problems.

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Economics of Occupational Cotton Dust Control in Cottonseed Oil Mills

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ABSTRACT

An economic analysis of the total cost for various dust control systems for a 500 ton/day model cottonseed oil mill has been performed. All cost data have been adjusted to reflect May 1981 prices. Cost data are presented for the dust collection system, cyclone(s), baghouse(s) and prime air mover(s) for each major processing area at 3 different air-to-cloth ratios. Data were obtained for equipment and installation costs from mills using the various devices and/or complete systems wherever possible. In cases where these data were not available, estimates were obtained from several firms that manufacture and install similar equipment. At the recommended air-to-cloth ratio of 20:1, the initial capital cost was estimated as $707,900, the annual operating expenses as $226,490 and the life cycle cost as $607,510.

INTRODUCTION

This paper presents an estimate of the total cost for the dust control system for a 500 ton/day model cottonseed oil mill previously described (1). In these calculations, it was assumed that the mill would operate 24 hr/day, 330 days/yr. Specifications of various segments of the dust control system were distributed to several manufacturers and suppliers (2-8) who customarily build and install such equipment for various segments of the raw cotton industry. With minor exceptions as noted later, prices as of mid-May 1981 were obtained and used in preparing this economic analysis. For the purpose of estimating the total pressure losses in the dust control systems, the pressure drop through a cyclone battery was estimated as 2.5 in. of water, through woven filter bags as 4 in. of water and through felted filter bags as 5 in. of water. These estimates are consistent with current technology.

DELIVERED EQUIPMENT COSTS

Cyclones and Accessories

The procedure for estimating the cost of cyclones and accessories has been described elsewhere (9). The cost of the cyclone is based on the size of the inlet area, type and thickness of the steel used and the cost of supports and dust hoppers (dust arrestors). In general, multiple cyclones cost the same as an equal number of single units of the same size. The use of an involute, rather than a tangential, entry for a cyclone increases the basic equipment cost by 10%. Because this increase in cost is more than offset by a corresponding increase in operating efficiency and a decrease in static pressure loss through the cyclone, involute entries were selected for use with all cyclones in these dust control systems. Costs for screw conveyors for removing collected dusts from the cyclone bottoms were not included in this economic analysis as those portions of the installations will vary among mills, depending on, e.g., existing dust control provisions and product handling systems.

Fans and Motors

At most of the oil mills visited during this research, centrifugal fans directly powered by electric motors were used to transport dust-laden air through the dust control system. There are 2 basic types of fans: the backward-curved fan and the radial-tip fan. The backward-curved fan, used for negative pressure systems, provides higher efficiency. It must be used downstream of the dust control system where the airstream is relatively dust-free. Radial-tip fans were selected as they are typically used in the raw cotton industry. The cost of such fans is based on type, actual flow rate, class and pressure drop at standard conditions. The prices of the motor and the starter are functions of the fan speed, total system pressure, air flow rate and selected motor housing.

Ductwork, Hoods and Dampers

The cost of ductwork (ducts, elbows, wyes, dampers, hangers and clamps) is a function of the duct diameter and metal thickness. Hoods are priced according to outside dimensions and metal thickness. Ten-gauge carbon steel was chosen for use uniformly throughout these systems. The cost of ductwork, elbows, wyes, hangers, flexible tubing and counterweight systems and strip curtains for hoods were obtained between May and August 1981 from vendors (2,5,6,8,10,11). These data were used as obtained without correction to May 1981. The maximal error involved is less than $5,000 for the entire model mill. Because of the variability in the cost of hangers, clamps and installation with size of ductwork, average values as suggested by several manufacturers (2,7,8) were used: $0.75, $3.16, and $10.25 per ft of duct, respectively.

