25 b/h, 25-35 b/h, and >35 b/h) as specified by Yarlagadda et al. (1994). Representative gin capacities in each category were used for various estimates and calculations. The representative gins were 10 b/h, 12.5 b/h, 20 b/h, 30 b/h, and 35 b/h plants.

The Texas Cotton Ginners Association provided data on the annual ginning volumes for a high percentage of gins in Texas for the years 1990 through 1994. These data were used to develop a model to simulate the typical ginning volumes of the plants in Texas. This model was used to determine the ginning volumes of gins in each of five categories: (<10, 10-15, 15-25, 25-35, and >35 b/h). Model gins were identified and their average ginning volumes were estimated. The simulation results were used to determine cost per tonne of reduced emissions (CPTRE) and return on investment (ROI) for Texas gins. Using the simulations and the emission factors, the mass of particulate released by different abatement strategies were determined and hence, CPTRE for the different abatement strategies were calculated.

Some of the gins had data points with no ginning, i.e. zero bales for that particular year. Zero bales could mean that the data were not available or the owners did not want to share this information or there was a bad crop that season. Data that was representative of the ginning volumes in Texas was selected using the following procedure:

1. All gins that had zero bales per season for three or more years were eliminated because they were unrepresentative data points. Hence, gins with ginning volumes for 3 or more years were considered.

2. Gins having a ginning volume for 1994 but zeros for the other years were included because it was assumed that these gins began their operations in 1994.

Using the TCGA data, gins were classified as <10, 10-15, 15-25, 25-35, >35 b/h plants and frequency distributions of the gins in each of these categories were determined. Discrete probability distributions of the volume ginned were developed for each category. The simulation process was facilitated using a software called Microcomputer support for Operations Research and management science (MOR). A Basic language program which incorporated the Monte Carlo process was used to simulate ginning volumes. The following steps were incorporated in the modeling process:

1. Gins in each category (<10, 10-15, 15-25, 25-35, >35 b/h) were sub-categorized into groups like Small Small (SS), Small Medium (SM), Small Large (SL), Medium Medium (MM), Medium Large (ML), and Large Large (LL). The first letter in each of these groups refers to the lowest ginning volume in the period from 1990-1994 and the second letter refers to the largest ginning volume. A gin was assumed to have 100% utilization if it was in operation for 1000 hours. For example, a 20 bph gin would be operating at 100% utilization potential if it ginned 20,000 bales in a season.

2. Small (S) means that the ginned volume was less than 50% of the utilization potential of a typical or representative gin in each category. Hence, 50% utilization means the gin operates for 500 hours. Medium (M) means that the ginning volume was between 50% and 100% of the utilization potential of a representative gin in its category while Large (L) means that the amount ginned was greater than 100% of the utilization potential of a typical gin in its category.

3. The typical or representative gins for the <10, 10-15, 15-25, 25-35, >35 b/h categories were defined as 10, 12.5, 20, 25, and 35 b/h, respectively.

Any gin can use its past annual ginning data and identify the sub-category corresponding to those used in this procedure. The simulation model can be used to predict a typical average annual ginning volume for a gin in each sub-category.

Defining Criteria for Economic Reasonableness

Two methods were investigated in an attempt to define economic reasonableness - the ROI and the CPTRE criterion.

Determining Return On Investment

The procedure used to calculate ROI utilized the following steps:

Step 1.
The investment costs were determined for a gin required to install additional control technology. The investment costs included costs of land, buildings, machinery, equipment, other fixed assets, and the costs of upgrading air pollution control equipment that the gin proposed to install.

Step 2.
The plant's ginning volumes were used to estimate the profit the gin was likely to make for the year that it installed the proposed additional controls. The average of simulating the last five years of ginning was used as an estimate of the probable ginning volume for the next year. This expected ginning volume was multiplied by the $/bale profit to determine the expected return.

Step 3.
If the ratio of the profit earned to the total investment was less than 0.147, then the gin was likely to have financial difficulties and the proposed abatement strategy was considered to be economically unreasonable.

Step 4.
In order to simplify and generalize the process for estimating ROI for cotton gins in Texas, the typical profits earned by gins in each ginning category were estimated using data from CoBank, the Bank for Cooperatives in Austin, Texas which prepared an income profile (1987-1991) for top performing gins in Texas.

Procedure to Estimate the Profit Per Bale of Cotton

The procedure used to estimate profit is outlined as follows: (All cost and revenue numbers were obtained from CoBank.)

1. The revenue from ginning was assumed to be $60 per bale for all ginning categories.

2. The total variable/direct expenses for <10, 10-15, 15-25, 25-35 b/h plants was $30/bale. For the >35 b/h plants, $25/bale was used. The variable expenses for the >35 b/h plants was less than for the rest of the categories because a large gin has lower unit costs.

3. The fixed expenses for 10-15, 15-25, 25-35 b/h plants were estimated to be $10/bale, while the fixed expenses for the <10 and >35 b/h plants were estimated to be $6/bale. The <10 b/h plants were assumed to be old and would likely have no interest payments. The >35 b/h plants were assumed to have low payroll expenses because they have a significant level of automation when compared to gins in other categories.

4. The depreciation for all gins was assumed to be $7/bale and other revenues such as dividends and income on interest were assumed to be $7/bale. Hence, these two entries canceled out each other.

5. Based on the above assumptions (1 to 4), the profit earned by gins in each category were estimated. The 10-15, 15-25, 25-35 b/h gin plants were estimated to have a profit of $20/bale; the <10 bale per hour gins were estimated to have a profit of $23/bale and the >35 b/h plants, $28/bale.

Estimating Cost Per Tonne of Reduced Emissions

In order to estimate the CPTRE, it was necessary to estimate the mass of particulate released annually. The mass of particulate released was estimated using the following equation:

$$MP = GV \times EF / 2000 \tag{2}$$

where:

MP = mass of particulate per season (tons)
GV = annual ginning volume (bales)
EF = emission factor (lb/b)

The mass of particulate released per season was estimated for different abatement strategies using the estimated emission factors for each abatement strategy and the simulated ginning volumes for gins in each category. The initial step was to estimate the mass of particulate emitted by a gin with BBACT. If the gin were to install a more efficient abatement strategy, the emission factor would decrease which would result in a decrease in the mass of particulate released. There will be a cost associated with the investment in upgraded air pollution controls. The cost per ton of reduced emissions were calculated using the estimated increase in investment cost associated with a more efficient abatement strategy and the corresponding decrease in the mass of particulate emitted per season. The CPTREs were estimated using the following equation:

$$CPTRE = I/(MP_1 - MP2) \tag{3}$$

where:

CPTRE = cost per tonne of reduced emissions in $/tonne ($/ton)
I = investment cost for additional controls ($)
MP_1 = mass of particulate released annually by BBACT in tonnes (tons)
MP_2 = mass of particulate released annually after installing additional controls in tonnes (tons)

Probability of Gins not Meeting the Criteria for Economic Reasonableness

It is possible to demonstrate the financial implications of investment in additional control strategies for the gins in Texas. In order to demonstrate the probability of gins not meeting the criterion of CPTRE, $10,000 per ton of reduced emission was considered to be the upper limit for gins required to install additional controls beyond BBACT. The number of gins in each sub-category not meeting the criteria of $10,000/tonne of reduced emissions were determined using the simulated ginning volumes. It should be noted that $10,000/tonne of reduced emissions was selected to demonstrate the process and the results using CPTRE as an indicator of economic reasonableness. It is anticipated that the ginning industry would negotiate the value that would be used as the criterion (in \$/tonne of reduced emissions) for CPTRE.

Mayfield et al. (1996) conducted a survey and estimated the investment costs for cotton gins in the Southwest region. This information was used to determine the investment costs for gins in each category. The bigger gins were associated with the higher investment costs. The <10 b/h plants were assumed to have an investment cost of \$0.5 million and the 10-15 b/h plants were assigned an investment cost of \$0.75 million. The SS gins in the 15-25 b/h category were assumed to have a \$1.0 million investment, the SM and MM gins were assumed to have an investment cost of \$1.5 million and the SL, ML, and LL gins were assumed to have an investment cost of \$2.0 million. The investment costs for the SS and SM gins in the 25-35 b/h category were assumed to be \$2.5 million while the SL, MM, ML, and LL gins in the 25-35 b/h category were assumed to have an investment cost of \$3.0 million. The SS and SM gins in the >35 b/h category were assumed to have an investment cost of \$4.0 million while the SL, ML, and LL gins were assumed to have an investment cost of \$5.0 million. Using these data and the simulated ginning volumes the probabilities of gins in various categories in Texas of meeting the criterion of 14.7% ROI were estimated.

