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Burning Tires for Fuel and Tire Pyrolysis: Air Implications

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BURNING TIRES FOR FUEL AND TIRE PYROLYSIS: AIR IMPLICATIONS

CONTROL TECHNOLOGY CENTER

Sponsored by

Emission Standards Division
Office of Air Quality Planning and Standards
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Research Triangle Park, NC 27711

Air and Energy Engineering Research Laboratory
Office of Research and Development
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by

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PREFACE

This project was funded by EPA's Control Technology Center (CTC) and prepared by Pacific Environmental Services, Inc. (PES).

The CTC was established by EPA's Office of Research and Development (ORD) and Office of Air Quality Planning and Standards (OAQPS) to provide technical assistance to State, local, and private air pollution control agencies. Three levels of assistance can be accessed through CTC. First, a CTC Hotline has been established to provide telephone assistance on matters relating to air pollution control technologies. Second, more in-depth engineering assistance can be provided when appropriate. Third, the CTC can provide technical guidance through publication of technical documents, development of personal computer software, and presentation of workshops on control technologies.

The technical guidance projects, such as this one, focus on topics of national or regional interest and are identified through contact with State and local agencies or private organizations. Sufficient interest in the disposal of scrap tires through their use as a fuel warranted development of a technical document on air emissions from the burning of tires for fuel and from tire pyrolysis. This document briefly discusses various industries that use tires either primary or supplemental fuel. In addition, this document discusses the pyrolysis of tires. This document serves as a reference source for those seeking further information.

DISCLAIMER

This report has been reviewed by the Control Technology Center (CTC) established by the Office of Research and Development (ORD) and Office of Air Quality Planning and Standards (OAQPS) of the U.S. Environmental Protection Agency (EPA), and has been approved for publication. Approval does not signify that the comments necessarily reflect the views and policies of the U.S. EPA nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

TABLE OF CONTENTS

		Page
List of Tables		viii
List of Figures		x
EXECUTIVE SUMMARY		ES-1
1.	Introduction	1-1
1.1	Waste Tire Generation and Disposal	1-2
1.2	Waste Tires As Fuel	1-3
1.2.1	Waste Tire Characteristics and Composition	1-5
1.2.2	Waste Tire and TDF Cost Considerations	1-5
1.2.3	Air Pollution Emissions Issues	1-10
1.3	Markets For Tires As Fuel	1-11
1.4	State Waste Tire Disposal Programs	1-12
1.5	Methodology	1-17
1.6	References	1-19
2.	Overview of Process Units Burning Tires For Fuel	2-1
2.1	Kilns	2-2
2.2	Boilers	2-2
2.2.1	Pulverized Coal Boilers	2-4
2.2.2	Cyclone Boilers	2-5
2.2.3	Stoker Boilers	2-6
2.2.4	Fluidized Bed Boilers	2-11
2.3	References	2-17
3.	Dedicated Tires-to-Energy Facilities	3-1
3.1	Industry Description	3-1
3.2	Process Description	3-3
3.2.1	General Operation	3-4
3.2.2	Operational Difficulties	3-6
3.3	Emissions, Control Techniques and Effectiveness	3-8
3.3.1	Emissions	3-8
3.3.2	Control Techniques	3-10
3.3.3	Permit Conditions and Issues	3-16
3.4	Other Environmental and Energy Impacts	3-17
3.5	Cost Considerations	3-18
3.6	Conclusions	3-20
3.7	References	3-21
4.0	Tire and TDF Use in Portland Cement Kilns	4-1
4.1	Industry Description	4-4
4.2	Process Description	4-9
4.2.1	Mixing and Grinding	4-9
4.2.2	Calcination	4-12
4.2.3	Preheaters and Precalciners	4-12
4.2.4	Finished Cement Grinding	4-14
4.2.5	Tires as Fuel in the Kiln	4-18

TABLE OF CONTENTS (Continued)

		Page
4.3	Emissions, Control Techniques and their Effectiveness.	4-19
4.4	Other Environmental and Energy Impacts	4-34
4.5	Cost Considerations	4-35
4.6	Conclusions	4-36
4.7	References	4-37
5.0	TDF as Fuel in Waste Wood Boilers at Pulp and Paper Mills	5-1
5.1	Industry Description	5-2
5.2	Process Description	5-5
5.3	Emissions, Control Techniques and their Effectiveness	5-8
5.3.1	Emissions	5-8
5.3.2	Control Techniques	5-22
5.4	Other Environmental and Energy Impacts	5-25
5.5	Cost Considerations	5-25
5.6	Conclusions	5-26
5.7	References	5-27
6.0	Tires and TDF as Supplemental Fuel In Electric Utility Boilers	6-1
6.1	Industry Description	6-1
6.2	Process Description	6-1
6.2.1	Materials Handling	6-4
6.2.2	Combustion	6-6
6.3	Emissions, Control Techniques and their Effectiveness	6-8
6.3.1	Particulate Emissions	6-8
6.3.2	SO_2 Emissions	6-14
6.3.3	NO_x Emissions	6-16
6.3.4	CO Emissions	6-16
6.3.5	Trace Metal Emissions	6-16
6.3.6	Other Air Emissions Information	6-16
6.3.7	Control Equipment Issues	6-20
6.4	Other Environmental and Energy Impacts	6-23
6.5	Cost Considerations	6-23
6.6	Conclusions	6-23
6.7	References	6-26
7.0	Use of TDF as a Supplemental Fuel at Other Industrial Facilities	7-1
7.1	Description of Industries	7-1
7.2	Process Description	7-4
7.3	Emissions, Control Techniques and their Effectiveness	7-5
7.4	Other Environmental and Energy Impacts	7-5
7.5	Cost Considerations	7-5
7.6	Conclusions	7-8
7.7	References	7-9

TABLE OF CONTENTS (Continued)

Page

8.0 Scrap Tire Pyrolysis 8-1
8.1 Process Description 8-2
8.1.1 Materials Handling 8-4
8.1.2 Generic Reactor Description 8-4
8.2 Specific Reactor Types 8-8
8.2.1 Sealed Box 8-10
8.2.2 Rotary Kiln 8-11
8.2.3 Screw Kiln 8-11
8.2.4 Traveling Grate Kiln 8-12
8.2.5 Fluidized Bed 8-12
8.2.6 Other Reactors 8-12
8.3 Environmental Impacts 8-13
8.3.1 Particulate Emissions 8-13
8.3.2 VOC Emissions 8-15
8.3.3 Other Emissions 8-16
8.4 Other Environmental and Energy Impacts 8-16
8.5 Cost Considerations 8-20
8.6 Conclusions 8-23
8.7 References 8-25

APPENDIX A State Contacts for Waste Tire Programs

LIST OF TABLES

		Page
Table ES-1.	Comparison of criteria pollutants from electric generating plant	ES-4
Table 1-1.	Scrap tire generation	1-4
Table 1-2.	Comparative fuel analysis, by weight	1-6
Table 1-3.	Comparative composition and fuel value of various tire types	1-6
Table 1-4.	Market barriers to TDF use	1-13
Table 1-5.	Waste tire disposal laws in the U.S.	1-14
Table 1-6.	States without laws or regulations for waste tire disposal	1-16
Table 2-1.	Emission test results of three pilot FBC boilers burning supplemental TDF	2-15
Table 3-1.	Permitted emission levels at The Modesto Energy Project, Westley, CA. . .	3-9
Table 3-2.	Permitted emission limits for each boiler, Exeter Energy Project, Sterling, CT	3-9
Table 3-3.	Criteria pollutant and metals emissions, by year, The Modesto Energy Project	3-11
Table 3-4.	Organic compound emissions, by year, The Modesto Energy Project	3-12
Table 4-1.	Portland cement facilities that have been, or are, burning TDF or whole tires.	4-5
Table 4-2.	Effect of burning 9 to 10 percent TDF in a gas and oil co-fired dry process, rotary cement kiln controlled by an ESP	4-20
Table 4-3.	Effect of burning TDF on HAP emissions from Holnam/Ideal Cement, Seattle, WA . . .	4-29
Table 4-4.	Effect of burning 15 percent TDF in a gas-fired rotary lime kiln	4-30
Table 4-5.	Emissions estimates for Calaveras' cement kiln stack while burning 20 percent TDF	4-32
Table 5-1.	Pulp and paper mills with experience burning TDF in waste wood boilers	5-3
Table 5-2.	Emission of PNA's and metals from Port Townsend Paper and Crown Zellerbach Corporation	5-9
Table 5-3.	Summary of particulate tests on two hog-fuel boilers at Smurfit Newsprint, Newberg, OR	5-10
Table 5-4.	Summary of non-particulate testing on the #10 boiler at Smurfit Newsprint, Newberg, OR	5-11

Page

Table 5-5.	Summary of tests on 3 hog-fuel boilers at Package Corp. of America	5-12
Table 5-6.	Emissions burning TDF and waste wood Dow Corning Corporation, Midland, MI	5-13
Table 5-7.	Summary of tests on hog-fuel boiler at Champion International Corp., Sartell, MN .	5-14
Table 6-1.	Electric utilities with TDF experience as a supplemental fuel	6-2
Table 6-2.	Air emission test data for Wisconsin Power and Light	6-9
Table 6-3.	Emission results at Ohio Edison	6-10
Table 6-4.	Summary of emission rates burning 2% TDF at Illinois Power, Baldwin Generation Station	6-11
Table 6-5.	Summary of emission rates from testing at United Power Association, Elk River, MN	6-11
Table 6-6.	Summary of emissions from a wood-fired utility boiler cofiring TDF	6-12
Table 6-7.	Comparison of heavy metal content of slag at baseline and 5% TDF at Wisconsin Power and Light	6-24
Table 7-1.	Other industrial boilers with TDF experience	7-2
Table 7-2.	Summary of emissions at Monsanto, Sauget, IL	7-7
Table 7-3.	Summary of air emissions test data while burning TDF at Saginaw Steering and Gear . .	7-7
Table 8-1.	Approximate product distribution as a function of pyrolysis reactor temperature for reductive process category	8-3
Table 8-2.	Manufacturers of pyrolysis units and operating conditions	8-9
Table 8-3.	Emission estimates from pyrolysis facility, Conrad Industries	8-14
Table 8-4.	Chromatographic analysis of pyrolytic gas from shredded automobile tires with bead wire in	8-17
Table 8-5.	Chromatographic analysis of light oil condensed from pyrolytic gas at 0°F using shredded tires with bead wire	8-18
Table 8-6.	Estimated fugitive VOC emissions from a "generic" pyrolysis plant	8-19
Table 8-7.	Tire acquisition prices and selling prices of products required to produce a 20 percent return-on-equity for five tire pyrolysis units	8-22