Fabric Filters (Baghouses)

The dust control system selected for the model mill uses continuously cleaned, pulse-jet fabric filter baghouses throughout. The method for estimating the cost of baghouses used in this project was as previously described (9). The cost is based on the net cloth area, defined as the total filter area available for airstream filtration. The net cloth area is determined by the air-to-cloth ratio (A/C) recommended for the particular application which in turn is dependent on the fabric type, weave and construction; dust size distribution and loading; carrier gas composition and available motive energy. Prices for pulse-jet fabric filters are based on the net cloth area which is calculated by dividing the gas volume entering the baghouse by the required air-to-cloth (A/C) ratio. For example, to handle 10,000 CFM at an A/C = 10 requires 1,000 ft^2 of net cloth area. Bag materials used in cottonseed oil mills usually are constructed of nylon, acrylic or polyester fibers. They have nominal operating temperatures of 200 F (92 C), 260 F (125 C) and 275 F (134 C), respectively. Prices for bags were determined from data presented elsewhere (9). The gross cloth area was obtained from the net cloth area by use of multiplying factors. The cost/ft^2 for the cloth was $0.57 and $0.86 for Dacron® and heavy felt, respectively, in December 1977.

INSTALLED COST

The installed costs of the cotton dust control systems for the model mill consist of the delivered equipment cost as determined in the previous section and the cost of all auxiliary equipment plus the direct and indirect installation costs.

As a result of comments made by several mill superintendents and equipment suppliers regarding the frequency and severity of baghouse fires, we elected to divide the first-cut linter system into 2 subsystems. Each subsystem was further divided into 2 equal parts. Thus, there are 4 small baghouse and cyclone systems associated with the first-cut linter line. No such division was necessary in either the second-cut delintering area or the beater room because of the small amounts of air required for dust control purposes in those 2 areas. Although the number of local exhaust hoods in the hulling and separating room is quite extensive, the total air flow rate is such that a battery of 4 cyclones followed by a single baghouse for the effluent from their common exhaust is sufficient for dust control purposes. The occupational dust control system in the linter baling room has been divided into 2 parts: the floor sweeps (including those in the press pit) and the local exhaust systems installed on the linter presses themselves.

For ductwork and fan systems, the installation costs used in this analysis were those quoted by the suppliers. For cyclones and baghouses, installation costs have been determined by use of the appropriate cost factors related to equipment costs as already described (12). Table I presents cost summaries for the hoods, ductwork, cyclones, baghouses and motive air systems for an air-to-cloth ratio of 5:1 for the cleaning room. Similar data are available from the authors at reproduction cost for the first- and second-cut delintering, beating, hulling/separating and baling areas.

ANNUAL OPERATING COSTS

Direct Operating Costs

The expenses of labor, materials, operation (including util-

TABLE I

Cost Summary for the Cleaning Room (A/C=5:1)

	22,000 CFM of air at -ΔP = 2.8 in. water 383.5/ft of duct ($)
Hoods	13,440
Duct material	2,610
Elbows	1,820
Wyes	2,005
Hangers	290
Clamps	1,210
Blast gates	380
Installation	3,930
Subtotal	25,685
Cyclones (4 required in parallel, -ΔP = 2.5 in. H_2O)	
Cyclone	3,190 each
Support	2,095 ↓
Hopper	515 ↓
Entry	320 ↓
Installation	2,080 ↓
Subtotal	32,800
Baghouse (-ΔP = 4 in. H_2O)	
Baghouse	64,660
Installation	75,650
Subtotal	140,310
Air	
Motor	6,200
Fan	2,255
Drive	695
Ductwork	945
Installation	710
Subtotal	10,805
Grand Total	209,600

ities) and maintenance including the cost of replacement bags are considered in the direct operating costs (12). Sample calculations are shown in the appendix for life cycle cost calculations (given later).

Indirect Operating Costs

Overhead, taxes, insurance and the capital charges for interest and depreciation are the components of the indirect operating costs (12). Because the dust control system is considered an add-on system to the process, the overhead costs have been omitted as they will vary among mills. The annualized capital charges reflect costs associated with capital recovery over the operable life of the system. For the purpose of this study, a 20% annual interest rate and a 20-year payout period have been used for calculating these costs.