Results and Discussions

Air Flow in Cotton Gins

The individual volume rates of flow (Q) for each of the ten processing systems were calculated from Shaw's data for the 7, 14, 21, 28 and 35 b/h plants processing picked and stripped cotton. The ratios of the total centrifugal and axial-flow volume rates of flow were calculated. The axial air flow refers to the air flow in the lint cleaning and battery condensing process. The average percentage of centrifugal fan flow for picker and stripper gins were 55.8% and 62.8% respectively, while the axial-fan flow fractions of total flow for picker and stripper gins were 44.2% and 37.2% respectively. In order to simplify the model, the centrifugal fan air flow in picker gins was assumed to be 55% of the total air flow and the axial fan air flow was assumed to be 45% of the total air flow. For stripper gins the centrifugal fan air flow was assumed to be 60% and the axial fan air flow was assumed to be 40% of the total air flow.

Based on the ratio of axial and centrifugal fan air flow to the total air flow and using 7000 cfm/bph for picker gins and 8000 cfm/bph for stripper gins, the air flows for typical gins in each category were determined. The axial-fan air flow was approximately the same for both stripper and picker gins. This is logical since approximately 550 pounds of lint and trash are entering the first stage lint cleaner irrespective of whether the gin is processing picked or stripped cotton. Since stripper gins have to process a larger amount of seed cotton per bale (2200 lbs) than the picker gins (1500 lbs), the air flow required by stripper gins was larger than for picker gins.

Emission Concentrations for BBACT

Using the results of the air flow model, the emission concentrations of the individual exhausts for picker gins were determined using the AP-42 emission factor for each process exhaust. It was assumed that stripper gins have the same emission concentration as picker gins for each process exhaust, hence the AP-42 emission factors from the individual process exhausts for stripper gins was different from that of picker gins. The emission concentrations and emission factors were constant for gins of all sizes. A 20 b/h plant was arbitrarily selected to illustrate emission concentrations calculations.

The 20 b/h picker gin will use an air flow of 140,000 cfm (20 b/h × 7000 cfm/bph) of which 77,000 cfm (140,000 × 0.55) is centrifugal fan air flow and 63,000 cfm (140,000 × 0.45) is the axial fan air flow.

Trash fans have the highest emission concentration (148 mg/m^3) among the centrifugal fan exhausts followed by mote fans (127 mg/m^3) and unloading fans (97 mg/m^3). The first stage lint cleaner exhausts have an emission concentration of 230 mg/m^3 and an emission factor of 0.81 lb/b which was the highest emission concentration and emission factor for all of the process exhausts.

The emission concentrations for stripper gin emissions were the same as those for picker gins. Since stripper gins utilize a larger air flow for the centrifugal fan systems, the emission factors for stripper gins centrifugal fan exhausts were higher than that of picker gins. The emission concentrations and emission factors for both picker and stripper gins were approximately the same for the axial fan exhausts. A 20 b/h stripper gin was used to illustrate the emission concentrations and emission factor calculations.

The total air flow from a 20 b/h stripper gin using 8000 cfm/bph is 160,000 cfm (20 b/h × 8000 cfm per b/h) of which 96,000 cfm (0.6 × 160,000 cfm) is the air flow from the centrifugal fans and 64,000 (0.4 × 160,000 cfm) is the air flow from the axial fans.

Proposed Additional Control Strategies

Four alternative air pollution abatement strategies were proposed. These abatement strategies were labeled ACT 1 (Additional Control Technology 1), ACT 2, ACT 3, and ACT 4. Each of these Additional Control Technologies (ACT +) are options that a gin may consider if the TNRCC permit engineers require the gin to upgrade their air pollution abatement system from BBACT. Baseline Best Available Control Technology is the minimum level of controls required by cotton gins in order to obtain a permit from the TNRCC. Figure 3 illustrates the different process exhausts of a gin and the associated BBACT abatement systems.

ACT 1

ACT 1 refers to Additional Control Technology 1. Figure 4 illustrates the ACT 1 abatement strategy. It is the least expensive additional control proposed. The fine mesh screens used in BBACT for the condenser drums of the first stage lint cleaning system are replaced with 1D2D cyclones. The first stage lint cleaner exhaust had the highest AP-42 emission factor. If the emission concentration from this exhaust were to be reduced to what would be expected from cyclones, it will result in a significant lowering of the overall emission factor. Since 1D2D cyclones are expected to have a low pressure drop (< 2 inches w.g.), it was assumed that this cyclone could be retrofitted onto the axial fan exhausts. (Hence, the axial-flow fans will not have to be replaced by centrifugal fans as is the case when 2D2D or 1D3D cyclones are used on these fans.) It is likely that the fine mesh screens would have to be removed. Fine mesh screens have a pressure drop of about approximately 1 inch w.g.. If 1D2D cyclones were used in conjunction with fine mesh screens, the axial fan may not be able to overcome the total pressure losses. Since cyclones are more efficient than fine mesh screens, it was assumed that the emission concentration from the first stage lint cleaning exhaust will be lowered from 230 mg/m^3 (0.1 gr/dscf) to 69 mg/m^3 (0.03 gr/dscf) when the fine mesh screens are replaced by 1D2D cyclones.

ACT 2

ACT 2 refers to Additional Control Technology 2 which was the next higher level of control proposed. Figure 5 illustrates the design for ACT 2. This strategy used a baffle type pre-separator to remove the large particles and trash in the trash laden air before it entered the 1D3D or 2D2D cyclone. ACT 2 is an additional control strategy for gins that already have BBACT. It was assumed that the gin had existing 1D3D or 2D2D cyclones on all the centrifugal exhausts. For ACT 2, pre-separator cyclone systems were used for the unloading, trash, and push pull fan exhausts while 1D2D cyclones were used for the first stage lint cleaning, second stage lint cleaning, and battery condenser exhausts. The exhausts from the unloading and push pull fans were directed into a baffle pre-separator. The air flow leaving the pre-separator was uniformly distributed to a bank of cyclones. Since the trash fan exhaust is usually located further away from the other exhausts another pre-separator/cyclone system would have to be designed for this exhaust.

It has been observed by Baker and Mihalski that pre-separators tend to concentrate lint fiber in the cyclones following the pre-separator for high lint laden exhausts. As a consequence, the pre-separator/cyclone system is not as efficient when used for the mote fan exhaust. Lint fibers penetrate baffle pre-separators. It was assumed that the pre-separator cyclone system would reduce the emission concentrations to 34.5 mg/m^3 (0.015 gr/dscf) for the ACT 2 applications. The inlet loading rates for the second stage lint cleaning system and battery condenser are below 3 g/m^3 of fine dust. It was assumed that the 1D2D cyclones could achieve emission concentrations of 34.5 mg/m^3 (0.015 gr/dscf). It is anticipated that the fine mesh screens would be removed from all the condenser drums so that the axial fans could overcome the pressure losses.

ACT 3

ACT 3 refers to Additional Control Technology 3. Figure 6 illustrates the design for ACT 3. This strategy uses barrel cyclones and 1D3D or 2D2D cyclones in series for the unloading, push pull, and trash fan exhausts. It was assumed that the cyclone series system could achieve an emission concentration of 23 mg/m^3 (0.01 gr/dscf). ACT 3 includes 1D2D cyclones on all the lint cleaner exhausts. Barrel or 1D2D cyclones are efficient abatement devices for trash with a high lint content. It was assumed that this control strategy could achieve an emission concentration of 69 mg/m^3 (0.03 gr/dscf).