LIST OF FIGURES

		Page
Figure 1-1.	Trace metal levels in whole waste tires compared to bituminous coal	1-7
Figure 2-1.	Typical cyclone coal burner	2-7
Figure 2-2.	Typical mechanical feeder on a spreader stoker	2-9
Figure 2-3.	Typical fluidized bed boiler	2-12
Figure 3-1.	Oxford Energy Process Flow Sheet	3-5
Figure 4-1.	Fuel Use at cement kilns	4-3
Figure 4-2.	Typical wet process material handling during Portland Cement manufacture	4-10
Figure 4-3.	Typical dry process material handling during Portland Cement manufacture	4-11
Figure 4-4.	Typical clinker production process during Portland Cement manufacture	4-13
Figure 4-5.	Four-stage suspension preheater with a precalciner at a Portland Cement plant	4-15
Figure 4-6.	Traveling grate preheater system at a Portland Cement plant	4-16
Figure 4-7.	Finish mill grinding and shipping during Portland Cement manufacture	4-17
Figure 4-8.	Effect of burning TDF on criteria pollutants emissions from Holnam/Ideal Cement, Seattle, WA	4-23
Figure 4-9.	Percent change in emissions of metals when burning TDF at Holnam/Ideal Cement, Seattle, WA	4-24
Figure 4-10.	Percent change in VOC emissions when burning TDF at Holnam/Ideal Cement, Seattle, WA	4-25
Figure 4-11.	Percent change in emissions when burning 15% TDF in a gas-fired rotary lime kiln controlled by a venturi scrubber	4-31
Figure 5-1.	Smurfit Newsprint Process Flows	5-7
Figure 5-2.	Percent change of particulate emissions over baseline (0% TDF) in wood waste boilers burning TDF	5-17
Figure 5-3.	Particulate emission rates from hog-fuel boilers burning TDF supplementally	5-18
Figure 5-4.	Change in emission rate of SO_2 over baseline (0% TDF) at varied TDF input rates for hog-fuel boilers	5-19
Figure 5-5.	Change in emission rate of NO_x over baseline (0% TDF) at varied TDF input rates for hog-fuel boilers	5-19

LIST OF FIGURES (Concluded)

Page

Figure 5-6. Change in emission rate of CO over baseline (0% TDF) at varied TDF input rates for hog-fuel boilers 5-20
Figure 5-7. Change in zinc emission rates when burning TDF at six pulp and paper plants 5-21
Figure 5-8. Percent change in metals emissions at five mills burning TDF 5-23
Figure 5-9. Percent change in emissions of PNA's at three paper mills burning TDF 5-24

Figure 6-1. Particulate emissions while burning TDF or whole tires at coal-fired electric utilities 6-13
Figure 6-2. SO_2 emissions while burning TDF or tires at coal-fired electric utilities 6-15
Figure 6-3. NO_x emissions while burning TDF or tires at coal-fired electric utilities 6-17
Figure 6-4. Trace metal emissions rates when burning waste tires compared to coal 6-18
Figure 6-5. Trace metal emission rate changes when burning waste tires compared to coal 6-19
Figure 6-6. Dioxin and furan emission rates when burning waste tires compared to coal 6-21
Figure 6-7. Dioxin and furan emission rate changes when burning waste tires compared to coal . 6-22

Figure 7-1. Summary of percent change in SO_2, NO_x, and particulate emissions at Monsanto Chemicals and Saginaw Gear 7-6

Figure 8-1. Generic Pyrolysis Process 8-5

EXECUTIVE SUMMARY

This report presents data and analysis concerning burning tires and tire-derived fuel (TDF) in process and power equipment in the United States. There is significant interest being expressed by several industries concerning the use of tires and TDF for fuel. This has caused an increase in requests for information from local agencies and for permit applications. Previously, there has not been a central publication on the effects of burning tires or TDF for fuel. The purpose of this report is to summarize data on the effect of burning tires or TDF on atmospheric emissions, emissions control techniques, control efficiencies, and economics.

Scrap tires present unusual disposal problems. The very characteristics that make them desirable as tires, long life and durability, makes disposal almost impossible. The fact that tires are thermal-set polymers means that they cannot be melted and separated into their chemical components. Tires are also virtually immune to biological degradation. Landfilling scrap tires is unacceptable for several reasons, not the least of which is the fact that they tend to rise to, and break through the surface liner.

Recycling scrap tires into useful products such as floor mats, sandal soles, and fish barriers, have very limited demand and at best could assemble only a small fraction of the available scrap tires.

This investigation found four industries that were using tires and TDF for fuel. Also investigated was the thermal degradation of tire and TDF (pyrolysis) into salable products. These industries were:

- Electric utilities that use TDF and whole tires as supplemental feed in power generation. One company was using whole tires as its sole source of fuel in power generation.
- Cement manufacturing companies use tires and TDF to supplement their primary fuel for firing cement kilns. Some of the companies were using tire or TDF directly in the kiln, some were using tires or TDF in the precalciner (prior to the kiln proper), and one company was using tires or TDF in both processes.
- Pulp and paper companies use tires or TDF as supplemental fuel in their waste-wood products boilers.
- Other industries use TDF in utility and process boilers as supplemental fuel.

TECHNICAL APPROACH

The approach used to collect and analyze data on burning tires and TDF is presented in this section.

Sources of Information

Initially, a detailed literature search was conducted to identify industries and companies with experience burning tires or TDF for fuel, emissions from the process, and emission controls and their effectiveness. A data base was created including all companies with experience burning tires or TDF, by industry and location. The U.S. EPA Regional Office for each plant location burning tires or TDF was contacted for specific emissions information. The State and local air pollution control agencies were also contacted for emissions data from plants testing or using tires or TDF for fuel.

Based on the information obtained from these sources, selected companies from each industry were contacted by telephone to determine if they were still burning tires or

TDF, if they had data on emissions while burning tires or TDF, and their future plans concerning tires or TDF as fuel.

Data obtained from the plants were compiled and analyzed. Based on this analysis, five companies were selected for site visits. Information on tires or TDF use, feed equipment modifications necessary to facilitate the burning of tires or TDF, operating problems created by using tires or TDF, operating advantages with using tires or TDF, and cost benefits of using tires or TDF was also gathered. Further information was obtained on emissions while burning tires or TDF, baseline emissions (emissions when tires or TDF are not being burned), emission controls in use, modifications to controls necessary to facilitate tire or TDF burning, and efficiency of emission controls.

Data obtained from the site visits were analyzed and detailed trip reports were written and reviewed by each affected company to verify technical data and remove confidential business information. The data from the trip reports, along with data from the literature search and air pollution control agencies, were compiled, summarized, and analyzed. These data were used as the basis of this report.

RESULTS

The primary area of interest of this investigation was the effect of burning tires or TDF on the emissions from the process. Other areas of concerns were the emission control devices, changes to controls necessary to facilitate burning tires or TDF, and the economics of burning tires or TDF.

Effect on Emission

The effect of burning tires or TDF on emissions varies substantially based on the industry and the type of emission controls installed. No emissions data were obtained during this investigation on tires or TDF for a process in which the emissions were uncontrolled. The effects of burning tires or TDF on emissions, by industry, are presented here.

Electric Utilities

Of all the emissions test data received from plants generating electric power using tires or TDF, the company reporting the lowest levels of emissions was Oxford Energy's Modesto, CA, plant. This plant's fuel was 100 percent whole, scrap tires, yet its emissions were several orders-of-magnitude lower than the other electric utilities (see Table ES-1).

The effect of burning tires on coal-burning utilities varied by pollutant. Particulates generally decreased as the percent of TDF in the fuel increased. This occurred in all but one series of tests. The sulfur oxides increased in some tests with increased TDF use, decreased in some tests, and stayed about the same in one series. The nitrogen oxides generally decreased with the increase use of tires or TDF; some by as much as 50 percent. In one series of tests, the nitrogen oxides increased 15 percent.

Cement Manufacturing

The effect of a fuel change to burning tires on emissions in cement kilns appears minor. Particulates increased slightly from 0.10 to 0.12 pounds per million Btu (20 percent) comparing baseline (zero TDF in the fuel) to 14 percent TDF. Both sulfur oxides and nitrogen oxides decreased (40 percent and 26 percent, respectively) in this range of TDF in the fuel. Carbon monoxide, however, increased 33 percent. The effect of burning tires or TDF in kilns on VOC's and HAP's appears to be positive (a significant reduction in most

Table ES-1. Comparison of Criteria Pollutants from Electric Generating Plants

Power Plant	Particulates	Sulfur Oxides	Nitrogen Oxides	Carbon Monoxide
	lb/MMBtu	lb/MMBtu	lb/MMBtu	lb/MMBtu
Oxford Energy 100% Tires	0.000022	0.000014	0.000098	0.000072
UPA, Elk River				
Baseline (0% TDF)	0.21	1.41	0.78	NT
5% TDF	0.015	1.80	0.58	NT
10% TDF	0.009	1.53	0.30	NT
WP&L, Beloit				
Baseline, 0% TDF	0.52	1.14	0.79	1.52
7% TDF	0.14	0.87	0.91	7.26
Ohio Edison				
Baseline	0.063	5.30	0.601	NT
5% TDF	0.0717	5.73	0.510	NT
10% TDF	0.0564	5.71	0.436	NT
15% TDF	0.0815	5.47	0.443	NT
20% TDF	0.0453	5.34	0.387	NT
Northern States				
Baseline	0.083	0.021	0.19	NT
7% TDF	0.310	0.074	0.125	NT
Illinois Power				
2% TDF	0.17	5.78	NT	NT

NT = Not tested or data not available.

cases). Notable exceptions are tetrachloroethane (up over 20 times the baseline rates) and 1,1,1-trichloroethane (up 6 times the baseline rates).

Pulp and Paper Mills

The effect of burning tires or TDF in waste-wood (hog fuel) boilers in pulp and paper mills was generally unfavorable on the emissions. Particulates increased in every series of tests when the TDF percentage was increased. The reason for this is probably due to the type of emissions control devices used on hog fuel boilers: venturi scrubbers. The effectiveness of venturi scrubbers decreases as the particle size in the emission decrease. Zinc oxide is used in the manufacture of tires, and is present in significant quantities in scrap tires. Zinc oxide has a relatively low vaporization temperature and is vaporized when tires are burned. When zinc oxide vapors condense, they form sub micro-sized particles that are too small to be removed with a venturi scrubber. This is verified by comparing the zinc emissions in hog-fuel boilers to baseline. Zinc emissions increased in most cases 300 percent (and in one case, almost 50 times the base line emission rate). The effect of burning tires on other pollutants was mixed, and distinctive trends could not be determined.

