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Project Summary

Control of Hydrocarbon Emissions from Cotton and Synthetic Textile Finishing Plants

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This report describes the approach to, and conclusions resulting from, an evaluation of the applicability and economics of emissions control technologies for the abatement of volatile organic compounds emanating from cotton and synthetic textile finishing plants. A survey of the state-of-the-art and control technologies design and costing preceded the evaluation. The economic feasibility was determined in two steps: preliminary design, costing, and relative ranking of all identified applicable technologies; followed by more detailed design, costing, and evaluation of the most economically feasible technologies.

A simple payback period approach was taken in the preliminary ecomonic evaluation. Rates of return on capital investment were determined for the final detailed evaluation. Capital and operating costs are provided to allow interested parties to conduct in-house evaluations.

Carbon bed adsorption with solvent recovery has been identified as the most viable of all technologies, and fluidized-bed carbon adsorption has the best potential to suit the variable operating conditions encountered in textile manufacturing.

The potential cost benefits, even under far more stringent control requirements than existing regulations for the industry, appear attractive.

This Project Summary was developed by EPA's Industrial Environmental Research Laboratory, Research Triangle Park, NC, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

The U.S. EPA has been studying technical feasibility and socioeconomic effects of air pollution control prior to providing state, local, and other regulatory agencies with guidelines and technical assistance. Currently available information for hydrocarbon control is very general and difficult to apply to any particular industry. EPA, through previous studies, established that textile processing contributed significantly to the hydrocarbon concentration in the atmosphere and needed a control method.

The EPA contracted with Foster-Miller, Inc. to conduct a state-of-the-art study and acquire technical and economic information to enable the design, construction, and demonstration of a full-scale hydrocarbon emissions control unit capable of 95 percent hydrocarbon removal on a textile fabric processing plant for EPA's use in its regulatory guidelines and technical assistance program.

A systematic stepwise approach for the successful completion of the program was undertaken to:

- Survey the textile processing industry and published information to determine emissions sources, nature of pollutants, and range of emissions.
- Investigate the types and effectiveness of control devices now in place in the textile industry.
- Investigate hydrocarbon emission control technologies used in other industries which may be applicable to hydrocarbon control in the textile industry.
- Conduct preliminary design and evaluation of applicable control technologies capable of reducing hydrocarbon emissions by 95 percent for a given stack gas temperature, flow rate, and a range of concentrations.

- Provide more detailed designs and cost estimates for the most appropriate technologies for varying emissions concentrations and flow rates.

State-of-the-Art Survey

The state-of-the-art survey led to the following conclusions:

- Textile fabric production is geared to the marketplace. The volumes of products, types of fabrics, types of operations (dyeing, printing, final finishing), volumes and types of solvent used, and the natures and ranges of emissions are highly variable.
- Fabric printing has the most potential for high hydrocarbon emissions; control technologies should address this operation.
- Current emissions regulations are qualitative and address only opacity or odor threshold. Regulations vary between states.
- Opacity is controlled by limiting aerosol emissions, the cause of opacity. Control devices include coalescing filters, electrostatic precipitators (ESPs), direct contact condensers, and demisters.
- Odor is controlled by dilution or incineration.
- No quantitative data are available on any control device now in use in the textile industry.

Applicable Control Technologies

The following control technologies were determined to be applicable for hydrocarbon emissions control in general:

- Aerosol formation and particulate capture; conventional particulate control devices include demisters/cyclones, scrubbers, filters, and ESPs.
- Incineration, including fixed- and fluidized-bed catalytic.
- Adsorption, including fixed- and fluidized-bed.
- Absorption.

A further analysis of the above technologies in the textile plant exhaust environs for 95 percent control narrowed the choices to:

- Refrigeration/condensation + aerosol removal.
- Thermal incineration.
- Fixed-bed catalytic incineration.
- Fluidized-bed catalytic incineration.
- Fixed-bed adsorption.
- Fluidized-bed adsorption.

Preliminary Design and Evaluation of Applicable Control Technologies

Having identified the emission control technologies particularly suited to textile printing plant stack gases, preliminary design and assessment of these technologies were made using design rules given in engineering manuals. Most of these are based on equipment industry practices and field experience in operating these control devices for volatile organic compound (VOC) pollution abatement both in and outside the textile industry.