ACT 4

ACT 4 refers to Additional Control Technology 4. Figure 7 illustrates the design for ACT 4. This strategy has 1D3D or 2D2D cyclones and a rotary drum filter connected in series for the unloading and push pull fan exhausts. A series cyclone system was used for the trash fan exhaust. ACT 4 incorporates barrel or 1D2D cyclones for the mote fan exhaust and 1D2D cyclones for all the lint cleaner exhausts. The cyclone - RDF system was assumed to have an emission concentration of 23 mg/m^3 (0.01 gr/dscf).

Emission Factors

The estimated emission factors for picker gins with the different additional control strategies are reported in Table 2 and the estimated emission factors for stripper gins are reported in Table 3, while Table 4 reports the overall emission factors for picker and stripper gins. ACT 4 and ACT 3 had the lowest emission factor at 0.97 lb/b. ACT 2 had an emission factor of 1.17 lb/b which was lower than ACT 1 (1.67 lb/b) and BBACT (2.24 lb/b) for picker gins. Similarly for stripper gins, ACT 4 (1.09 lb/b) and ACT 3 (1.09 lb/b) had the lowest emission factor while ACT 2 (1.34 lb/b) was lower than ACT 1 (1.96 lb/b) and BBACT (2.52 lb/b).

Air Pollution Abatement Equipment Costs

Based on data from sheet metal manufacturers, the following models were developed to estimate the costs for cyclones:

1. $C = 2520\ (D_c)\ -1260$

where:

C = cost of cyclone ($)

D_c = diameter of cyclone (m)

2. $C = 6512\ (IA) + 670$

where:
C = cost of cyclones ($)
IA = sum of the inlet areas of cyclones (m^2)

3. $C = 6.7\ (AF_c) + 670$

where:
C = cost of cyclones ($)
Af_c = sum of the air flow through cyclones (m^3/min)

Models 1, 2 and 3 can be used to determine the costs of a bank of cyclones. These models do not include the cost of transitions, augers, and ductwork. The cost of a 1.58 m (62" cyclone) was determined as follows

Model 1

$D_c = 1.58$; then $C = 2520\ (1.58) - 1260 = \$2720$ per cyclone.

Model 2

$IA = (D_c)^2 \div 8 = (1.58)^2 \div 8 = 0.312$; then $C = (6512 \times 0.312) + 670 = \$2702$

Model 3

$AF_c = 0.312\ m^2 \times 975$ m/min$= 304\ m^3$/min; then $C = (6.7 \times 304) + 670 = \$2707$

Using these models, the cost of cyclones was determined to be $0.25/cfm. In order to account for the variability of cyclone costs and to be conservative, the cost of cyclones was estimated to be $0.40 per cfm.

The cost of air pollution equipment for a 20 b/h stripper gin which proposes to install BBACT was calculated as follows:

1. Centrifugal fan air flow = 2719 m^3/min and Axial fan air flow = 1813 m^3/min

2. Cost of equipment for the centrifugal fan exhaust =
2719 (14.1 + 8.8) + 24,000 + 7000 + 450 (13) = $99115

where:
2719 = centrifugal fan air flow (m^3/min)
14.1 = cost factor for cyclones ($ per m^3/min)
8.8 = cost factor for fans ($ per m^3/min)
24,000 = cost of burr hopper ($)
7000 = cost of auger system ($)
450 = cost per transition ($)
13 = number of transitions =2719 m^3/min ÷ 212 m^3/min per cyclone

3. Cost of equipment for the axial fan exhaust = 1813 (10.6 + 8.8)

where:
1813 = axial fan air flow (m^3/min)
10.6 = cost factor for fine mesh screens ($ per m^3/min)
8.8 = cost factor for fans ($ per m^3/min)

In case a gin upgraded its abatement strategy to ACT +,it was possible to estimate the additional investment required by using cost factors of the equipment and the air flow from individual process exhausts. For example, if the 20 b/h stripper gin planned on upgrading its controls from BBACT to ACT 2, the extra cost was calculated as follows:

Cost of pre-separators = 1767 × 10.6 = $18730

where:
1767 = air flow from the unloading, push pull and trash fans (m^3/min)
10.6 = cost factor for pre-separators ($ per m^3/min)

Cost of cyclones for the lint cleaner exhausts = (1813 × 14.1) + 9 (450) = $29613

where:
1813 = air flow from the lint cleaner exhausts (m^3/min)
14.1 = cost factor for cyclones ($ per m^3/min)
450 = cost per transition ($)
9 = number of transitions =1813 m^3/min ÷ 212 m^3/min per cyclone

A 20 b/h stripper gin with BBACT must invest approximately $48500 in order to upgrade its controls to ACT 2.

Using similar procedures and methodology, the costs of investing in BBACT, ACT 1, ACT 2, ACT 3, and ACT 4 were estimated for representative gins in each category. The costs of investing in air pollution controls are reported in Tables 5 and 6 for a new picker gin and a new stripper gin, respectively. The cost factors for these gins in terms of dollars per m^3/min are reported in Tables 7 and 8. The cost of installing ACT 4 for a new gin was approximately twice the cost of BBACT, while the cost of ACT 3 was about 20 to 30% more than BBACT. ACT 2 and ACT 1 were only marginally more expensive than BBACT. Suppose a gin had already installed BBACT, the additional investments required to upgrade its controls to ACT + are reported in Tables 9 and 10 for a picker and stripper gin respectively. The cost factors for these gins in terms of dollars per m^3/min are reported in Tables 11 and 12. Gins that already have BBACT and want to upgrade their controls to ACT 1 have to invest $5000 to $15,000 depending on the size of the gin and in the case of ACT 2 the investment costs range from $23,000 to $83,000. If gins want to upgrade their controls from BBACT to ACT 3 or ACT 4 the additional investments would range from $29,000 to $106,00 for ACT 3 and $62,00 to $256,000 for ACT 4.

Simulation of Ginning Volumes in Texas

Simulations of 5 annual ginning volumes were developed for 20 gins in each sub-category and then averaged to obtain an average annual ginning volume which was used to determine the profit from ginning.

The average simulated ginning volume for each categorization of cotton gins in Texas for the < 10 b/h, 10-15 b/h, 15-25 b/h, 25-35 b/h, and >35 b/h categories were determined. Approximately 87% of gins in the <10 b/h category, 81% of gins in the 10-15 b/h category, 64% of gins in the 15-25 b/h category, 7% of gins in the 25-35 b/h category, and 11% of gins in the >35 b/h category had an average ginning volume which was less than that achieved by the representative gin (for each category) at 50% utilization.

Results of the ROI for Gins in Texas

The profits earned by gins in each category and subcategory were estimated using the average simulated ginning volumes and the data from CoBank. These values were assumed to be representative of the typical profits earned by gins in Texas. Using these estimates of profits, the ROI for gins in each category were calculated using data from Mayfield et al. (1996) to estimate the investment costs. Since more than 85% of the gins in Texas are of the stripper type, the ROIs were estimated only for stripper gins. The additional investment costs of the abatement strategies reported in Table 10 were added to the investment costs to determine the total investment costs for gins upgrading their controls. The ROI for the gins with BBACT were also calculated.

The ROI for stripper gins that have a capacity < 10 b/h are reported in Table 13 while the ROI calculations for a 10-15 b/h, 15-25 b/h, 25-35 b/h, and > 35 b/h are reported by Ramaiyer (1996).. All gins in the SS and SM sub-category for the 10-15 b/h category have an ROI that is less than 14.7%

The number of gins (in Texas) in each category that will not meet the criteria of economic reasonableness for different abatement strategies are reported in Table 14. Most of the gins in Texas will not be able to install additional controls. Approximately 87 gins in the 15-25 b/h and 21 gins in the 25-35 b/h categories will not be able to meet the criteria of economic reasonableness (with their present ginning volume) even for BBACT but if these gins install ACT 4, 111 gins in the 15-25 b/h and 29 gins in the 25-35 b/h would not be able to meet the ROI criteria. Table 31 also illustrates that the same number of gins (in <10 b/h, 10-15 b/h, and >35 b/h categories) do not meet the ROI criteria for BBACT, ACT 1, ACT 2, ACT 3, and ACT 4.