Other Industries

During the investigation, TDF trials and emission test data were obtained from industries not listed above. Most of the processes were burning TDF in a plant's utility steam or process boiler. One test, at Dow Chemical, involved burning TDF in a waste-wood boiler and is discussed in Chapter 5, TDF as fuel in Waste Wood Boilers at Pulp and Paper Mills. Another plant in this category, Boise-Cascade, was burning

TDF in a lime kiln, and is included in Chapter 4, Tire and TDF Use in Portland Cement Kilns.

Of the remaining "other" category, only two supplied test data. The results are so mixed that no trends or conclusions could be drawn.

Pyrolysis

There are essentially no process emissions from pyrolysis units. The primary sources of emissions are fugitive sources (for particulate emissions) and equipment leaks (for VOC emissions). The fugitive particulate emissions come from handling, crushing, screening, and packaging the char by-product from the process. There is nothing meritorious about these emissions and they can be handled using standard dust control practices, canopy hoods for dust collection, and a baghouse for particulate removed. The dust generated does not appear to be hazardous.

The VOC emissions occur from leaks around from valve stems, pump shafts, worn packings, and pipe joints. Fugitive VOC emissions can be minimized with proper design and specifying seal-less pumps and valves, and with good preventive maintenance.

Emission Control Devices

All plants that tested and/or used TDF used the control devices already installed at the facility except Oxford Energy, who designed their control equipment specifically for controlling emissions from burning tires. Most plants have not modified their control equipment to facilitate burning tires or TDF. An exception was Smurfit, a pulp and paper mill. Smurfit was replacing their venturi scrubber with an ESP to improve particulate removal and to increase the amount of TDF they are permitted to burn.

Whether burning tires or TDF improves or deteriorates emissions appears to depend on the control devices installed. ESP's seem to work the best for controlling emissions while burning tires or TDF. It is believed that the zinc content actually helps the ESP perform better, and this improved performance is seen in reduced emissions. Fabric filters (baghouses) also seem to be well suited for the control of emissions while burning tires or TDF. However, venturi scrubbers do not perform well when the process is burning tires or TDF. As noted earlier, the efficiency of venturi scrubbers decreases as particle size decreases and emissions from tires and TDF contain pollutants that are too small to be removed by venturi scrubbers.

Cost Indications

Some companies have tested burning tire or TDF in their fuel at the request of State agencies, but most are motivated by the possibility of lowering their operating costs. The savings resulting from replacing some of the primary fuel with tires or TDF is very site specific. Factors that affect the potential savings include the availability of scrap tires, local processing costs to make TDF, transportation cost, inventory and handling costs, and governmental incentives. Other major factors are the availability of primary fuel, transportation cost of primary fuels, and availability and cost of other alternative fuel.

There are other considerations in using tires or TDF that are not cost related, but could affect profitability. These include the stabilizing effect of using a high-energy, low-moisture fuel, and the possibility of reduced criteria pollutants emissions. The latter could result in the consumption of lower grade (and, therefore, lower cost) fuel and still meet emission limits.

Conclusion

With the proper emission controls, burning tires for their fuel energy can be an environmentally sound method of disposing of a difficult waste. It can also be financially advantageous and can improve the operating characteristic of a number of processes.

1. INTRODUCTION

Air pollution control agency personnel have an increasing need for technical information describing the air pollution implications of several methods of waste or scrap tire disposal. Environmental concern for tire disposal has historically focused on the solid and hazardous waste issues involved. Further, much information has already been written describing the comparative merits of disposal alternatives such as recycling, pyrolysis, and burning for fuel, in minimizing scrap tires and maximizing recycle markets. Air quality issues resulting from waste tire disposal issues, however, have not been as well documented.

The U.S. Environmental Protection Agency's Control Technology Center recognizes the need for data describing the air quality impacts of two of these disposal options -- the controlled burning of tires to recover its fuel value and pyrolysis for fuel and carbon black. The purpose of this report is to summarize available air emissions and control data and information on tire pyrolysis and burning tires for fuel.

This report describes air pollution issues by source category. Chapter 2 contains an overview describing the types of process units primarily burning tires. Chapter 3 describes dedicated tire-to-energy facilities. Portland Cement plants with experience burning tires are covered in Chapter 4. Chapter 5 summarizes the experience of pulp and paper plants in burning chipped tires as a supplemental fuel. Electric utilities burning tires as a supplemental fuel are described in Chapter 6. Chapter 7 includes any other industrial facilities with experience burning rubber. Last, Chapter 8 contains information on tire pyrolysis.

1.1 WASTE TIRE GENERATION AND DISPOSAL

Waste tires are generated in the United States at an estimated rate of approximately 240 million tires (approximately 2.4 million tons) per year.[1,2] These estimates do not include tires that are retreaded or reused second-hand; retreading and reuse are considered to extend the life of a tire before it is scrapped.

Of the 240 million, between 170 and 204 million waste tires generated annually are estimated to be landfilled or stockpiled.[1,2] Tires pose a unique landfill problem, not only because of their large numbers, but also because the materials used to ensure their durability and safety also make their disposal difficult. For example, whole tires do not compact well, and actually "rise" through a landfill mass to the surface as the dirt surrounding them compacts.[1] Further, when stored in the open (either in a landfill or in a tire stockpile), tire piles provide breeding grounds for insects such as mosquitoes and rodents. One mosquito, the Asian Tiger Mosquito, is slowly migrating across the country, and is of particular concern, because it can carry dangerous diseases such as encephalitis. Tires retain heat and provide many pockets of still, shallow water that are ideal for mosquito breeding. Open tire piles also can ignite easily, creating toxic smoke and fumes, and are difficult to extinguish. The resulting sludge creates a serious ground water pollution problem.

Approximately 8 to 11 percent of the scrap tires generated annually (approximately 192,000 to 264,000 tons/year) are estimated to be burned for fuel.[1,2] Section 1.2 below discusses the advantage and disadvantages of tires as fuel.

Disposal options other than landfilling, stockpiling, or burning account for approximately 5 to 16 percent of the tires generated.[1,2] These options include manufacture of fabricated products such as car moldings; reclaiming of the rubber; manufacture of asphalt rubber for road binding material, sealcoat, or asphalt paving aggregate; formation of underwater reefs or highway barriers; and tire export.[1,2] Table 1-1 provides additional detail on the estimated number of tires for various recycle and energy recovery options. Altogether, the existing stockpile inventory on a national scale is estimated to be approximately 2 billion tires (20 million tons).[1,2]

1.2 WASTE TIRES AS FUEL

Tires can be burned whole, or can be shredded or chipped before burning. Tires that are shredded into pieces are called Tire-Derived-Fuel, or TDF. TDF that is very small (i.e., less than 1/4" diameter) is sometimes called crumb rubber. Crumb rubber can be burned or can be fabricated into other rubber products. TDF that results from tire recapping operations is called rubber buffings, and is made up of small one-half inch slivers. Material handling capabilities of facilities burning whole tires must be able to accommodate a fuel that is large, heat intensive, and contains a significant amount of metal. Burning TDF also requires material handling creativity, but TDF is more readily adaptable to the material handling and combustion capabilities of many fuel-burning sources. TDF can be shredded to sizes as small as 1-inch square.

Radial wire is the mat of steel placed under the tread to enhance tread strength and durability. Bead wire consists of many strands of high tensile strength steel that provide strength and reinforcement to the tire side walls. Radial and bead wires can account for as much as 10 percent of the total weight of a tire.[3] The remainder of the weight of the tire is about 60 percent rubber, and 30 percent fiber.

Table 1-1. Scrap Tire Generation
(millions of tires per year)

	EPA, Markets for Scrap Tire Study[1]	Scrap Tire Management Council, 1990[2]
Total Scrap Tires Generated	242	240
Landfill/ Stockpile	187.8	170.4 - 204.0
Energy Recovery	25.9	19.2 - 26.4
Fabricated Products	11.1	2.4 - 12.0
Reclaim Rubber	2.9	4.8 - 12.0
Asphalt Rubber	2.0	1.2
Reefs/Barriers	0.3[a]	0.2 - 4.8
Tire Exports	12	4.8 - 9.6
Retread[b]	33.5	12
Reuse[b]	10	0

[a] Includes use for playground equipment and erosion control.

[b] Retreaded tires and reused tires are not considered "scrap" tires. Thus, although the number of tires retreaded or reused are reported here for completeness, they are not included in the estimates of total scrap tires generated.

1.2.1 Waste Tire Characteristics and Composition

Tires are a good fuel for several reasons. Tires contain about 15,000 Btu's per pound (about 300,000 Btu's per tire). Coal heating values range from 6,000 to 13,500 Btu's per pound. Further, they are compact, have a consistent composition, and contain a low moisture content. Also, many components of tires, such as sulfur and nitrogen, compare favorably to coal in percent makeup. Table 1-2 compares composition of tires to that of midwest coal.[4] Table 1-3 compares composition of various types of tires.[5] Most trace metal levels in tires are equivalent to the levels in coal; zinc and cobalt are higher in tires.[6] Figure 1-1 shows trace metal level of whole tires compared to bituminous coal.[6]

On the other hand, the size of whole tires requires the ability to feed large fuel to a burner, and their strength makes them difficult to cut into more manageably sized pieces of fuel. Also, chlorine, ash, and volatiles are present in higher quantities in tires and TDF than in most coals. Further, the metal contained in tires, in the form of the radial wire and bead, wire can be a problem in many fuel applications. For example, loose or molten wire can clog ash exit or grate combustion openings in boilers.