Capital and operating costs were developed to include optional heat recovery in incineration systems and the possibilities of using any solvent recovered in refrigeration or adsorption systems back in the process or as supplementary fuel.

Costs for systems designed for operation at 200, 3000, and 8000 ppm stack gas are given in Table 1 under Cases 1, 2, and 3, respectively.

Since textile mill operating practices necessitate varying the print paste solvent content frequently, causing variations in the VOC emissions, several combinations of operations at 200, 3000, and 8000 ppm emissions during different periods of a year, have also been considered. The 10 combinations chosen, where operations at any one concentration occur for less than a whole year, are shown in Table 2 as Cases 4 through 13. Thus, Case 6 conditions refer to an operation where the emissions are 3000 ppm for 80 percent, and 8000 ppm for 20 percent of the year. The costs and economic impact, as represented by payback periods of varying concentration levels during operation, are listed in Table 1. Systems that did not result in paybacks were excluded from further consideration.

The above analyses lead to the following preliminary conclusions:

- The only control technology with projected paybacks for all concentration conditions considered is fluidized-bed adsorption with recovered solvent reused. No other technology projects a payback for 100 percent operation at the low concentration level (200 ppm).
- As long as operations at low level exhaust concentration is not more than 80 percent, fixed-bed adsorption and refrigeration/condensation (both with reuse of recovered solvent) also project reasonable paybacks for all other concentration combinations.
- Considering the top three technologies ranked by average payback, the payback for fixed-bed adsorption and refrigeration/condensation is approximately 200 and 350 percent, respectively, more than that of fluidized-bed adsorption (all with recovered solvent reuse).
- The fourth ranked technology is fluidized-bed adsorption with recovered solvent used as fuel. This technology actually projects shorter paybacks than refrigeration/condensation with solvent reuse if operation never occurs at high exhaust concentration (8000 ppm).
- Fluidized-bed catalytic incineration and thermal incineration (both with heat recovery) are closely ranked technologies. Overall, the former has the fifth best average payback, although the latter projects better paybacks when high concentrations never occur during operation.
- The final three technologies considered, in order of average payback, are fixed-bed catalytic incineration with heat recovery, fixed-bed adsorption with recovered solvent used as fuel, and refrigeration/condensation with recovered solvent used as fuel. In order for these techniques to realize a reasonable payback, concentrations must be in the medium (3000 ppm) to high (8000 ppm) range more than 50 percent of the time. In order for refrigeration/ condensation with solvent as fuel to project a payback of less than 10 years, more than 20 percent operation in the high range is required if the remaining operation is at medium concentration (more than 50 percent is required in the high range if the remainder is at low concentration).
- Because the value of recovered solvent is three times greater with reuse than as fuel, systems with solvent recovery have better paybacks with reuse.
- Fluidized-bed adsorption has a shorter payback than fixed-bed adsorption despite nearly equal capital costs, due to the lower utility and maintenance costs of the former.

Detailed Design and Costing of Selected Control Technologies

The design and costs for the adsorber and catalytic incineration systems were developed in sufficient detail in the preliminary analyses to allow a reasonable cost-benefit evaluation of these technologies. The refrigeration/condensation aerosol removal system and the thermal incineration system designs were considered in more detail in order to provide a more comprehensive basis for final ranking of applicable emission control technologies.

Table 1. *Effect of Changes in Duration of Emissions at Different Concentrations on the Economics of Selected Control Technologies*