Cost Per Tonne of Reduced Emissions for Gins in Texas

The costs per tonne of reduced emissions were calculated for stripper gins that planned to upgrade their controls from BBACT to Additional Control Technologies. Tables 15 to 21 report the CPTRE for stripper gins belonging to <10 b/h, 10-15 b/h, 15-25 b/h, 25-35 b/h and >35 b/h. The shaded area in the tables indicate a CPTRE which is greater than $10,000/tonne. The CPTRE for ACT 1 ranges from $1,176/tonne to $10,042/tonne; the CPTRE for ACT 2 ranges from $3,097/tonne to 23,896/tonne. The higher $/tonne values are associated with the SS sub-category of gins. This is a consequence of gins have ginning volumes less than 50% utilization. The lower $/tonne values are associated with the larger sub-category gins like SL, MM, ML, and LL. The CPTRE for ACT 3 ranges from $3,272/tonne to $25,304/tonne; the CPTRE for ACT 4 ranges from $7,903/tonne to $59,306/tonne. The emission factors for ACT 3 and Act 4 are the same but there is a significant difference in the CPTRE because of the high investment costs associated with ACT 4.

An air pollution regulatory agency like the TNRCC can define economic reasonableness in terms of "X" dollars per tonne of reduced emissions, where "X" is a value which TNRCC can assign as the limit beyond which any abatement strategy would be considered economically unreasonable. In this research it was proposed to assume that $10,000/tonne would be the limit for CPTRE. If this limit for CPTRE was greater than $10,000/tonne, it would indicate that gins in the SL, MM, and ML sub-categories (which account for 117 gins in Texas) are financially capable of installing ACT 4. Most of the SL and ML gins have highly variable ginning volumes and may not be able to invest the $100,000 to $200,000 needed to install ACT 4. On the other hand if the limit for CPTRE for additional controls was less than $10,000/tonne, most of the small gins (SS, SM) could not afford to install additional controls. The $10,000/tonne is an estimate to be used in this research so as to determine the impact of such a limit on the gins in Texas.

All the values of CPTRE that have a shaded background in Tables 15 to 19 are representative of gins that will not meet the criteria of $10,000/tonne used to determine economic reasonableness. Table 20 reports the number of gins in each category that will meet the criteria for economic reasonableness while Table 21 reports the number of gins that will not meet the criteria of $10,000 per tonne of reduced emissions. Based on the limit of $10,000/tonne of reduced emissions, all the gins in the 10-15 b/h, 15-15 b/h, 25-35 b/h and >35 b/h categories can afford to install ACT 1. A majority of the gins in the 15-25 b/h (106 gins which account for approximately 77% of the gins in this category), 25-35 b/h (50 gins which account for approximately 93% of the gins in this category), and >35 b/h (16 gins which account for approximately 89% of the gins in this category) categories can afford to install ACT 2. Most of the gins in 25-35 b/h (50 gins which account for approximately 93% of the gins in this category) and >35 b/h (16 gins which account for approximately 89% of the gins in this category) categories can afford to install ACT 3 while only 5 gins (4 belonging to >35 b/h and 1 belonging to 10-15 b/h) in the LL sub-category could afford to install ACT 4.

Summary of Results and Conclusions

Cotton gins are regulated by the TNRCC which requires all gins obtain a permit unless they are "grandfathered". Gins that are not problematic must install Baseline Best Available Control Technology (BBACT). BBACT is defined by the TNRCC as 1D3D or 2D2D cyclones on all centrifugal fan exhausts and fine mesh screens for the condenser drums of the axial fan exhausts. Additional controls (beyond BBACT) are required if gins are located in densely populated areas or if gins have a history of non-compliance. These additional controls are not specified and permit engineers may mandate that the gin install sophisticated additional controls to reduce emission factors.

Additional controls are expensive and may have an impact on the financial status of the gin. The definition for Best Available Control Technology (BACT) requires that the SAPRA permit engineers consider "technical practicability and economic reasonableness". The intent of this research was to provide a basis to negotiate an appropriate air pollution abatement strategy with the permit engineers by using "economic reasonableness" as the tool for negotiation.

The objectives of this research were to define a criteria and methodology for determining economic reasonableness and define low cost abatement strategies that could be used by gins that are not able to meet SAPRA regulations with BBACT.

Additional control strategies were defined based on the emission concentrations of each process exhaust. The objective in defining the additional controls was to address the process exhausts with the highest emission concentrations and emission factors in order to lower emission factors and minimize the cost of compliance.

Without an estimate of the air flow from each exhaust, it was not possible to estimate emission factors from emission concentrations or vice versa. Prior to this research work, there was no standard procedure (other than taking actual measurements of the volumetric flow rate) to estimate the air flow from each process exhaust. A significant contribution of this research was the development of an air flow model for a typical gin. This model could be used to estimate the air flow from the following 10 process fan exhausts: unloading, push-pull 1 and push-pull 2, trash, mote, overflow, separator, 1st stage lint cleaning, 2nd stage lint cleaning, and battery condenser. The air flow from the exhausts of a typical gin were estimated using data from Shaw et al. (1977) and material conveying rates. The assumptions and procedures used to develop the air flow model were as follows:

- A bale of stripped cotton contains 2200 lb of seed cotton consisting of 500 lb of lint, 800 lb of seed, and 900 lb of trash.
- A bale of picked cotton contains 1500 lb of seed cotton consisting of 500 lb of lint, 800 lb of seed and 200 lb of trash.
- the amount of lint and trash conveyed from the gin stand to the first stage lint cleaning system was the same for picker and stripper gins (150 lb/b).
- Unloading systems must have a minimum conveying rate of 30 ft^3/lb cotton () while all the other process systems must have a minimum conveying rate of 25 ft^3/lb.
- Since the trash content of stripper gins is more than that of picker gins, it was assumed that stripper gins use a larger air flow of 8000 cfm per b/h while picker gins use 7000 cfm of air flow per b/h (Parnell et al., 1990). For example, a 20 b/h stripper gin would utilize 7,000 cfm per b/h × 20 b/h = 160,000 cfm.
- Shaw's data was used to estimate the ratio of axial and centrifugal fan air flow for picker and stripper gins. It was determined that axial and centrifugal fan air flow accounted for 45% and 55% of the total air flow, respectively for a picker gin; 40% and 60% of the total air flow, respectively for a stripper gin. It was observed that the axial fan air flow for picker and stripper gins were approximately the same. This is logical because both picker and stripper gins convey the same amount of lint and trash to the first stage lint cleaning system.
- The air flow from each exhaust were listed as a percentage of the total air flow.

Emission concentrations for each process exhaust were calculated for picker gins with BBACT using the AP-42 (1988) emission factors. The average emission concentration from picker gins was estimated to be 86 mg/m^3 (0.0373 gr/dscf) based on the AP-42 emission factor of 1.02 kg/b (2.24 lb/b). The AP-42 emission factors do not specify different emission factors for stripper and picker gins. Hence, it could be interpreted by SAPRA permit engineers that picker and stripper gins have the same emission factors. For this research, it was assumed that picker and stripper gins do not have the same emission factors. Since the amount of fine dust in picked and stripped cotton are approximately the same, it was assumed that the emission concentrations for picker and stripper gins would be the same and since stripper gins utilize a larger air flow than picker gins, it was concluded that the AP-42 emission factors for stripper gins should be larger than that of picker gins. If the average emission concentration for a stripper gin was 86 mg/m^3, the corresponding emission factor of a stripper gin should be 2.56 lb/b. Emission concentrations corresponding to the emission factors were estimated for each process exhaust in a typical picker gin. Assuming that stripper gin exhausts had the same emission concentrations as picker gins, the emission factors for the individual process exhausts of stripper gins were determined. The sum of the emission factors from the individual process exhausts of stripper gins was estimated to be 2.52 lb/b, (this did not equate to 2.56 lb/b because of a slight round off error.)