LIFE CYCLE COST

The life cycle cost (LCC) which is the annualized cost for the dust control system is composed of the following annual expenses: taxes, insurance, direct operations (primarily utility costs), maintenance and the equivalent annual cost of capital recovery. The costs of power and maintenance are assumed to inflate. Taxes and insurance are assumed to be fixed percentages of the fixed capital cost. The life cycle cost is expressed by Equation I:

Life cycle cost = annual (tax + insurance) cost + annual power cost + annual maintenance cost + equivalent annual cost of capital recovery [Ia]

$$LCC = T + I + (C_p + C_m) \cdot F/P_{X,1} \cdot F/A_{X,n} \cdot A/P_{MARR,n} + FC \cdot A/P_{MARR,n}, \quad [Ib]$$

where T+I = annual cost of tax and insurance = fixed cost • 3%; = (FC)•0.03; C_p = power cost for base yr (May '81); C_m = maintenance cost for base yr; MARR = minimal attractive rate of return, assumed to be 20%; n = system life, assumed to be 20 yr, and:

X = composite interest and inflation factor [IIa]

$$= \frac{\lambda - MARR}{1 + MARR} = \frac{0.12 - 0.2}{1 + 0.2} = -0.0667 \quad [IIb]$$

λ = assumed annual inflation rate, 12%

$$A/P_{MARR,n} = \frac{MARR \cdot (1+MARR)^n}{(1+MARR)^n - 1} = \frac{0.2 \cdot (1.2)^{20}}{(1.2)^{20} - 1} = 0.20536 \quad [III]$$

$$F/P_{X,1} = (1+X)^1 = 0.933 \quad [IV]$$

$$F/A_{X,n} = \frac{(1+X)^n - 1}{X} = 11.2258 \quad [V]$$

FC = first cost of capital equipment.

The product of the single payment compound amount cost factor for 1 year, $F/P_{X,1}$, and the equal payment series compound amount cost factor for n years, $F/A_{X,n}$, results in a value used to determine the present worth of a series of future inflated annual costs. The capital recovery factor using the minimal attractive rate of return selected by the user and the life of the project is expressed as $A/P_{MARR,n}$.

COST CALCULATIONS

The power cost (C_p) for the base year is the sum of the power costs for operating the control system (C_{pf}) and the air compressor (C_{pc}) required for cleaning the bags. The cost of the power for dust collection and transport was calculated from Equation VI:

C_{pf} = (unit power rate, \$/KWH) (power to operate the dust control system) [VIa]

= unit power rate • hr/yr • H_{pf} • 0.74548, [VIb]

where unit power rate = \$0.0473/KWH; H_{pf} = fan motor rating, H_p. Power ratings for the fans and costs of the motors, drives, starters and housings were obtained locally (4).

If continuous pulse-jet fabric filters are used as the final air control elements as recommended, it will be necessary to install an air compressor to supply the air for cleaning the filter bags. The compressed air requirements are related to the net filter area and, hence, to the air-to-cloth ratio. Once the net filter area was determined, the compressed air requirement was found by consulting fabric filter baghouse manufacturers' catalogs (13,14). For any compressor cost (CC) the installation costs are:

Piping = 0.141 CC
Concrete pad = 0.043 CC
Electrical = 0.068 CC
Labor = 0.295 CC
Total = 0.507 CC

The installation costs were estimated (15) for central air compressors where long, multiple compressed air pipe runs are involved. The compressor costs used in this economic analysis were obtained locally (3).

The power requirements for the compressor, H_{pc}, have been calculated from Equation VII:

$$H_{pc} = [3.02 \times 10^{-5} P_1 Q_1 \ln(P_2/P_1)] 0.74548/\eta_c, \quad [VII]$$

where P_1 = intake pressure, lb_f/ft^2; P_2 = delivery pressure, lb_f/ft^2; Q_1 = air volume at intake conditions, CFM; η_c = isothermal compressor efficiency (assumed to be 55%).

The cost of compressing the air has been calculated from Equation VIII as:

$$C_{pc} = C_{KWH} \cdot H_y \cdot H_{pc} \cdot 0.74548 \text{ KWH}/H_p,$$

where C_{KWH} = cost/KWH, \$; H_y = operating time, hr/yr, and:

$$C_{pc} = (\$0.0473/\text{KWH}) 7920 \text{ hr/yr} (H_{pc}) (0.74548 \text{ KWH}/H_p). \quad [VIII]$$

The cost/KWH was based on the current commercial rate for customers using more than 20,000 KWH/month by Southwestern Public Service Company. Power requirements for the average oil mill are in excess of this value.