		Identification No.[a,b]									
Case No.[c]	*Cost Item*	*I*	*II*	*IV*	*VI*	*VII*	*VIII*	*IX*	*X*	*XI*	*Comments*
1	Capital	505,100	505,100	165,600	185,700	214,300	140,000	140,000	84,800	84,800	100% low concentration
	Annual direct[d]	−75,200	−91,500	−21,100	−34,300	−37,800	−7,200	−23,900	+13,000	−3,700	
	Payback	–	–	–	–	–	–	–	6.5	–	
2	Capital	505,100	505,100	174,800	240,400	224,800	140,000	140,000	122,500	122,500	100% medium concentration
	Annual direct	+250,800	+10,800	+80,600	+60,200	+63,300	+262,500	+32,700	+314,800	+85,000	
	Payback	2.0	47	2.2	4.0	3.6	0.5	4.3	0.4	1.4	
3	Capital	505,100	505,100	324,100	469,300	256,500	259,600	259,600	177,200	177,200	100% high concentration
	Annual direct	+820,800	+195,800	+249,100	+211,500	+242,500	+734,300	+121,000	+857,900	+244,600	
	Payback	0.6	2.6	1.3	2.2	1.1	0.4	2.1	0.2	0.7	
4	Capital	505,100	505,100	174,800	240,400	224,800	140,000	140,000	122,500	122,500	Predominantly low some medium concentrations
	Annual direct	−10,000	−71,000	−800	−15,400	−17,600	+46,700	−12,000	+73,400	+14,000	
	Payback	–	–	–	–	–	3.0	–	1.7	8.8	
5	Capital	505,100	505,100	174,800	240,400	224,800	140,000	140,000	122,500	122,500	Predominantly medium some low concentrations
	Annual direct	185,600	−9,700	+60,300	+41,300	+43,100	+208,600	+21,400	+254,400	+67,300	
	Payback	2.7	–	2.9	5.8	5.2	0.7	6.5	0.5	1.8	
6	Capital	505,100	505,100	324,100	469,300	256,500	259,600	259,600	177,200	177,200	Predominantly medium some high concentrations
	Annual direct	+364,800	+47,800	+114,300	+90,500	+99,100	+356,900	+50,400	+423,400	+116,900	
	Payback	1.4	10.6	2.8	5.2	2.6	0.7	5.2	0.4	1.5	
7	Capital	505,100	505,100	324,100	469,300	256,500	259,600	259,600	177,200	177,200	Predominantly high some medium concentrations
	Annual direct	+706,800	+158,800	+215,400	+181,200	+206,700	+639,900	+103,300	+749,300	212,700	
	Payback	0.7	3.2	1.5	2.6	1.2	0.4	2.5	0.2	0.8	
8	Capital	505,100	505,100	174,800	240,400	224,800	140,000	140,000	122,500	122,500	All operations at low and medium concentrations
	Annual direct	+55,200	−50,600	+19,600	+3,500	+2,600	+100,700	−1,300	+126,700	+31,800	
	Payback	9.2	–	8.9	69	86	1.4	–	1.0	3.9	
9	Capital	505,100	505,100	324,100	469,300	256,500	259,600	259,600	177,200	177,200	All operations at low and high concentrations
	Annual direct	+283,200	+23,400	+87,000	+64,000	+74,300	+289,400	+34,100	+351,000	+95,600	
	Payback	1.8	22	3.7	7.3	3.5	0.9	7.6	0.5	1.9	
10	Capital	505,100	505,100	324,100	469,300	256,500	259,600	259,600	177,200	177,200	All operations at low and high concentrations
	Annual direct	+462,400	+80,900	+141,000	+113,200	+130,400	+437,700	+63,000	+519,900	+145,300	
	Payback	1.1	6.2	2.3	4.1	2.0	0.6	4.1	0.3	1.2	
11	Capital	505,100	505,100	324,100	469,300	256,500	259,600	259,600	177,200	177,200	All operations at medium and high concentrations
	Annual direct	+478,800	+84,800	+148,000	+120,700	+135,000	+451,200	+68,000	+532,000	+148,800	
	Payback	1.1	6.0	2.2	3.9	1.9	0.6	3.8	0.3	1.2	
12	Capital	505,100	505,100	324,100	469,300	256,500	259,600	259,600	177,200	177,200	All operations at medium and high concentrations
	Annual direct	+592,800	+121,800	+181,700	+151,000	+170,800	+545,600	+85,700	+640,700	+180,800	
	Payback	0.9	4.1	1.8	3.1	1.5	0.5	3.0	0.3	1.0	
13	Capital	505,100	505,100	324,100	469,300	256,500	259,600	259,600	177,200	177,200	Operations at low, medium and high concentrations
	Annual direct	+331,300	+38,100	+102,600	+78,900	+89,100	+329,200	+43,200	+394,400	+108,400	
	Payback	1.5	13	3.2	5.9	2.9	0.8	6.0	0.4	1.6	

[a] See Table 3 for identification numbers.