Hence, the overall AP-42 emission factors for picker and stripper gins were assumed to be 2.24 lb/b and 2.52 lb/b, respectively. Four additional abatement strategies (ACT 1, ACT 2, Act 3, and ACT 4) were defined in order to reduce the overall emission factor. ACT 1 incorporated 1D2D cyclones on the 1st lint cleaner exhaust while all the other exhausts have the same controls specified in BBACT. ACT 2 incorporated baffle type pre-separators and 1D3D or 2D2D cyclones in series for the unloading, push pull, and trash fan exhausts, 1D3D or 2D2D cyclones for the separator, overflow, and mote fan exhausts, and 1D2D cyclones for all the axial fan exhausts. ACT 3 incorporated barrel cyclones and 1D3D or 2D2D cyclones in series for the unloading, push pull, and trash fan exhausts, 1D3D or

2D2D cyclones for the overflow and separator exhausts, barrel or 1D2D cyclones for the mote fan exhausts, and 1D2D cyclones for all the axial fan exhausts. ACT 4 incorporated 1D3D or 2D2D cyclones and a rotary drum filter (RDF) connected in series for the unloading and push pull fan exhausts, a series cyclone system for the trash fan exhausts, barrel or 1D2D cyclones for the mote fan exhausts, 1D3D or 2D2D cyclones for the separator and overflow fan exhausts, and 1D2D cyclones for all the axial fan exhausts.

Five gin plant sizes were studied. They were <10 b/h, 10-15 b/h, 15-25 b/h, 25-35 b/h and >35 b/h. Representative gins were defined for each category and were assumed to have ginning capacities of 10 b/h, 12.5 b/h, 20 b/h, 30 b/h, and 35 b/h. Costs of abatement equipment were defined for each ginning category based on the estimates for the representative gins. Using data from manufacturers, cost models were developed to estimate the cost of abatement systems.

The additional abatement strategies had emission factors ranging from 0.97 lb/b to 1.67 lb/b for picker gins and 1.09 lb/b to 1.96 lb/b for stripper gins. ACT 3 and ACT 4 had the lowest emission factors, while ACT 2 had an emission factor that was lower than ACT 1. The least expensive additional abatement strategy was ACT 1. Gins having BBACT would have to spend $5000 to $15,000 to install ACT 1 and $23,000 to 83,000 to install ACT 2. Installing ACT 3 would involve an investment ranging from $29,000 to $106,000 and the investment for ACT 4 would range from $62,000 to $256,000. Rotary drum filters were an expensive abatement strategy and were usually used as a secondary abatement control with cyclones being the primary air pollution abatement device. A series cyclone system consisting of barrel cyclones as the primary abatement device and 1D3D cyclones as the secondary abatement control achieved similar emission concentrations as the cyclone-RDF system. The investment costs for a series cyclone systems were lower than for a cyclone-RDF system.

One of the significant results of this research was the development of a simulation model to predict the ginning volumes in Texas. The major categories (<10, 10-15, 15-25, 25-35, >35 b/h) were divided into sub-categories (SS, SM, SL, MM, ML, and LL). Any gin in Texas could use the procedures illustrated in this research to determine its sub-category. Every sub-category had a model gin with a simulated average ginning volume which was representative of any gin in that sub-category. The calculations and estimates made for the model gin in each sub-category were ssumed to be applicable to all the gins in that sub-category. The model gins in each sub-category were used to illustrate the cost per tonne of reduced emissions (CPTRE) and return on investment (ROI) calculations. The results of the simulation modeling work suggested that approximately 221 gins in Texas operate at less than 50% utilization.

Two criteria (ROI and CPTRE) for defining economic reasonableness were examined. Although ROI is typically used as a criteria to determine long term investments. For purposes of this study, it was assumed that gins would not be able to invest in additional controls if the return on investment was less than 14.7% for the year that the gins install additional controls. The return on investment (ROI) calculations were done using investment data from Mayfield et al. (1996), revenue and expenses data from CoBank, and the simulated ginning volumes in Texas. It was estimated that more than 80% (> 315 gins) of all gins in Texas would not meet the 14.7% ROI criteria with a BBACT abatement strategy. Since gins in Texas are required to install BBACT to obtain a permit, it was estimated that approximately 80% (>315 gins) of these gins will not be able invest in BBACT. If this is the case, then these gins cannot afford to install any additional controls. But, in actuality there are more than 180 gins (>45%) in Texas that have a permit and hence BBACT. It was concluded that the ROI criteria was not a good indicator for economic reasonableness.

The cost per tonne of reduced emissions (CPRTE) criterion incorporates the investment costs associated with additional controls and takes into account the efficiency of the abatement device by incorporating the reduction in the mass of particulate emitted as a result of installing the additional controls. Permit engineers and engineers with industry are familiar with the concept of using CPTRE to define the criteria of economic reasonableness for air pollution abatement strategies. For example, Reasonably Available Control Technology (RACT) for nitrogen oxide (NO_x) sources is assumed to be less than $2,000/ton of reduced emissions.

If a gin is required to reduce its emission factors, the onus of installing additional controls lies on the problematic gin. It is possible for the TNRCC and the ginning industry to use the data reported in this research to negotiate an appropriate control strategy that will meet the criteria of "consideration for economic reasonableness" required by BACT.

In order to illustrate this procedure, the effect of using $10,000 per ton of reduced emissions as the criteria for economic reasonableness was analyzed. It was determined that problematic gins with large ginning volumes (> 100% utilization) may be able to invest in ACT 1, ACT 2, and ACT 3. Gins with medium ginning volumes (50 to 100% utilization) also had a possibility of investing in ACT 1, ACT 2, and ACT 3 while gins with a small ginning volume (< 50% utilization) would not be able to afford additional controls.

A summary of this research is as follows:

- An air flow model was developed to estimate the air flow from individual process exhausts of typical cotton gins based on the percentage of total air flow.
- The emission concentrations for picker and stripper gins were assumed to be the same and hence the AP-42 emission factors for picker and stripper gins were estimated to be 2.24 lb/b and 2.52 lb/b, respectively.
- Using the air flow model, the emission concentrations from each process exhaust were estimated. The focus was to reduce the emission concentrations for the exhausts with large emission concentrations and emission factors by defining appropriate abatement strategies.
- Four additional abatement strategies referred to as ACT 1, 2, 3, and 4 were defined and the emission factors for each of these abatement strategies were estimated.
- A cost model was developed which could be used to estimate the cost of cyclones. The costs of abatement strategies were estimated for representative gins.
- A simulation model was developed that could be used to simulate the ginning volumes in Texas.
- We examined two criteria (14.7% ROI and CPTRE) to define economic reasonableness.
- It was determined that the 14.7% ROI criteria was not a good indicator of economic reasonableness since most of the gins in Texas have an ROI that is less than 14.7% even when using BBACT.
- The cost per tonne of reduced emissions was estimated for representative gins in each category. Based on a standard of $10,000/tonne of reduced emissions, it was observed that some gins can afford to install additional controls and some of the smaller gins cannot afford to install additional controls. It was concluded that CPTRE is the best indicator for economic reasonableness. The TNRCC and the ginning community can negotiate whether an appropriate abatement strategy is economically reasonable by defining a criteria based on cost per tonne of reduced emissions.