1.2.2 Waste Tire and TDF Cost Considerations

Sources desiring to burn tires may obtain them in several ways. Whole tires can be obtained from two basic sources. First, tires can come from the "flow"; that is, from retail businesses collecting old tires on a daily basis. This includes tire manufacturers, tire retail stores, and tire collectors, sometimes called tire jockeys. Tire jockeys cull the tires they collect for those that can be reused or retreaded, and then sell the remainder. Second, tires can

Table 1-2. Comparative Fuel Analysis, by Weight[4]

Fuel	Component (percent)							Heating Value
	Carbon	Hydrogen	Oxygen	Nitrogen	Sulfur	Ash	Moisture	Btu/lb
TDF	83.87	7.09	2.17	0.24	1.23	4.78	0.62	15,500
Clarifier Sludge	4.86	0.49	2.17	0.47	0.26	3.16	88.69	924
Coal	73.92	4.85	6.41	1.76	1.59	6.23	5.24	13,346
Wood Waste								
Test 1	30.98	3.16	23.33	0.13	0.04	1.31	41.05	5,225
Test 2	28.29	2.37	20.95	0.13	0.03	1.49	46.73	4,676
Test 3	25.67	2.54	19.17	0.12	0.03	1.11	51.36	4,031
Test 4	24.71	2.44	18.46	0.12	0.02	1.13	53.12	4,233

Table 1-3. Comparative Composition and Fuel Value of Various Tire Types[5]

Tire Stock	Heating Value (Btu/lb)	Components, Wt%						
		C	H_2	O_2	N_2	S	Ash	Fl
Fiberglass belt	13,974	75.8	6.62	4.39	0.2	1.29	11.7	<0.02
Steel belted	11,478	64.2	5.00	4.40	0.1	0.91	25.2	<0.02
Nylon	14,908	78.9	6.97	5.42	<0.1	1.51	7.2	<0.02
Polyester	14,752	83.5	7.08	1.72	<0.1	1.20	6.5	<0.02
Kevlar Belted	16,870	86.5	7.35	2.11	<0.1	1.49	2.5	<0.02

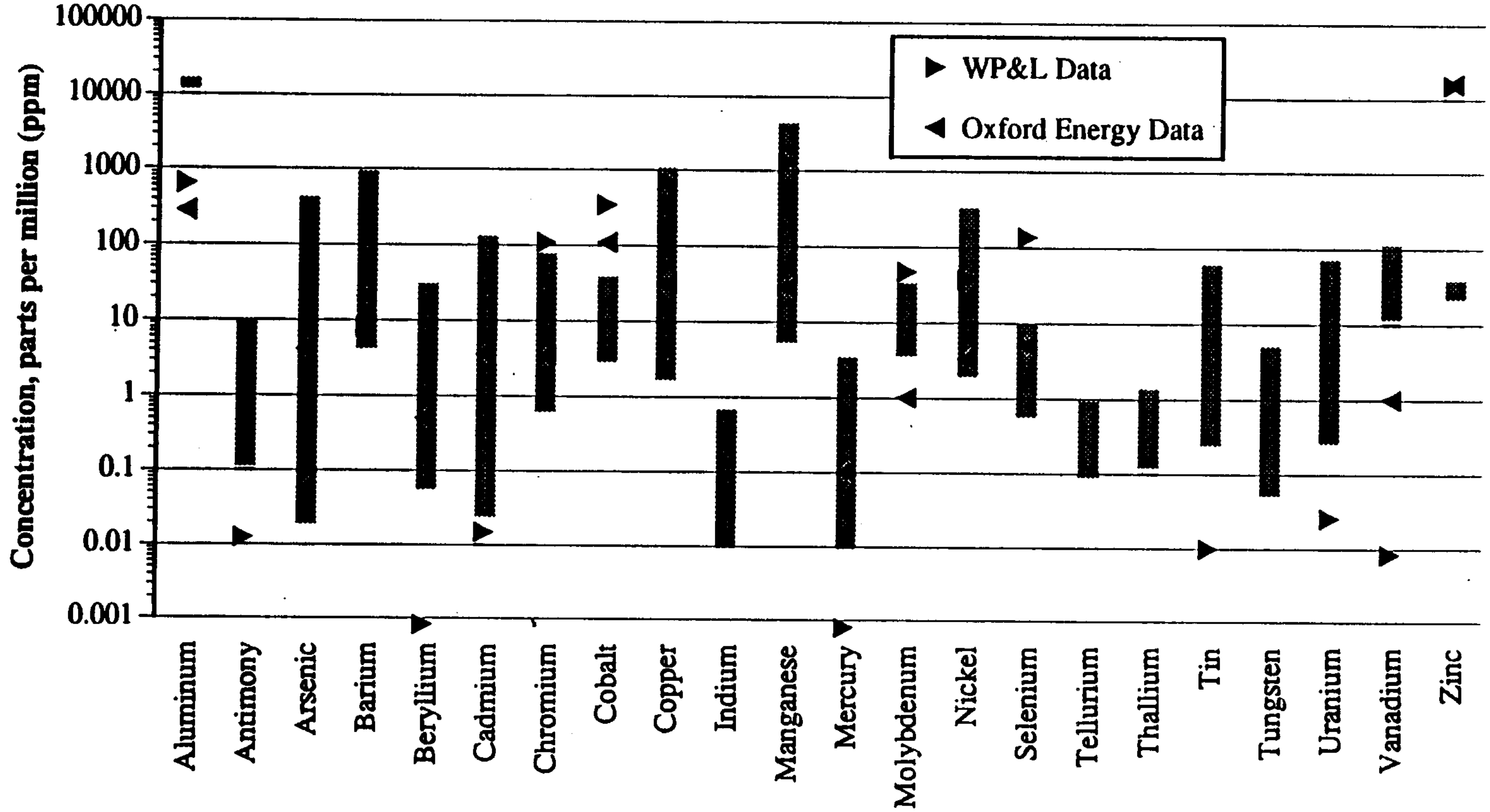


Figure 1-1. Trace metal levels in whole waste tires compared to bituminous coal.[5]

NOTE: Tick marks indicate measured waste tire metal concentrations. Bar shows the range in trace metal concentrations measured in bituminous coal.

come from existing piles, in which the tires are often old and very dirty. TDF must be purchased from a tire-shredder, or shredded on-site using purchased or leased equipment.

Energy required to produce smaller sizes of rubber pieces increases exponentially.[7] For example, about 40 Btu's are required to produce one pound of 6-inch TDF, while 750 Btu's are required to produce a pound of 1-inch TDF.[7] From a general cost perspective, 2-inch TDF, wire-in TDF, can cost as little as $20/ton, whereas crumb rubber (wire-free, from 20-30 mesh) averages $160/ton.[7] Capital costs, of course, vary according to capacity. A shredder that can chip 100 tires/hr into 2-inch TDF costs about $50,000; larger machines (1000 tires/hr capacity) can cost $500,000.[7]

Haulers may be paid from $0.35 to $5.00 to dispose of whole tires.[1] In general, the cost to landfill whole tires is double the cost to landfill mixed municipal solid waste. The rate charged for landfilling whole tires depends on the quantity of tires being landfilled and the region of the country. For small quantities, landfill fees range from $2 to $5 per truck tire.[1] One survey in Illinois found that, in 1990, Chicago-area landfills charged an average of $2.98 to landfill each passenger tire.[7] For large quantities, tipping fees range from $35 to $100 per ton for whole tires. In some instances, a landfill's bad experience with whole scrap tires have led to a ban on the tires.

Shredding companies charge from $19 to $75 per ton to form TDF.[1] Many States and municipalities allow landfilling of shredded tires, but not whole tires. In States where landfill space is at a premium, and tire tipping fees are high, landfilling shredded tires can result in a considerable savings over disposing of the tires whole.[1]

One TDF supplier has found that pulp and paper mills are the most profitable (i.e., purchase the most expensive type of TDF) type of customer, followed by cement plants and utility boilers.[8] Pulp and paper mills pay a higher price for TDF for several reasons. First, the pulp and paper mills demand a higher quality of shredded tire; that is, tires that are clean and have all the metal removed.[8] Second, they do not have the fuel-buying power that a utility might have; thus, tires provide a proportionally larger economic incentive for them.[8] One pulp and paper mill was paying approximately $39 and $43/ton for TDF in 1990 and in part of 1991, respectively.[9]

Cement manufacture is a power-intensive process, which allows cement companies to buy fuel in bulk and obtain the fuel at a somewhat lower price. Also, kiln feed mechanisms are easily modified, to accept alternate fuels. Further, because temperatures in a kiln reach 2700°F, kilns can burn poorer quality coal than pulp and paper mills or even utilities, and can easily tolerate a wide variety of waste products.[10] In addition, kilns can accommodate the lower priced TDF (wire-in TDF and even whole tires). These factors make the economics of supplying TDF to cement manufacturers less favorable than for pulp and paper mills.[10] One cement manufacturer is paying approximately $30/ton for TDF.[11]

Utilities have the least economic incentive to use tires.[8] Often, power plants that use TDF only substitute up to 5 percent of their total energy requirements with TDF. Utilities must buy better quality coal (i.e., higher heat value and lower ash) than cement plants, but have significant bulk fuel-buying power. They are not usually interested in TDF unless the price is $1 per million Btu's (MMBtu's) ($30-$31 per ton) or less.[8] The use of petroleum coke has recently been increasing in the utility industry, partially in response to the reduced demand for coke in the depressed steel industry.[10] Coke often costs from $0.50 to $0.75/MMBtu ($14 to $21 per ton), which is difficult for TDF to match in many regions.[10]

Regional economics of TDF are paramount. Electric Power Research Institute (EPRI) created a computer model of TDF use in a cyclone-fired boiler. The model included an economic analysis of alternative fuel firings to account for the fact that, if boiler efficiency decreases, the company would need to purchase power to replace power lost by the boiler derating.[12] These costs are called "busbar power costs".[12] Even considering the decrease in the net heat rate caused by TDF use, the model found that TDF provided overall savings in levelized busbar power costs relative to 100 percent coal-firing.[12]

1.2.3 Air Pollution Emissions Issues

The principal concern when using tires for fuel is the effect on emissions. Pollutants of particular concern include criteria pollutants, particulates, metals, and unburned organics.

Particulate emissions may increase if combustion is not complete. As seen in Tables 1-2 and 1-3, sulfur emissions may decrease if the tires or TDF replace higher sulfur coal, but may increase if tires or TDF replace wood waste containing little sulfur. NO_x emissions, likewise, may increase or decrease based on the relative nitrogen content of the fuel. Also, NO_x emissions may increase if additional excess air enters the combustion system to facilitate the feed of the tires or TDF.

Heavy metal content varies in tires and TDF relative to coal as shown in Figure 1-1. In particular, zinc, which is added to tires during rubber compounding to control the rate of vulcanization, has the potential to increase from an emissions standpoint.[13]

Organics, especially polynuclear aromatic hydrocarbons, were measured at a number of facilities. Dioxin and furan formation are also of concern because of their toxic nature.

The two main process units burning TDF and tires are kilns and boilers. Kilns are usually controlled by electrostatic precipitators (ESP's) or fabric filters. Boilers are usually controlled by venturi scrubbers or ESP's, although some are uncontrolled.

A recent EPA report characterized the emissions from the simulated open burning of scrap tires under experimental conditions.[14] The report identified several pollutants of potentially significant health concern from uncontrolled scrap tire fires, including benzo(a)pyrene, benzene, lead, zinc, and numerous aromatic organic compounds.[14] Environmental concerns identified by the report included leaching of metals present in the ash to groundwater systems and localized problems resulting from high SO_2 emissions.