[b] Systems III and V excluded because they did not result in paybacks.

[c] See Table 2 for case numbers.

[d] Positive annual direct costs indicate revenue; negative annual direct costs indicate expenditures.

Table 2. *Changes In Duration Of Emissions at Different Concentrations*

Description	*Case No.*	*200 ppm (%)*	*3000 ppm (%)*	*8000 ppm (%)*
		Emissions concentration for percent of year		
Operation at single concentration level	*1*	*100*	*0*	*0*
	2	*0*	*100*	*0*
	3	*0*	*0*	*100*
Predominant concentration level with overlap into one other level	*4*	*80*	*20*	*0*
	5	*20*	*80*	*0*
	6	*0*	*80*	*20*
	7	*0*	*20*	*80*
Operation at two concentration levels, one slightly dominant	*8*	*60*	*40*	*0*
	9	*60*	*0*	*40*
	10	*40*	*0*	*60*
	11	*0*	*60*	*40*
	12	*0*	*40*	*60*
Operation at all levels equally	*13*	*33*	*34*	*33*

Analyses at 200 ppm were presented since the overall economic viability of a system is greatly influenced by system performance at low emission concentrations.

Table 3 summarizes the capital cost and annual direct costs of emissions control technologies determined from the detailed system designs and economics. The systems listed generate revenue at stack gas concentrations of 8000 ppm or less for the given stack gas temperature, flow rate, and relative humidity. Each system has been designed for the specified emissions concentration, and a 10 percent thermal loss has been assumed for each heat exchanger employed. Also the solvent recovery efficiency is assumed to be 90 percent to account for solvent replacement and recovery inefficiencies. If a heat recovery exchanger is used to warm dryer air, the mass flow rates on each side of the exchanger have been assumed equal. If the recovered waste heat is transferred to boiler feedwater, a flow rate of 100 gpm has been assumed. As was the case for all previous cost reports, annual direct cost is equal to annual operating savings minus annual operating costs. Therefore, a positive direct cost indicates earned revenue, and a negative direct cost indicates a net annual expenditure.

In order to determine the systems with the greatest potential for application, an annual return rate for each system and stack gas concentration has been determined using the following model of capital recovery in a uniform series:

$$R = C \frac{i(1+i)^n}{(1+i)^n - 1}$$

where:

R = annual return required on capital investment, \$/year

C = capital cost of system, \$

i = annual rate of return, fraction

n = system life, years

Thus, the rate of return values, i, associated with the revenue generated, R (positive direct cost), and money invested, C (capital cost), for each system reported in Table 3 have been determined.

The estimates of rate of return on investment (ROI) show that:

- Fluidized-bed carbon adsorption with solvent reused projects the best ROI at every stack gas concentration level by a wide margin. It is also the only system which generates revenue at 200 ppm. Fluidized-bed carbon adsorption is still the best technology overall if recovered solvent can only be used as fuel.
- Fixed-bed carbon adsorption with solvent reused projects excellent ROI values for 3000 and 8000 ppm. If recovered solvent can only be used as fuel, however, the rate of return is seriously reduced: other technologies are preferable.
- The refrigeration/condensation aerosol removal system is competitive only at 8000 ppm stack gas concentration and only if the recovered solvent can be reused.
- Thermal incineration provides reasonable ROI at 3000 and 8000 ppm.