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Figures

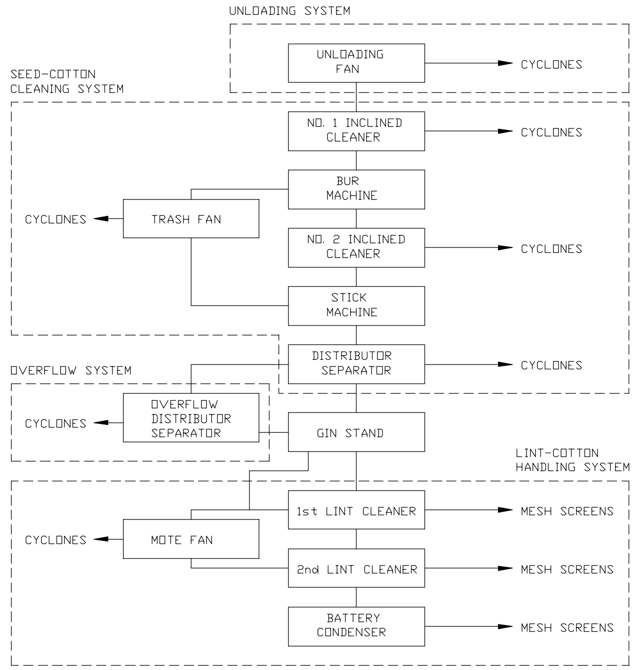

Figure 1. Schematic illustration of the cotton ginning process

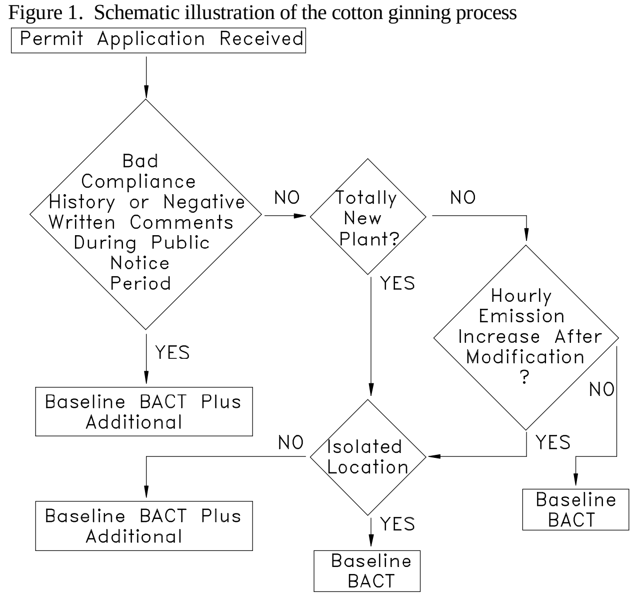

Figure 2. TNRCC policy for determining abatement strategies for cotton gins in Texas

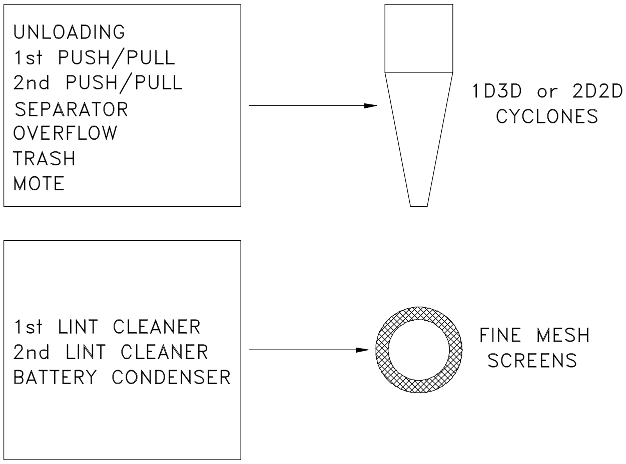

Figure 3. Schematic illustration of process fans and abatement systems for BBACT

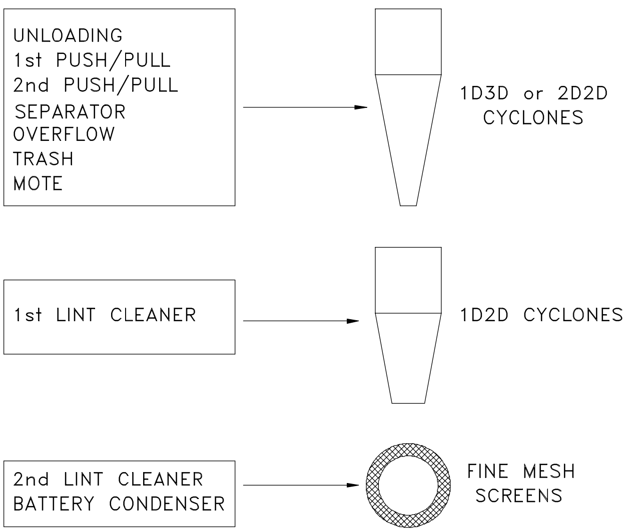

Figure 4. Schematic illustration of process fans and abatement systems for ACT 1.

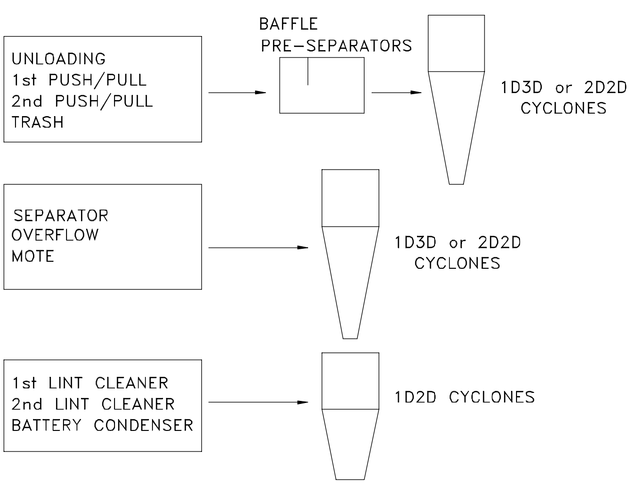

Figure 5. Schematic illustration of process fans and abatement systems for ACT 2.

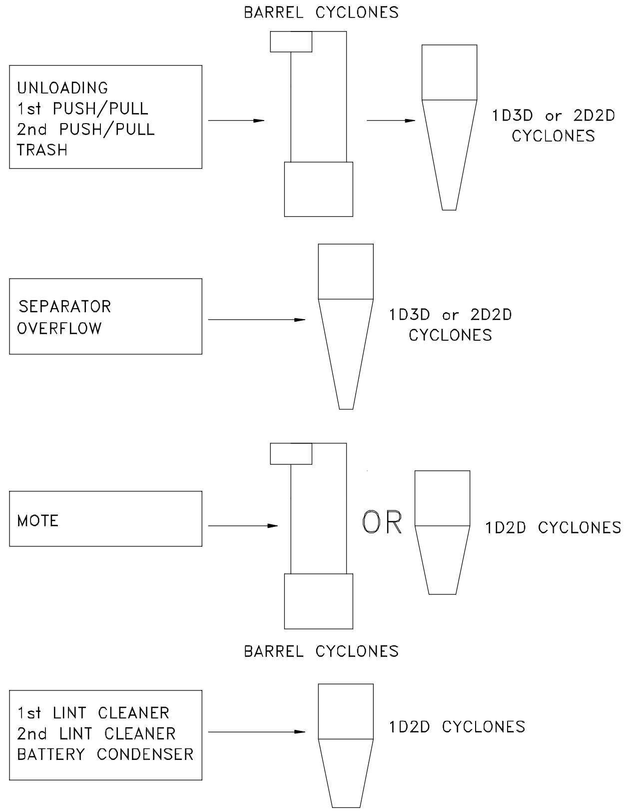

Figure 6. Schematic illustration of process fans and abatement systems for ACT 3.

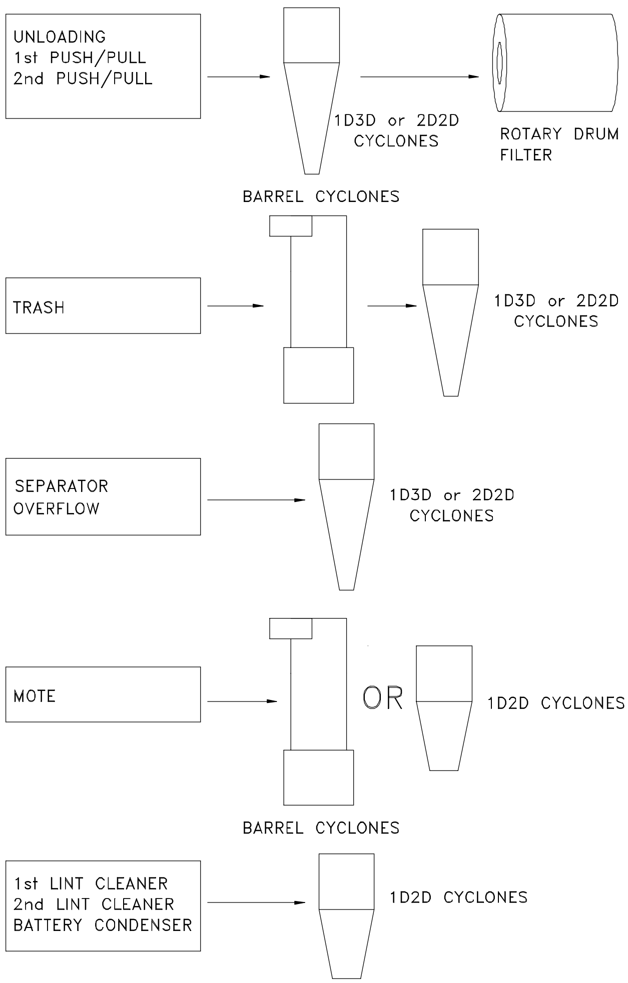

Figure 7. Schematic illustration of process fans and abatement systems for ACT 4.