1.3 MARKETS FOR TIRES AS FUEL

Applications that can burn whole tires include a few cement kilns, large dedicated tires-for-fuel boilers, and some experimental applications in utility boilers. Applications that can use TDF include most cement kilns, many thermal decomposition units, boilers at pulp and paper plants, utility plants, and other industrial facilities.

As described in more detail in subsequent chapters, the desirability of tires or TDF varies among each industry. Often that advantage is regionally specific, because the incremental benefit of tires is tied to regionally comparative fuel prices.

The U.S. Environmental Protection Agency's Office of Solid Waste recently produced a report entitled "Markets for Scrap Tires", which summarizes the barriers to development of TDF markets for dedicated tire-to-energy facilities, other utility facilities, the cement industry, the pulp and paper industry, and pyrolysis facilities. Table 1-4 summarizes the reported barriers.

1.4 STATE WASTE TIRE DISPOSAL PROGRAMS

As of January 1991, 33 States had laws or regulations pertaining to disposal of waste tires. Other States introduced waste tire measures in their respective 1991 State legislatures. Nine States remain with no legislation passed or pending.[15]

Table 1-5 shows the status of waste tire disposal laws for States with laws, and summarizes some features of the measures.[15] Table 1-6 lists States with laws or regulations proposed and those with no planned laws or regulations. Many States have provided funding for reasons such as developing scrap tire recycling industries and administering disposal programs. Funds also are dedicated to increasing tire or TDF market incentives by methods such as allowing price preferences when purchasing recycled and recyclable goods, or to give priority status to businesses proposing to expand use of tire derived material. Table 1-5 also lists which regulations cover storage, processing, or transportation of tires.[15]

Of the 33 States with either laws or regulations in place, over half (18) include market incentives for tire use, such as a monetary rebate, grant, loan, or funds for testing.

Table 1-4. Market Barriers to TDF Use[1]

Industry	Economic Barriers	Non-economic barriers
Dedicated Tire-to-energy	1. Cost of air pollution equipment.	1. Siting.
Power Industry	1. Low utility buy-back rates for electricity in many regions of the U.S. 2. Low tipping fee in many regions.	1. Siting.
Cement	1. Handling and feeding capital costs. 2. Low cost of alternate fuels. 3. Expense and downtime in environmental permitting process.	1. Delay in environmental permitting procedures.
Pulp and Paper Mills	1. Wire-free TDF is expensive. 2. Handling costs. 3. Low alternate fuel cost.	1. Wire in TDF can plug some hog fuel boilers. 2. Wire can limit ash market. 3. Higher PM emissions than for hog-fuel alone. 4. Use of new fuel often requires reopening of environmental permits.
Pyrolysis Facilities	1. Capital and operating costs. 2. High cost for upgrading char by-products.	1. Upgrading char needs to be commercially demonstrated on a sustained basis.

Table 1-5. Waste Tire Disposal Laws in the U.S.[15]
January 1991

State	Regulatory Coverage[a]	Funding Source	Market Incentives	Landfill Restrictions	Air Emissions Related Comments
AZ	P	2% sales tax on retail sale		bans whole tires	
CA	S,P	$.25/tire disposal fee	grants		Report from Integrated Waste Management Fund due 12/1/91 on feasibility of tire use in cement kilns, pulp and paper, and other operations.
CO	S,P				
CT	S				
FL	S,P,H	$1/tire retail sales	R&D grants	tires must be cut	
IL	S,P.H	$.50/vehicle title	grants/loans		Funding 5 TDF test burns in 1991; IL pays 90% of test cost (Reference 7). Low interest loans to fuel users to retrofit or improve equipment.
IN	S	permit fees/tire storage sites	grants	tires must be cut	Funding 5 TDF test burns in 1991 pays 90% of test cost (Reference 7). Low interest loans to fuel users to retrofit or improve equipment.
IA				bans whole tires	Waste tire abatement report recommends use of TDF at the 3 State Universities.
KS	S,P,H	$.50/tire retail sales	grants	tires must be cut	
KY	S	$1/tire retail sales		tires must be cut	
LA	S			tires must be cut	
ME	S,P, H (draft)	$1/tire disposal fee			
MD	S,P,H	State budget appropriations			
MI	S,P,H	$.50/vehicle title fee	grants		
MN	S,P,H	$4/vehicle title transfer	grants	bans whole and cut tires	
MO	S,H	$.50/tire retail sales	funds/testing	bans whole tires	
NE		$1/tire retail sales			

Table 1-5. (Concluded)

State	Regulatory Coverage[a]	Funding Source	Market Incentives	Landfill Restrictions	Air Emissions Related Comments
NC	S,P,H	1% sales tax on new tires	funds county tire collection	tires must be cut	
NH	S	town graduated vehicle registration fee			
OH				tires must be cut	
OK	S,P	$1/tire surcharge new tire sales	grants	tires must be cut	
OR	S,P,H	$1/tire disposal tax on new tire sales	$.01/lb	tires must be cut	
RI	S,P	$.50/tire tax on new tire sales			Law bans tires as a source of fuel within State, within 30 mile of any reservoir watershed, and bans tire export outside State as a fuel source.
SD	S,P			tires must be cut	Open burning banned except in areas with populations under 5,000.
TN				bans whole tires	
TX				bans whole tires	
UT		graduated tax per tire size	$20/ton		
VA		$.50/tire disposal fee on new tire sales	funds/testing		Several State subsidized tests of TDF and whole tires.
VT					
WA	S,P,H	$1/vehicle registration	grants		
WI	S,P,H	$2/tire per vehicle title fee	$20/ton	tires must be cut	Tires have been burned at 4 facilities in WI.
WV					
WY					

[a] S = Storage regulations
P = Processor regulations
H = Hauler regulations

Table 1-6. States Without Laws or Regulations for Waste Tire Disposal[15] January 1991

State	Status	Legislative Comments	Air Emissions Related Comments
AK	Proposed		
AR	Proposed		
MS	Proposed		
NY	Proposed		NY also has environmental conservation law with section that regulates tire transportation.
SC	Proposed		
AL	None	Solid waste management plan under development	
DE	None	No legislation	
GA	None	1990 Comprehensive Solid Waste Management plan has no stated tire disposal requirements.	
HI	None	Draft statewide solid waste management plan does not address tires.	Honolulu County plans a scrap tire management program that would provide for tire shredding for sale to Honolulu Power.
ID	None	Proposed bill to require State solid waste planning encourages general recycling.	
NV	None	Solid waste plan before legislature does not mention tires.	
NJ	None	1987 Recycling Act has tire recycling incentives, but no restrictions.	
ND	None	No legislation.	
PA	None	Two waste tire bills introduced in last years; neither resulted in legislation. No plans for 1992.	

[a] S = Storage regulations
P = Processor regulations
H = Hauler regulations

The law in one State, Rhode Island, bans tire burning as a source of fuel within the State and within 30 miles of reservoir watershed.[15] Furthermore, it bans tires exported from the state to be burned as fuel.[15] South Dakota regulations, on the other hand, permit open burning in areas with populations under 5000.[15]

1.5 METHODOLOGY

First, a literature search was conducted to gather information on pyrolysis and burning tires for fuel and to identify companies using tires or TDF in their process. Information was gathered on emissions, control techniques required, control technique effectiveness, and control equipment cost.

Second, information was gathered through contacts with EPA Regional, State, and local air pollution control agencies. Copies of emission test results were requested and analyzed to determine the effect of burning tires either as the sole fuel or as a supplemental fuel. Permit applications and permits were reviewed to determine the processes using tires, the control techniques used, the limits set, and the permit conditions under which the permits were approved. Trade associations provided information on companies burning tires, and other available information.

Third, site visits were planned to facilities burning tires or TDF. Six companies, one from each major industry group using tires for fuel or pyrolysis, were selected for site visits. The facilities visited included the following:

- An electrical generating plant using tires as its only source of fuel
- An electrical generating plant using tires to supplement their primary fuel

- A cement manufacturer using tires to supplement its primary fuel in a wet process cement kiln
- A cement manufacturer using tires to supplement its primary fuel in a dry process cement kiln
- A paper mill using tires to supplement their fuel in a waste heat boiler
- A pyrolysis plant thermally decomposing tires into products.

In addition, a facility that shredded whole tires into TDF was visited. At each site, information was collected on the processes using tires, modifications necessary to accommodate tire use, control equipment in use, effect of tire use on emissions, control equipment effectiveness, cost of process and control equipment changes, changes in personnel or resource needs, and benefits of tire use. Problems using tires, and tire supply issues, such as source, quality, and reliability, were also discussed.

1.6 REFERENCES

1. U.S. Environmental Protection Agency, Office of Solid Waste. Markets for Scrap Tires. EPA/530-SW-90-074B. September 1991.

2. Scrap Tire Management Council. Scrap Tire Use/Disposal Study. September 11, 1990. p. 1-4

3. Murphy, M.L. Fluidized Bed Combustion of Rubber Chips: Demonstration of the Technical and Environmental Feasibility. Energy Biomass Wastes. 11:371-380. 1988.

4. Jones, R.M., J.M. Kennedy, Jr., and N.L. Heberer. Supplementary Firing of Tire-Derived Fuel (TDF) in a Combination Fuel Boiler. TAPPI Journal. May 1990.

5. Pope, K.M. Tires to Energy in a Fluidized Bed Combustion System. Presented at EPRI Conference: Waste Tires as a Utility Fuel. San Jose, CA. January 28, 1991.

6. Wisconsin Power and Light. The Operational and Environmental Feasibility of utilizing Tires as a Supplemental Fuel in a Coal-Fired Utility Boiler Preliminary Report. State of Wisconsin. 1990 Waste Tire Management and Recovery Program.

7. Berger, C., Illinois Scrap Tire Management Study Summary. Illinois Department of Energy and Natural Resources. Presented at the EPRI Conference: Waste Tires as a Utility Fuel. San Jose, CA. January 28, 1991.

8. Memorandum from Clark, C., Pacific Environmental Services, Inc. (PES), to Michelitsch, D., EPA/ESD/CTC. October 2, 1991. Site Visit -- Waste Recovery, Inc.

9. Memorandum from Clark, C., PES, to Michelitsch, D., EPA/ESD/CTC. October 2, 1991. Site Visit -- Smurfit Newsprint Corp.

10. Schwartz, J.W., Jr. Engineering for Success in the TDF Market. Presented at the Recycling Research Institute's Scrap Tire Processing and Recycling Seminar, West Palm Beach, FL. April 27, 1989.