Table 3. *Summary of Costs for Selected Emissions Control Technologies Including Detailed Designs*

		I	*II*	*IV*	*VI*	*VII*	*VIII*	*IX*	*X*	*XI*
		Refrigeration/ condensation, aerosol removal		*Thermal incineration (stack gas diluted to 3500 ppm, if higher)*	*Fixed-bed catalytic incineration (stack gas diluted to 1580 ppm, if higher)*	*Fluidized-bed catalytic incineration*	*Fixed-bed carbon adsorption (stack gas diluted to 3500 ppm, if higher)*		*Fluidized-bed carbon adsorption*	
Stack gas emissions concentration (ppm, volume)	*Cost item*	*Recovered solvent reused*	*Recovered solvent used as fuel*	*Heat recovery*	*Heat recovery*	*Heat recovery*	*Recovered solvent reused*	*Recovered solvent used as fuel*	*Recovered solvent reused*	*Recovered solvent used as fuel*
200	*Total capital cost ($)*	*691,600*	*691,600*	*169,600*	*185,700*	*214,300*	*140,000*	*140,000*	*84,800*	*84,800*
	Annual direct cost ($/year)	*-147,600*	*-161,900*	*-40,000*	*-40,000*	*-43,700*	*-9,700*	*-24,700*	*+10,500*	*-4,500*
3000	*Total capital cost ($)*	*706,300*	*706,300*	*174,800*	*240,400*	*224,800*	*140,000*	*140,000*	*122,500*	*122,500*
	Annual direct cost ($/year)	*+175,800*	*-35,200*	*+69,600*	*+49,200*	*+47,100*	*+228,600*	*+21,800*	*+280,900*	*+74,100*
8000	*Total capital cost ($)*	*613,500*	*685,700*	*324,100*	*469,300*	*256,500*	*259,600*	*259,600*	*177,200*	*177,200*
	Annual direct cost ($/year)	*+687,200*	*+160,000*	*+219,900*	*+182,300*	*+207,900*	*+643,800*	*+91,800*	*+767,400*	*+215,400*

Notes: Negative annual direct cost indicates expenditure; positive annual direct cost indicates earned revenue.

- Fixed- and fluidized-bed catalytic incineration generate competitive returns only at 8000 ppm.
- At 8000 ppm fluidized-bed catalytic incineration is preferable to either thermal incineration or fixed-bed catalytic incineration.

Effect of Stack Gas Flow Rate on the Economics of Selected Control Technologies

Figure 1 shows the ROI factors for the best six technologies versus stack gas flow rate. Hence, if the ROI for one selected emissions control system operating at 3000 ppm is known for a particular flow rate, the ROI for smaller or bigger units can be ascertained from Figure 1.

For the selected systems operating with 8000 ppm stack gas, the ROI factors for gas flows higher than 5000 scfm are the same as those shown in Figure 1, except for fluidized-bed catalytic incineration and refrigeration/condensation. The ROI factors for these two systems are about 80 percent of those shown. For 8000 ppm stack gas and a flow rate of 1000 scfm, the ROI factors for fluidized- and fixed-bed adsorption are the same as those illustrated. The ROI factor for all other systems at 8000 ppm and 1000 scfm is approximately 0.49 (±0.05).

With 200 ppm stack gas only fluidized-bed carbon adsorption with solvent reused projects a return, and only for flow rates greater than 5000 scfm.

The ranking of the top three technologies does not vary with stack gas flow rate.