Tables

Table 1. AP-42 emission factors for cotton gins (U.S. EPA, 1977)

Process Equipment	kg/bale (lb/bale)	Associated Fans
Unloading Fans	0.145 (0.32)	Centrifugal
1st Drier/Cleaner (Cyclones)	0.082 (0.18)	Centrifugal
2nd Drier/Cleaner (Cyclones)	0.045 (0.10)	Centrifugal
Gin Stand/Feeder (Cyclones)	0.018 (0.04)	Centrifugal
Overflow (Cyclones)	0.036 (0.08)	Centrifugal
1st Lint Cleaner	0.368 (0.81)	Axial
2nd Lint Cleaner	0.068 (0.15)	Axial
Battery Condenser	0.086 (0.19)	Axial
Motes (Cyclones)	0.091 (0.20)	Centrifugal
Master Trash Fan (Cyclones)	0.077 (0.17)	Centrifugal
Total	**1.02 (2.24)**	

Table 2. Emission factors in kg/b (lb/b) from each process exhaust of picker gins using Additional Control Technologies (ACT +)

Process Exhaust	BBACT	ACT 1	ACT 2	ACT 3	ACT 4
Unloading	0.145 (0.32)	0.145 (0.32)	0.052 (0.114)	0.034 (0.076)	0.034 (0.076)
PushPull 1	0.082 (0.18)	0.082 (0.18)	0.043 (0.094)	0.029 (0.063)	0.029 (0.063)
PushPull 2	0.045 (0.10)	0.045 (0.10)	0.034 (0.075)	0.023 (0.05)	0.023 (0.05)
Separator	0.018 (0.04)	0.018 (0.04)	0.018 (0.04)	0.018 (0.04)	0.018 (0.04)
Overflow	0.036 (0.08)	0.036 (0.08)	0.036 (0.08)	0.036 (0.04)	0.036 (0.04)
Trash	0.077 (0.17)	0.077 (0.17)	0.018 (0.04)	0.012 (0.027)	0.012 (0.027)
Motes	0.091 (0.20)	0.091 (0.20)	0.091 (0.20)	0.049 (0.109)	0.049 (0.109)
Sub-Total	**0.494 (1.09)**	**0.494 (1.09)**	**0.292 (0.643)**	**0.201 (0.445)**	**0.201 (0.445)**
1st Lint Cleaner	0.367 (0.81)	0.11 (0.243)	0.11 (0.243)	0.11 (0.243)	0.11 (0.243)
2nd Lint Cleaner	0.068 (0.15)	0.068 (0.15)	0.054 (0.12)	0.054 (0.12)	0.054 (0.12)
Battery Condenser	0.086 (0.19)	0.086 (0.19)	0.073 (0.162)	0.073 (0.162)	0.073 (0.162)
Sub-Total	**0.521 (1.15)**	**0.264 (0.583)**	**0.237 (0.525)**	**0.237 (0.525)**	**0.237 (0.525)**
Total	**1.015 (2.24)**	**0.758 (1.673)**	**0.529 (1.168)**	**0.438 (0.97)**	**0.438 (0.97)**

Table 3. Emission factors in kg/b (lb/b) from each process exhaust of stripper gins using Additional Control Technologies (ACT +)

Process Exhaust	BBACT	ACT 1	ACT 2	ACT 3	ACT 4
Unloading	0.181 (0.40)	0.181 (0.40)	0.064 (0.142)	0.043 (0.095)	0.043 (0.095)
PushPull 1	0.104 (0.23)	0.104 (0.23)	0.053 (0.117)	0.035 (0.078)	0.035 (0.078)
PushPull 2	0.059 (0.13)	0.059 (0.13)	0.042 (0.093)	0.028 (0.062)	0.028 (0.062)
Separator	0.023 (0.05)	0.023 (0.05)	0.023 (0.05)	0.023 (0.05)	0.023 (0.05)
Overflow	0.046 (0.10)	0.046 (0.10)	0.046 (0.10)	0.046 (0.10)	0.046 (0.10)
Trash	0.095 (0.21)	0.095 (0.21)	0.022 (0.049)	0.015 (0.033)	0.015 (0.033)
Motes	0.113 (0.25)	0.113 (0.25)	0.113 (0.25)	0.062 (0.136)	0.062 (0.136)
Sub-Total	**0.621 (1.37)**	**0.621 (1.37)**	**0.363 (0.801)**	**0.252 (0.554)**	**0.252 (0.554)**
1st Lint Cleaner	0.367 (0.81)	0.112 (0.247)	0.112 (0.247)	0.112 (0.247)	0.112 (0.247)
2nd Lint Cleaner	0.068 (0.15)	0.068 (0.15)	0.056 (0.124)	0.056 (0.124)	0.056 (0.124)
Battery Condenser	0.086 (0.19)	0.086 (0.19)	0.075 (0.165)	0.075 (0.165)	0.075 (0.165)
Sub-Total	**0.521 (1.15)**	**0.266 (0.587)**	**0.243 (0.536)**	**0.243 (0.536)**	**0.243 (0.536)**
Total	**1.142 (2.52)**	**0.887 (1.957)**	**0.606 (1.337)**	**0.495 (1.09)**	**0.495 (1.09)**

Table 4. Emission factors in kg/b (lb/b) for picker and stripper gins

Abatement Strategy	Emission Factor for Picker Gins kg/b (lb/b)	Emission Factor for Stripper Gins kg/b (lb/b)
BBACT	1.015 (2.24)	1.142 (2.52)
ACT 1	0.758 (1.673)	0.887 (1.957)
ACT 2	0.529 (1.168)	0.606 (1.337)
AACT 3	0.438 (0.97)	0.495 (1.09)
ACT 4	0.438 (0.97)	0.495 (1.09)

Table 5. Cost of installing abatement strategies for a new picker gin (Prices in Thousands of Dollars)

Strategy	<10 b/h	10-15 b/h	15-25 b/h	25-35 b/h	>35 b/h
BBACT	$76	$87	$121	$164	$216
ACT 1	$77.9	$89	$124	$168	$221
ACT 2	$89	$101	$146	$201	$259
ACT 3	$92	$106	$154	$212	$271
ACT 4	$128	$148	$222	$314	$391

Table 6. Cost of installing abatement strategies for a new stripper gin (Prices in Thousands of Dollars)

Strategy	<10 b/h	10-15 b/h	15-25 b/h	25-35 b/h	>35 b/h
BBACT	$83	$96	$135	$184	$240
ACT 1	$85	$98	$138	$188	$245
ACT 2	$98	$114	$164	$226	$289
ACT 3	$103	$121	$174	$239	$305
ACT 4	$145	$173	$258	$367	$454

Table 7. Cost of abatement strategies for a new picker gin in dollars per m^3/min ($/cfm)

Strategy	<10 b/h	10-15 b/h	15-25 b/h	25-35 b/h	>35 b/h
BBACT	38.5 (1.09)	35.3 (1.0)	30.4 (0.86)	27.5 (0.78)	30.4 (0.86)
ACT 1	39.2 (1.11)	36 (1.02)	31.4 (0.89)	28.2 (0.80)	30.7 (0.87)
ACT 2	44.8 (1.27)	41 (1.16)	36.7 (1.04)	33.9 (0.96)	36.4 (1.03)
ACT 3	47 (1.33)	42.7 (1.21)	38.8 (1.10)	35.7 (1.01)	38.5 (1.09)
ACT 4	64.6 (1.83)	59.7 (1.69)	55.8 (1.58)	52.6 (1.49)	7.2 (1.62)