11. Memorandum from Clark, C., PES, to Michelitsch, D., EPA/ESD/CTC. October 28, 1991. Site Visit -- Calaveras Cement Company.

12. McGowin, C.R. Alternate Fuel Co-Firing with Coal in Utility Boilers. Presented at the EPRI Conference: Waste Tires as a Utility Fuel. San Jose, CA. January 28, 1991.

13. Gaglia, N., R. Lundquist, R. Benfield, and J. Fair. Design of a 470,000 lb/hr Coal/Tire-Fired Circulating Fluidized Bed Boiler for United Development Group. Presented at EPRI Conference: Waste Fuels in Utility Boilers. San Jose, CA. January 28, 1991.

14. U.S. Environmental Protection Agency: ORD:AEERL:CRB. Characterization of Emissions from the Simulated Open Burning of Scrap Tires. EPA-600/2-89-054. October 1989.

15. Recycling Research Institute. Third Annual Legislative Update. The Scrap Tire News. Vol. 5, No. 1. January 1991.

2. OVERVIEW OF PROCESS UNITS BURNING TIRES FOR FUEL

Controlled burning of tires or TDF for fuel value occurs most frequently in two types of process units - kilns and boilers. This chapter will describe the general process operation of cement kilns and boilers. The various types of boiler configurations will be described with attention to the implications for burning tires or TDF. Kilns in two industries have burned tires or TDF supplementally - lime manufacturing and, more commonly, cement manufacturing.

Currently, in the U.S., a few boilers operate by burning solely whole tires or TDF, all in the electric utility industry. These are discussed in Chapter 3, Dedicated Tires-to-Energy Facilities. Chapter 4, Tire and TDF Use in Portland Cement Kilns, discusses in more detail the use of TDF in lime and cement kilns.

Most often, boilers burn tires or TDF as a supplemental fuel for either coal, gas, refuse-derived-fuel (RDF), or wood waste. The two industries where supplemental use of TDF is most prevalent are electric utilities, where the primary fuel is most often coal, and pulp and paper mills, where the primary fuel is most often wood waste, also known as hog fuel. These industries are discussed further in Chapter 5, TDF Use in Waste Wood Boilers, and Chapter 6, Tires as Supplemental Fuel in Electric Utility Boilers.

Finally, several other industrial processes have tested or used TDF as a supplemental boiler fuel to coal or RDF. These include plants that manufacture chemicals, glass, grain, steering and gear manufacturing, and tractors. These other industrial processes are grouped together, and are discussed in Chapter 7, Supplemental TDF Use in Other Boiler Applications.

2.1 KILNS

Rotary portland cement kilns can use TDF or whole tires as supplemental fuel. Kilns are large cylinders that tilt slightly downward to one end and rotate slowly, so that feed materials travel to the far end by gravity.[1] Fuel is generally fired at the lower end, so that the hot gases rise upward through the kiln, passing countercurrent to the descending raw feed material.[1] As feed travels down the kiln, water is evaporated, and a chemical reaction occurs by which the feed changes to a rock-like substance called clinker. Clinker is cooled after exiting the kiln, and then ground with gypsum to make cement.[1] Under normal operation, no solid waste such as ash or slag exits the kiln; all raw feed and fuel components are incorporated into the clinker. Even if the kiln is upset, the out-of-specification clinker that results can often be reground and recycled to the kiln. Details of the cement process and environmental impacts are presented in Chapter 4.

When whole tires are used as supplemental fuel in cement manufacture, they generally enter the process at the upper feed end of the kiln. Depending on the specific process flow at a facility, TDF can be added at the feed end, at the lower (firing) end, or in a raw feed preheater/precalciner that is located before the raw feed entrance. These options are described in more detail in Chapter 4, Tire and TDF Use in Portland Cement Kilns.

2.2 BOILERS

The type of boiler configuration and firing method significantly affect the success of burning tires or TDF. This section serves to summarize the implications of burning TDF in several boiler configurations most common in the industry at this time.

Coal fuel in boilers is primarily combusted by suspension firing or by grate firing. Boiler configurations that combust fuel in suspension include the fluidized bed and the cyclone types. Combustion occurs primarily on the grate in underfed stoker boilers. Combustion happens both in suspension and on the grates in spreader stoker type boilers, depending on the fuel size and the grate type, i.e., traveling, reciprocating, or chain.

TDF is difficult to burn in suspension because of its size and weight. Some industrial experience exists burning TDF in pulverized, cyclone, and spreader/stoker boilers. One utility tested whole tires in a pulverized boiler. Recently, much interest and some TDF testing has focused on TDF use in fluidized bed boilers, where fuel is suspended in a hot bed of inert material.

Metal contained in tires can cause operational difficulties. If whole tires or TDF, wire-in, is used, the wire must be removed from the grate or bed. Wire that becomes trapped on the grate can become molten and plug grate holes vital to incoming combustion air.[2] Small pieces of radial mat-type wire can form "bird-nest" shaped accumulations that block conveyor joints, slag exit points, and augers.[2] Further, facilities selling the slag that results from combustion may need to separate the metal from the slag to maintain a salable product. One facility quenches their slag into small beads, which they sell. Because buyers could not tolerate the heavy sharp bead wire, the company installed a magnetic separator to remove the wire. Other facilities have decided that wire-free TDF is mandatory.[3,4]

Zinc content of the tires may be an issue, also. Boilers that combust fuel in suspension typically maintain a higher chamber temperature (2000°F) than those that combust on a grate (1600-1650°F). At 2000°F, zinc compounds from the TDF may be fairly volatile.[5] Zinc oxide crystals could condense onto the slag or ash surface in cooler areas, in which case the zinc could leach later from a landfill and cause the groundwater to exceed health standards.[5] Zinc, however, could also be trapped in the glassy melt, from which it would not be leachable.[5]

The following sections describe each boiler type and summarize its operation with and without TDF.

2.2.1 Pulverized Coal Boilers

In a pulverized boiler, the coal is ground to the consistency of talcum powder in a mill, and then entrained in an air stream that is fed through the burners to the boiler combustion chamber.[6] Firing, therefore, occurs in suspension. Pulverized boilers can be wet-bottom, which means that coals with low ash fusion temperatures are used, and molten ash is drained from the bottom of the furnace, or can be dry bottom, which means that coals with high ash fusion temperatures are used, and dry ash removal techniques can occur.[6]

The ash fusion temperature is the temperature the ash particles begin to melt and agglomerate; fused ash causes plugging of the holes in the grate, and can cause significant damage to the boiler. Therefore, a higher ash fusion temperature means fewer ash problems. However, the iron content in TDF tends to lower the fusion temperature of the ash. In some cases, therefore, a higher quality coal with a higher fusion temperature may be required to counteract the effect of the TDF.

Because pulverized coal boilers are designed to burn fuel in suspension, small TDF are typically used.[7] TDF is often a maximum of 1-inch in diameter, but can be as small as 1/4-

inch.[7] Even so, pulverized coal boilers must often be modified with a bottom dump grate, so that the TDF that falls to the bottom can combust.[7] One utility is testing whole tires in a pulverized coal boiler.[8] This is described in more detail in Chapter 6.

The Electrical Power Research Institute (EPRI) created a computer model to evaluate co-firing three alternate fuels with coal in a 50 MW pulverized unit, retrofitted to accommodate feeding of the alternate fuels.[7] The particulate emissions from the boiler were assumed to be controlled by an ESP. The model assumed that TDF were 1-inch maximum in size, wire-free, and that the percent TDF varied from 0 to 100 percent. The boiler was assumed to require modification of receiving, storage, and pneumatic transport equipment, and installation of a bottom dump grate to ensure complete combustion of larger pieces.[7] The results showed that TDF, co-fired with coal, does not significantly affect boiler performance.[7] Boiler efficiency did decrease and net heat rate did increase with increased percent TDF, because the higher excess air that was required more than offset benefits of higher heat and lower moisture of the TDF as compared to coal.[7] Although EPRI did model TDF input up to 100 percent, the paper noted that, in reality, 20 percent TDF might be the limit in most boiler configurations because of boiler limitations on fuel or performance.[7]

2.2.2 Cyclone Boilers

Cyclone boilers, like wet-bottom pulverized coal units, burn low ash fusion temperature coal, but the coal is crushed so that 95 percent is smaller than 1/4 inch.[9] The coal is fed tangentially to the cyclone burners, which are mounted horizontally on the outside of the boiler and are cylindrical in shape.[9] A typical cyclone burner is shown in

Figure 2-1.[10] Small coal particles are burned in suspension, but larger particles are forced against the outer wall. The resulting slag is mostly liquid because of the high radiant temperature and low fusion temperature, and is drained from the bottom of the furnace through a tap.[6] Cyclone furnaces are most common in utility and large industrial applications.

Because most of the ash is removed as molten slag, addition of a bottom grate is not necessary.[7] However, small TDF is required, because much of the combustion must occur in suspension.[7] TDF that is too large to combust completely can get carried over into the boiler or dust collection system, and cause blockage problems.[9] Therefore, particle size may inversely determine the amount of TDF that can be used in a cyclone boiler.[11] Three cyclone-fired boilers at utilities have burned 1" x 1" TDF in test operation, one at the 2 percent, one at the 5 percent, and one at up to a 10 percent level.[3,9,12] One pulp and paper mill plans the use of TDF in a cyclone-fired hog-fuel boiler.[13]

2.2.3 Stoker Boilers

In stoker boilers, fuel is either dropped or rammed onto a grate. Stoker boilers are identified by the type of feed mechanism and the type of grate. Feed may be by spreader, overfeed, or underfeed. Grates may be travelling, reciprocating, chain, or dump type.

Approximately 12 stoker boilers are burning TDF supplementally on a commercial basis, all in the pulp and paper industry (see Chapter 5). One industrial stoker boiler at a tractor factory is testing TDF use. Five of these 13 are underfeed stokers, and 8 are spreader stokers. Of the spreader stoked boilers, 2 are reciprocating grates, 2 are travelling grates, and 4 are of unknown grate type.