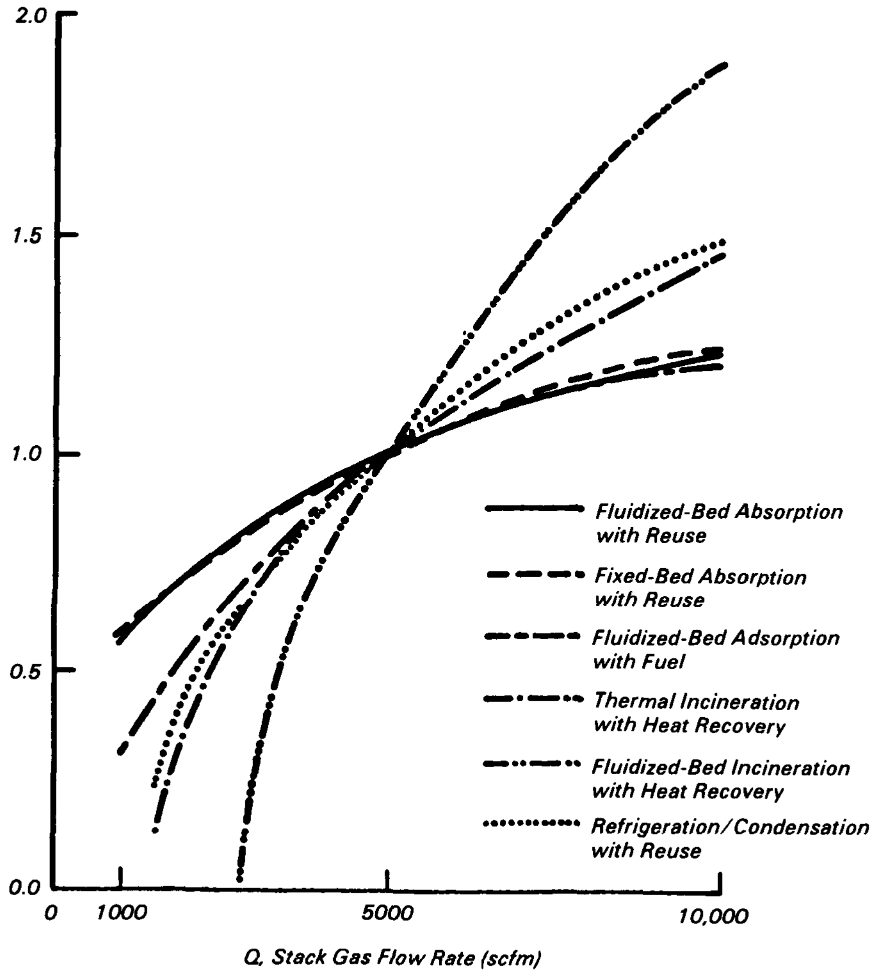

Figure 1. *Economics of size for selected emissions control systems. (3000 ppm stack gas concentration)*

Conclusions

The technological and economic evaluations presented resulted in the following conclusions:

- Activated carbon adsorption and incineration are the only technologies capable of achieving over 95 percent emissions control.
- Direct or indirect condensation using refrigeration can approach 95 percent control.
- Cyclones, scrubbers, fabric filters, demisters, electrically augmented precipitators, and other particulate (aerosol) collection devices are not suitable for 95 percent control without refrigeration.
- For the best six control technologies and a stack gas concentration of 8000 ppm, the ROIs for 1000 and 10,000 scfm gas flow rates are, respectively, about 0.52 and 1.29 times that for a 5000 scfm system. The changes in ROI with flow rates vary widely when stack gas concentration is 3000 ppm. At 200 ppm only fluidized-bed carbon adsorption projects a return, and only at greater than 5000 scfm.
- Applicable technologies for 95 percent hydrocarbon removal rank in the following general order of economic viability on the basis of ROI:
  - Fluidized-bed activated carbon adsorption with recovered solvent reused.
  - Fixed-bed activated carbon adsorption with recovered solvent reused.
  - Fluidized-bed activated carbon adsorption with recovered solvent used as fuel.
  - Thermal incineration with heat recovery.
  - Refrigeration condensation/aerosol capture with recovered solvent reused.
  - Fluidized-bed catalytic incineration with heat recovery.
  - Fixed-bed catalytic incineration with heat recovery.
  - Fixed-bed activated carbon adsorption with recovered solvent used as fuel.
  - Refrigeration condensation/aerosol capture with recovered solvent used as fuel.

Recommendations

Based on the results of this study, Foster-Miller suggests several areas where further study could advance the state-of-the-art:

- Solicit the cooperation of a textile fabric finishing plant which has annual solvent used in its printing operations representative of the industry average; select the most appropriate stack for control.
- Determine stack gas conditions: species emitted, concentration and its variability, flow rate, temperature, moisture content, etc.

- Conduct detailed design and cost evaluation of two best available control technologies, specifically for the stack selected.
- Fabricate, install, and demonstrate the more economically viable control technology.

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The complete report, entitled "Control of Hydrocarbon Emissions from Cotton and Synthetic Textile Finishing Plants," (Order No. PB 83-209 676; Cost: $16.00, subject to change) will be available only from:

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
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