Maintenance costs (C_m) are usually 2-6% of the installed capital costs for relatively simple processes such as the dust control system for the model mill (15). Based on experiences encountered at the mills visited during this study, baghouse fires will necessitate 2 complete bag changes each year for each baghouse. If the maintenance cost is assumed to be 4% of the installed capital cost, then the annual maintenance cost is as calculated from Equation IX:

$$C_m = FC \cdot 0.04 + 2 \text{ sets of filter bags/yr.} \quad [IX]$$

For those costs taken from data presented in the previous section for December 1977, an average inflation rate of 1%/month was used to obtain the May 1981 costs. December 1977 costs are thus multiplied by $(1.01)^{42}$ to account for the inflation in the intervening 42 months. This inflation rate was used because the *Chemical Engineering*, chemical construction, and Marshall and Stevens cost indices were not based on the types of equipment and installations involved in the cottonseed industry. All costs have been rounded to the nearest \$5 for subsequent calculations.

For the canopy hoods on the raw seed cleaners, the huller shakers and the purifier, the vinyl-strip curtains which have been recommended were designed to have a 4-in. clearance between the floor and the bottom of the curtain when the hood was in the lowered position. They were also designed to have only 50% overlap to facilitate ease of access for, e.g., maintenance and choke clearing.

The appendices to this paper present details of the calculations for the dust control systems. They are available at reproduction cost from the authors and contain the details of the calculations of the life cycle costs for the dust control systems for the cleaning room (Appendix A), the first-cut delintering area (Appendix B), the second-cut delintering area (Appendix C), the beater room (Appendix D), the hulling and separating room (Appendix E), the baling room (Appendix F) and the air cleaning system (Appendix G).

Appendix G includes the details of the calculations for the required air compressor to meet filter cleaning requirements and the power requirements for compressor operation. The life cycle cost for the compressor has been calculated from Equation X:

$$LCC = CC \cdot A/P_{MARR,n}, \qquad [X]$$

where the symbols are as previously defined.

To estimate the cost of adding dust control to any of the mechanical areas of an existing oil mill, the required air volume rate and duct size must be calculated using the velocity pressure or other equivalent method. Once that has been done and the length and sizes of the required ductwork including junctions, wyes and elbows have been determined, one obtains the costs for all system components as shown in the corresponding appendix. Estimates of the total capital investment, insurance and taxes, power and maintenance costs and the cost of the fabric filter cleaning system may be obtained in the same fashion as shown in Table II. All such cost estimates must be multiplied by $(1+X)^n$, where X is the average monthly inflation rate for the n months which have elapsed since May 1981. If a cost estimate is desired for March 1982 (n=10) and the average monthly inflation rate has been 0.8%, then the cost adjustment factor is $(1.008)^{10} = 1.0829$.

TABLE II

Capital and Other Costs for the Dust Control System in the Cleaning Room

Capital cost = FC = total ductwork + cyclone cost + fabric filter + fan system
Ductwork cost = $25,685
Cyclone cost = $32,800
Fan system cost = $10,805

(1) *With fabric filter A/C = 5:1*—fabric filter cost = $140,310
Capital cost = FC = $209,600

Power cost = C_p = unit power cost ($/KWH) × hr/yr × H_{pf} × 0.74548

Assuming the system operates 330 days/year, the total operating hr = 24 × 330 = 7,920

C_p = $0.0473 × 7,920 × 125 × 0.74548 = $34,905/yr

Insurance and taxes = 0.03(FC) = $6,290/yr

Maintenance and replacement cost = C_m
C_m = Maintenance + 2 bag changes = 0.04(FC) + 2 bag changes/yr
= $209,600 × 0.04 + 2 × 0.57 × 6600 × $(1.01)^{42}$
= $19,810/yr

Life cycle cost
= $I + T + (C_p + C_m) \cdot F/P_{X,1} \cdot F/A_{X,n} \cdot A/P_{MARR,n} + FC \cdot A/P_{MARR,n}$
= $6,290 + ($34,905 + $19,810) 0.9333 × 11.2258 × 0.20536 + $209,600 (0.20536)
= $167,055/yr

(2) *With fabric filter A/C = 10:1*—fabric filter cost = $81,070
FC = $150,360
C_p = $34,905/yr
I + T = $4,510/yr
C_m = $13,630/yr
LCC = $139,815/yr

(3) *With fabric filter A/C = 20:1*—fabric filter cost = $51,450
FC = $120,740
C_p = $34,905/yr
I + T = $3,625/yr
C_m = $10,540/yr
LCC = $126,200/yr