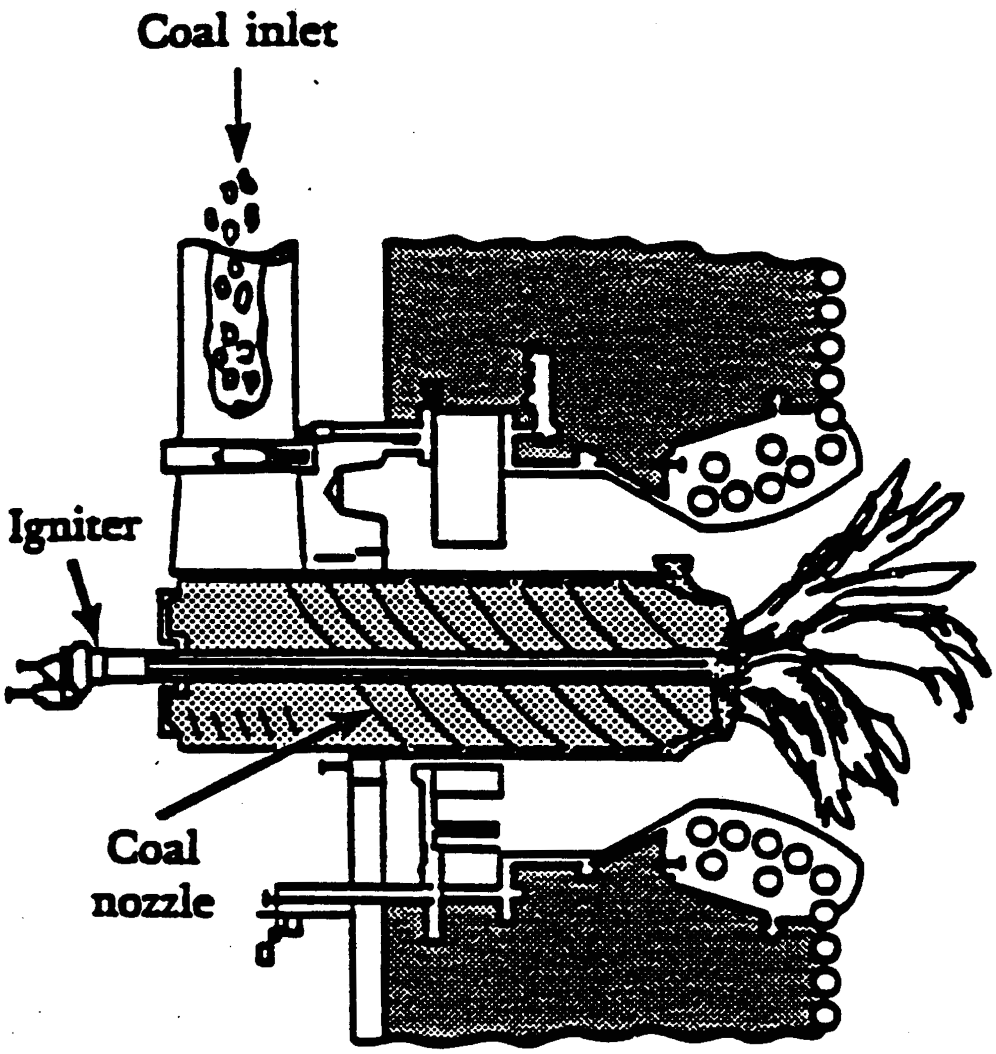


Figure 2-1. Typical cyclone coal burner.[10]

2.2.3.1 Spreader Stoker Boilers. The large majority of boilers used to combust waste wood, or hog-fuel, are of the spreader stoker type. The term "spreader" refers to the type of fuel feeder used. A typical mechanical feeder on a spreader stoker is illustrated in Figure 2-2. A spreader stoker feeder imparts energy to a stream of crushed coal being fed to the furnace.[6] Fuel drops from a hopper through a slot onto a flipping mechanism, often a wheel.[2] Material hitting the wheel is propelled onto the grate.[2] Because size of the fuel pieces affects how far the piece is thrown by the wheel (larger pieces are propelled further than smaller pieces), uniform coverage of the grate by the fuel occurs.[12] Some combustion occurs in suspension, and some occurs on the grate. This type of combustion produces ash that retains significant carbon content, and flyash reinjection is common.

Spreader stoker boilers can have traveling grates, reciprocating grates, or dump grates.[6] A traveling grate travels toward the feeder, and fuel on the grate is burned with air coming through the grate. Large fuel pieces fall quickly to the grate. Mid-sized pieces fall more slowly and often land on top of larger pieces. The fines are caught in the air up-draft, and are burned while suspended in air. Ash is dumped at the end of the hearth, and is collected in an ash pit below the grate.[6] A reciprocating, or vibrating, grate is comprised of bars that resemble a series of steps sloping downward that move back and forth, pushing the burning material through the boiler. This provides air flow above and below the hearth. Ash and other materials may fall through the grate to hoppers or be dropped in hoppers at the end of the grate. Reciprocating and traveling grates are continuously cleaned of ash. A dump grate does not have continuously moving parts, and simply dumps ash at intermittent intervals to a hopper. All these grates must maintain a constant covering of ash or fuel, because exposed

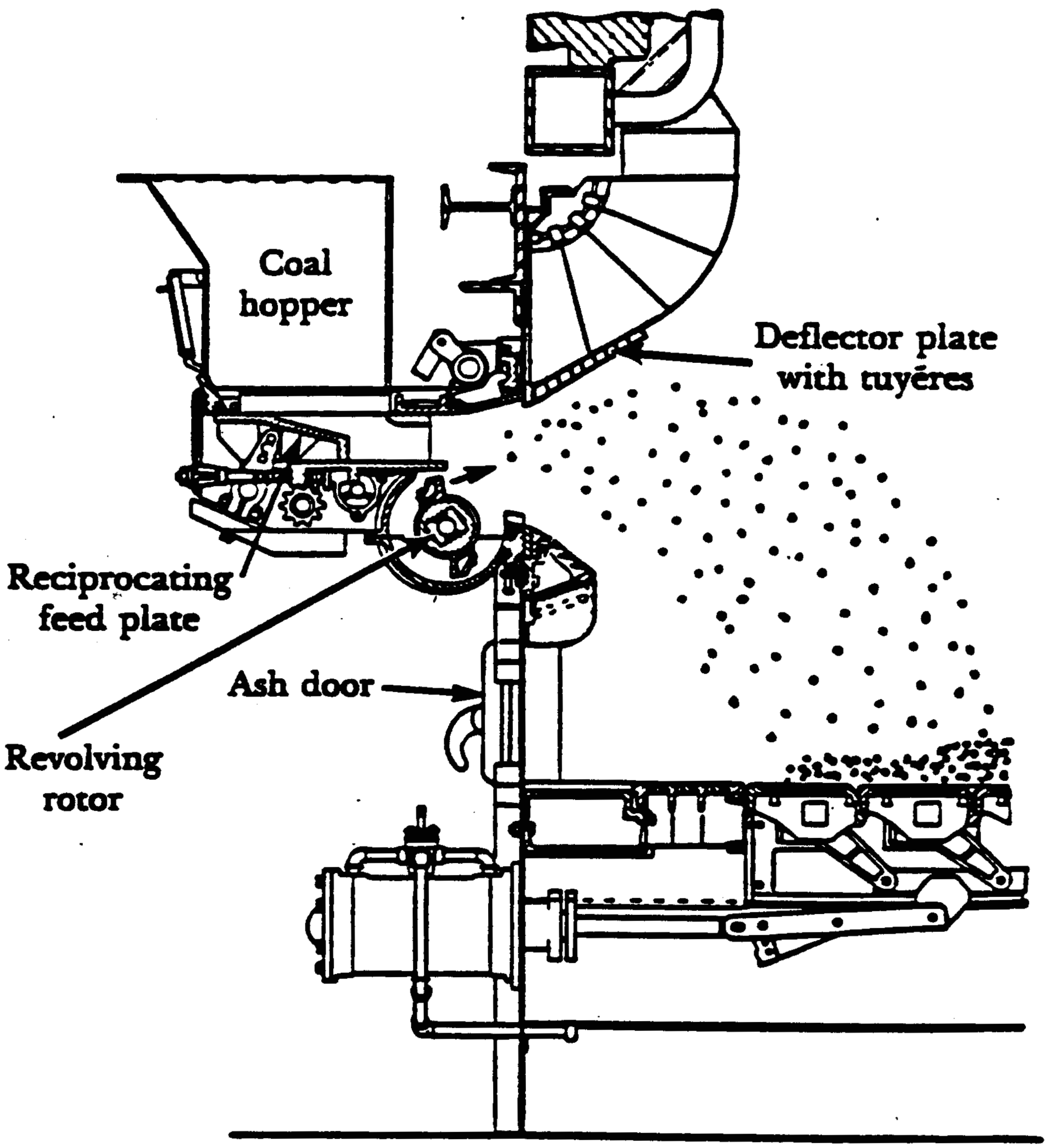


Figure 2-2. Typical mechanical feeder on a spreader stoker.[10]

grate metal can be damaged by direct contact with the heat.[6] Therefore, proper fuel sizing is imperative so that good distribution of coal and ash on the grate results. Cooling from the combustion air passing through the grate protects the grate as does the insulating effect of the coal/ash layer on top.[6]

To burn TDF successfully in a spreader/stoker furnace, the particle size of the chipped tires must be slightly smaller than the largest coal or wood size permitted so that the TDF falls on top of a layer of primary fuel. Theoretically, a bed of large fuel pieces is created on the grate, covered with a layer of mixed TDF and smaller fuel pieces. If TDF is in direct contact with the grate, oils from the rubber would flow into the grate openings, carbonize, and plug the grate. The size of TDF can be 2 to 4 inches in diameter.

2.2.3.2 <u>Overfeed Stoker Boilers</u>. Coal combusted in overfeed stoker boilers is fed from above onto a traveling or chain grate, and burns on the fuel bed as it progresses through the furnace. Ash falls into a pit at the rear of the stoker.[6] The same TDF issues apply as were mentioned under spreader stoker boilers.

2.2.3.3 <u>Underfeed Stoker Boilers</u>. In underfeed boilers, fuel is pushed by rams or screw conveyors from underneath the grate into the furnace through a channel, or retort, and spills out of the channel onto the grate to feed the fuel bed. As the fuel is pushed further from the center channel, it combusts, and ash falls over the peripheral sides of the grate into shallow pits.[6] Some underfeed stokers have only one retort, but double retorts exist with side ash dump, as do multiple retort units with rear ash discharge. Heat loss and maintenance costs are higher for this type of stoker.

2.2.4 Fluidized Bed Boilers

A fluidized bed combustion system (FBC) is one that has a high temperature (1500°F to 1600°F) inert material, such as sand, ash, or limestone, occupying the bottom of the chamber.[14] Figure 2-3 illustrates a typical fluidized bed boiler. Limestone, either as primary bed material, or as an addition, provides the additional advantage of SO_2 scrubbing.[14,15] The advantage of fluidized bed combustion over the other 3 boiler types is that the fluidization of the inert bed material allows fuels with higher moisture and ash content to be burned, and still yield nearly complete combustion. Further, SO_x control is easily and efficiently accomplished. The bed material is fluidized by one of two methods as described below.