Table 8. Cost of abatement strategies for a new stripper gin in dollars per m^3/min ($/cfm)

Strategy	<10 b/h	10-15 b/h	15-25 b/h	25-35 b/h	>35 b/h
BBACT	36.7 (1.04)	33.9 (0.96)	29.7 (0.84)	27.2 (0.77)	30.4 (0.86)
ACT 1	37.4 (1.06)	34.6 (0.98)	30.4 (0.86)	27.5 (0.78)	30.7 (0.87)
ACT 2	43.1 (1.22)	40.3 (1.14)	36 (1.02)	33.2 (0.94)	36.4 (1.03)
ACT 3	45.2 (1.28)	42.7 (1.21)	38.5 (1.09)	35 (0.99)	38.5 (1.09)
ACT 4	63.9 (1.81)	61.1 (1.73)	56.8 (1.61)	54 (1.53)	57.2 (1.62)

Table 9. Costs of upgrading controls to ACT + for picker gins that already have Baseline Best Available Control Technology (Prices in Thousands of Dollars)

ACT +	<10 b/h	10-15 b/h	15-25 b/h	25-35 b/h	>35 b/h
ACT 1	$5	$6	$9	$13	$15
ACT 2	$23	$28	$45	$65	$76
ACT 3	$29	$36	$57	$82	$95
ACT 4	$62	$78	$124	$184	$215

Table 10. Costs of upgrading controls to ACT + for stripper gins that already have Baseline Best Available Control Technology (Prices in Thousands of Dollars)

	<10 b/h	10-15 b/h	15-25 b/h	25-35 b/h	>35 b/h
ACT 1	$5	$6	$9	$13	$15
ACT 2	$25	$31	$49	$71	$83
ACT 3	$32	$40	$64	$91	$106
ACT 4	$75	$93	$148	$219	$256

Table 11. Costs of upgrading controls in dollars per m^3/min ($/cfm) for picker gins that already have Baseline Best Available Control Technology

	<10 b/h	10-15 b/h	15-25 b/h	25-35 b/h	>35 b/h
ACT 1	2.5 (0.07)	2.5 (0.07)	2.1 (0.06)	2.1 (0.06)	2.1 (0.06)
ACT 2	11.7 (0.33)	11.3 (0.32)	11.3 (0.32)	10.9 (0.31)	10.9 (0.31)
ACT 3	14.5 (0.41)	14.5 (0.41)	14.5 (0.41)	13.8 (0.39)	13.8 (0.39)
ACT 4	31.4 (0.89)	31.4 (0.89)	31.4 (0.89)	31.1 (0.88)	31.1 (0.88)

Table 12. Costs of upgrading controls in dollars per m^3/min ($/cfm) for stripper gins that already have Baseline Best Available Control Technology

	<10 b/h	10-15 b/h	15-25 b/h	25-35 b/h	>35 b/h
ACT 1	21.2 (0.06)	21.2 (0.06)	21.2 (0.06)	1.8 (0.05)	1.8 (0.05)
ACT 2	10.9 (0.31)	10.9 (0.31)	10.9 (0.31)	10.6 (0.30)	10.6 (0.30)
ACT 3	14.1 (0.40)	14.1 (0.40)	14.1 (0.40)	13.4 (0.38)	13.4 (0.38)
ACT 4	33.2 (0.94)	32.8 (0.93)	32.8 (0.93)	32.1 (0.91)	32.1 (0.91)

Table 13. ROI for <10 b/h gins with an initial investment of $0.5 million

Abatement Strategy	Investment ($)	ROI % SS Gins	ROI % SL Gins	ROI % LL Gins
BBACT	500000	8.97	19.18	40.11
ACT 1	505000	8.88	18.99	39.71
ACT 2	525000	8.54	18.27	38.20
ACT 3	532000	8.43	18.03	37.70
ACT 4	575000	7.80	16.68	34.88

* SS = 14 gins in Texas; Avg. Ginning = 1950 bales; Profit = $44850
† SL = 6 gins in Texas; Avg. Ginning =4170 bales; Avg. Profit = $95910
‡ LL = 3 gins in Texas; Avg. Ginning =8720 bales; Avg. Profit = $200560

Table 14. Number of gins in each category that will not meet the 14.7 % ROI criteria

	< 10 b/h	10-15 b/h	15-25 b/h	25-35 b/h	> 35 b/h
BBACT	14 (61%)	88 (81%)	87 (64%)	21 (39%)	7 (39%)
ACT 1	14 (61%)	88 (81%)	87 (64%)	21 (39%)	7 (39%)
ACT 2	14 (61%)	88 (81%)	87 (64%)	21 (39%)	7 (39%)
ACT 3	14 (61%)	88 (81%)	87 (64%)	21 (39%)	7 (39%)
ACT 4	14 (61%)	88 (81%)	111 (81%)	29 (54%)	7 (39%)

Table 15. CPTRE ($/tonne) of ACT + for <10 b/h stripper gins

Sub-category	Average ginning Volume (bales)	No. Of Gins	ACT 1	ACT 2	ACT 3	ACT 4
SS	1950	14	10042	23896	25304	59306
SL	4170	6	4696	11174	11833	27733
LL	8720	3	2246	5344	5659	13262

Table 16. CPTRE ($/tonne) of ACT + for 10-15 b/h stripper gins

Sub-category	Average Ginning Volume (bales)	No. of Gins	ACT 1	ACT 2	ACT 3	ACT 4
SS	2990	42	7859	19325	20628	47961
SM	5430	46	4328	10641	11359	26409
SL	9750	8	2410	5926	6326	14708
MM	8980	9	2617	6434	6868	15969
ML	11800	3	1991	4897	5227	12153
LL	16400	1	1433	3523	3761	8744

Table 17. CPTRE ($/tonne) of ACT + for 15-25 b/h stripper gins

Sub-category	Average Ginning Volume (bales)	No. of Gins	ACT 1	ACT 2	ACT 3	ACT 4
SS	5500	31	6409	16606	17943	41493
SM	9320	56	3782	9800	10589	24486
SL	15610	24	2258	5851	6322	14619
MM	13510	9	2609	6760	7305	16892
ML	17540	17	2010	5207	5626	13011

Table 18. CPTRE ($/tonne) of ACT + for 25-35 b/h stripper gins

Sub-category	Average Ginning Volume (bales)	No. of Gins	ACT 1	ACT 2	ACT 3	ACT 4
SS	8900	4	5721	14869	15766	37943
SM	15870	17	3208	8339	8842	21278
SL	25740	16	1978	5141	5451	13119
MM	23120	8	2202	5724	6069	14606
ML	28320	8	1798	4673	4955	11924
LL	33020	1	1542	4008	4249	10227

Table 19. CPTRE ($/tonne) of ACT + for >35 b/h stripper gins

Sub-category	Average Ginning Volume (bales)	No. of Gins	ACT 1	ACT 2	ACT 3	ACT 4
SS	12200	2	4815	12681	13397	32356
SM	19900	5	2952	7774	8213	19836
SL	36900	4	1592	4193	4429	10698
ML	33690	3	1744	4592	4852	11717
LL	49950	4	1176	3097	3272	7903

Table 20. Number of gins in each category that will meet the $10000/tonne of reduced emissions criteria

	< 10 b/h	10-15 b/h	15-25 b/h	25-35 b/h	> 35 b/h
ACT 1	9	109	137	54	18
ACT 2	3	21	106	50	16
ACT 3	3	21	50	50	16
ACT 4	0	1	0	0	4

Table 21. Number of gins in each category that will not meet the $10000/tonne of reduced emissions criteria

	< 10 b/h	10-15 b/h	15-25 b/h	25-35 b/h	> 35 b/h
ACT 1	14 (61%)	0	0	0	0
ACT 2	20 (87%)	88 (81%)	31 (26%)	4 (7%)	2 (11%)
ACT 3	20 (87%)	88 (81%)	87 (64%)	4 (7%)	2 (11%)
ACT 4	23 (100%)	108 (99%)	137 (100%)	54 (100%)	14 (78%)