Table II shows the capital costs, power charges, maintenance costs, insurance and taxes and life cycle costs (LCC) per year for the cleaning room of the model mill for fabric filter air-to-cloth ratios of 5:1, 10:1 and 20:1. The A/C ratio in most common use throughout the mills visited in this study was between 3 and 5 $ft^3/min/ft^2$ (≈FPM) of net filtering area. Dacron® or other light-weight fabrics have been in use in such installations. As can be seen in Table III (which is an overall cost summary), this situation results in maximal capital expenditures and maximal life cycle costs. When the air-to-cloth ratio is doubled from 5:1 to 10:1, Dacron® or other light-weight woven bags are still feasible. There is a corresponding 24% decrease in life cycle cost and ca. 36% decrease in capital cost for the dust control system. Maintenance costs and insurance and taxes are reduced by 40 and 28%, respectively. If improved pulse-jet baghouses were used with an air-to-cloth ratio of 20:1 which would require felted (nonwoven) fabric bags, there is a further decrease in life cycle costs and in total capital expenditure.

An A/C of 20:1 is recommended for the model mill and for all new cottonseed oil mills. When the technology described in this report is adapted to existing cottonseed or other oilseed mills, individual economic analyses must accompany the technological evaluation of the existing air control system in the mill and its integration with the process air system prior to selecting the elements of the cotton dust control system, the type of baghouse and the air-to-cloth ratio involved.

Life cycle costs represent the annualized cost of the initial and future anticipated expenses including the effect of inflation. For example, at an A/C = 20:1 using a 20-year life and a 12% annual inflation rate, the cost of power in 2001 to operate the dust control system then is estimated to be $150,205 × $(1.12)^{20}$ = $1,148,920. Insurance and taxes, maintenance and capital recovery should similarly inflate. For this reason, economic evaluation of alternative technology must be made using life cycle costs rather than the fixed costs alone.

The fabric filters are the single most expensive component of the dust control system and thus the air-to-cloth ratio chosen affects the life cycle and capital costs to the greatest extent. The capital expenditures proposed for the model mill appear formidable. These costs must be viewed from the proper perspective: they are worst-case costs. They do not assume the existence of any dust control system in any of the mechanical areas of the mill. The system presented in this report is designed as a completely separate system, totally independent of the process air system. Such a design would never be conceived or implemented in any existing or planned mill. This approach was taken in the present case to elucidate the maximal cost of adding an occupational cotton dust control system to an uncontrolled mill, to demonstrate the complexity for such a system and to illustrate the necessity for designing the dust control and process air systems as an integral unit.

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TABLE III

Cost Summary for the Model Mill Dust Control System

Area	Fixed capital ($)	Power ($/yr)	Maintenance ($/yr)	Insurance, taxes ($/yr)	LCC ($/yr)[a]
Air/Cloth = 5:1					
Cleaning	209,600	34,905	19,810	6,290	167,055
Delintering	389,290	40,490	38,630	11,680	261,860
Beater room	87,120	6,980	8,090	2,610	52,925
Hulling	177,295	27,925	18,795	5,320	143,250
Bale room	291,260	34,910	32,305	8,740	213,170
Compressor	31,210	19,980	1,250	935	49,400
Total	1,185,775	165,190	118,880	35,575	887,660
Air/Cloth = 10:1					
Cleaning	150,360	34,905	13,630	4,510	139,815
Delintering	293,380	40,490	23,255	8,800	206,140
Beater room	67,995	6,980	5,025	2,035	41,830
Hulling	128,600	27,925	10,995	3,860	114,010
Bale room	205,615	34,910	18,510	6,170	163,330
Compressor	12,055	9,680	480	360	23,300
Total	758,005	154,890	71,895	25,735	688,425
Air/cloth = 20:1					
Cleaning	120,740	34,905	10,540	3,625	126,200
Delintering	248,580	40,490	18,595	7,455	185,630
Beater room	59,025	6,980	4,085	1,770	37,700
Hulling	105,845	27,925	7,160	3,175	100,620
Bale room	165,590	34,910	14,345	4,965	144,945
Compressor	8,140	4,995	325	245	12,415
Total	707,900	150,205	55,050	21,235	607,510

[a]Based on a 20-yr life, 12% annual inflation rate, MARR = 20%.

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