In a bubbling FBC, incoming combustion air enters the chamber through nozzles located a couple of feet below the surface of the bed, producing a violent boiling action.[14] Fuel is pneumatically injected into the chamber and is suspended by this action.[14] Combustion occurs partially in suspension and partially in the bed. The bed material continually scrubs the outside layer of ash from the fuel, exposing fresh combustible material for burning.[14] Dense materials, like rocks and metal sink to the bottom of the sand, where a line-bed changeout system continually pulls this bottom layer out.[14] The removed material is cooled, magnets pull out the metal, and screens retain rocks or other tramp debris. Bed material is then returned to the combustor.[14]

In a circulating FBC system, the bed is fluidized by air passing through a wall-mounted distributor.[15] Combustion occurs in the same way as in the bubbling FBC. Bed material is gravity fed down into the bed.[15] Fuel is fed into the

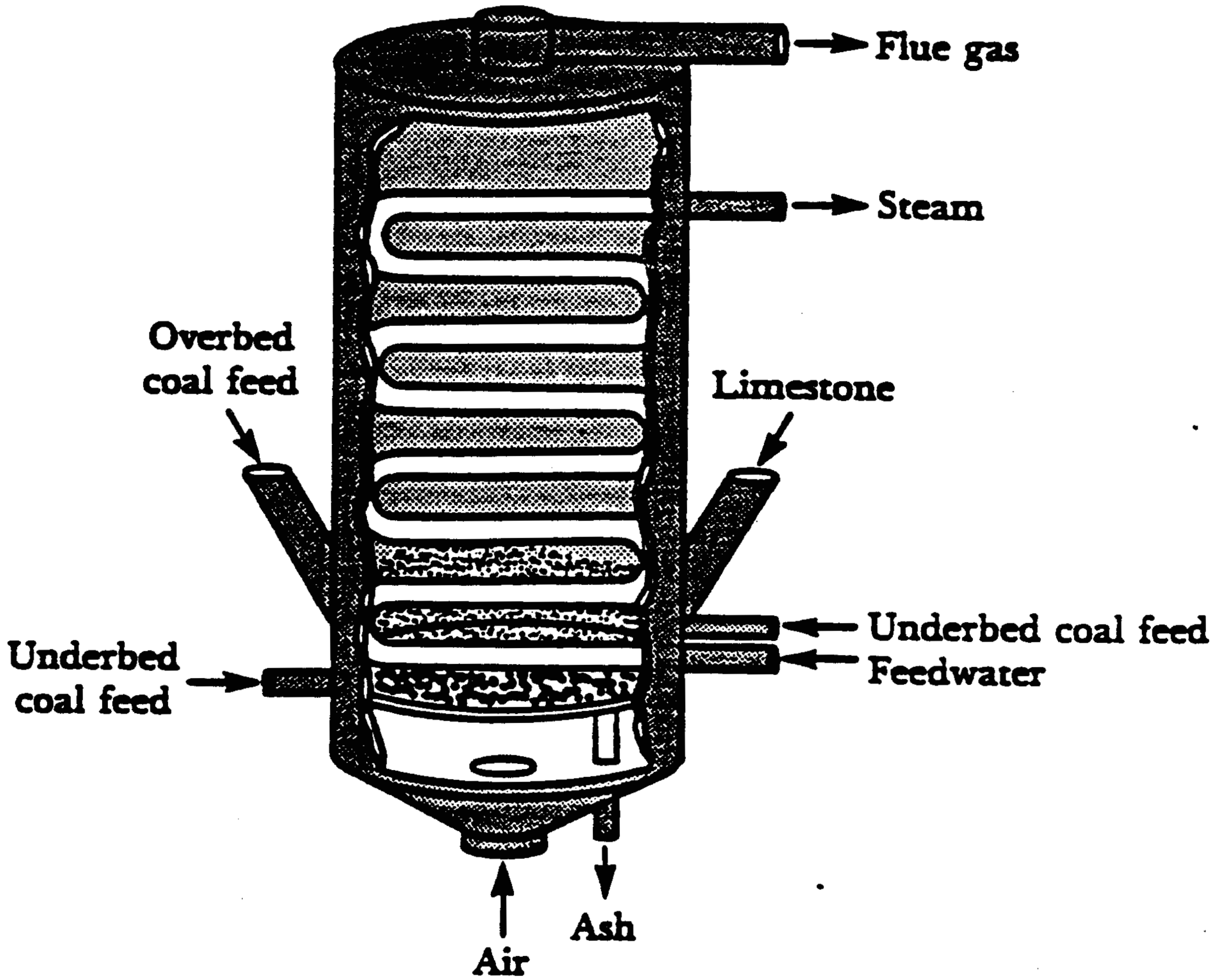


Figure 2-3. Typical fluidized bed boiler.[10]

combustion chamber by an air-swept spout.[15] The bed material, containing fuel and ash, is then circulated through a cyclone, where the lighter bed material and unspent fuel are separated from the heavier ash, metal, and other tramp material, and are recirculated back to the bed.[15]

Wire removal from the fluidized bed in both systems has been a design challenge. Wire can compose up to 10 percent of a tire's weight.[16] This wire does not change physical form in a fluidized bed boiler, and accumulates, inhibiting or even eliminating fluidization in the bed.[16] Poor air/fuel distribution results, eventually causing the system to shut down.[16]

One FBC currently operating in Japan uses a revolving-type fluidized bed that allows relatively large tire chunks (up to 10 inches) to be fed to the chamber.[4] The central portion of this bed is more fluidized than the outer portions, so solids flow to the center, where fuel is injected.[4] Deflectors above the outer bed area "lap" waves of material back to the center.[4] An air distributor directs non-combustibles to drain chutes on each side of the bed.[4] The amount of fluidizing air and overfire air is automatically proportioned by optical devices that measure furnace luminosity.[4]

One utility unsuccessfully tested TDF in a circulating FBC boiler that had been retrofitted from a spreader/stoker design.[4] Problems involved wire clogging the boiler grate openings and ash drawdown, and overload of the particulate control device. Two other FBC boilers are in the planning stages, both at utilities, and both are designed for supplemental TDF use. One is a circulating FBC design, and one is a bubbling design.[14,15]

Three pilot tests burning TDF have been performed on FBC boilers, one of a bubbling FBC boiler, and two of circulating FBC boilers. First, Energy Products of Idaho, Inc. (EPI), tested a pilot 3 ft x 3 ft. bubbling bed FBC. The test was in response to problems resulting from TDF burning in a FBC boiler retrofitted from a spreader/stoker design, and located at a Wisconsin power plant.[16] Problems during the commercial test indicated that better tramp metal removal was necessary, combustion was not adequate, and that the particulate control device, an electrified filter bed, was not commensurate with the ash levels generated.[16]

Because the utility test showed that the tramp material exit from the bed, a perforated "draw-down" cone, became clogged, EPI designed an on-line bed changeout system, which continually pulls the bottom layer of sand and wire out of the bed, cleanses it, and returns it.[14] Emission results of the pilot test burning 100 percent tires are shown in Table 2-1.[14]

A second pilot test has been performed by Pyropower, Inc., in preparation for construction of a 52 MW, 468,000 lb/hr circulating bed FBC in Niagara Falls, NY, for United Development Group.[5] Design is for the plant to burn up to 20 percent TDF, wire-free.[5] The pilot test was run on a 0.6 MW plant using from 16 to 50 percent TDF, wire-in, on a weight basis.[5] The test experienced problems with uneven tire feed and wire accumulation at ash discharge points. Lime was added to the bed to reduce sulfur emissions.[16] Calcium to sulfur ratio was about 1.7 to 2.0, and resulted in 90 percent sulfur capture.[5] Emissions of the pilot test are summarized in Table 2-1.[5]

Third, a pilot test was performed by Foster-Wheeler Development Corp., in preparation for the construction of a

Table 2-1. Emission test results of three pilot FBC boilers burning supplemental TDF[5,14,15]

	PM	NO_x	SO_2	VOC	HCl	CO
EPI, bubbling bed FBC 100% TDF[a]	-	222 ppm, 46 ppm[b]	630 ppm, 60 ppm[c]	ND[d]	0, 0[b]	30 ppm
Pyropower, circulating bed FBC 16-50% TDF	-	0.21-0.33 lb/MMBtu	0.25-0.36 lb/MMBtu[b]	-	-	0.1-0.3 lb/MMBtu
Foster-Wheeler circulating bed FBC 20% TDF, wire-in	-	0.146 lb/MMBtu	0.486 lb/MMBtu	-	-	0.116 lb/MMBtu

[a] Fuel consumption and mass flow rate were not available; therefore, pounds per million Btu's could not be determined.
[b] With ammonia spray for NO_x reduction.
[c] With lime injected into bed for SO_x reduction.
[d] Not detected.

20 MW, 200,000 lb/hr circulating bed FBC in Manitowoc, WI, for Manitowoc Public Utility.[15] The plant will be designed to accommodate coal, petroleum coke, and limited amounts of municipal waste water sludge, refuse-derived-fuel, and TDF, wire-in. The pilot test burned 20 percent (by weight), 2-inch, wire-in TDF.[15] Two parallel baghouses controlled the pilot unit.[15] Emission results of the pilot test are summarized in Table 2-1.[15]

2.3 REFERENCES

1. U.S. Environmental Protection Agency. Office of Air Quality Planning and Standards. Portland Cement Plants -- Background Information for Proposed Revisions to Standards. EPA-450/3-85-003a. May 1985.

2. Schwartz, J.W., Jr. Engineering for Success in the TDF Market. Presented at the Recycling Research Institute's Scrap Tire Processing and Recycling Seminar, West Palm Beach, FL. April 27, 1989.

3. Schreurs, S.T. Tire-Derived Fuel and Lignite Co-Firing Test in a Cyclone-Fired Utility Boiler. Presented at EPRI Conference: Waste Fuels in Utility Boilers. San Jose, CA. January 28, 1991.

4. Howe, W.C. Fluidized Bed Combustion Experience with Waste Tires and Other Alternate Fuels. Presented at EPRI Conference: Waste Tires as A Utility Fuel. San Jose, CA. January 28, 1991.

5. Gaglia, N., R. Lundquist, R. Benfield, and J. Fair. Design of a 470,000 lb/hr Coal/Tire-Fired Circulating Fluidized Bed Boiler for United Development Group. Presented at EPRI Conference: Waste Fuels in Utility Boilers. San Jose, CA. January 28, 1991.

6. U.S. Environmental Protection Agency. Compilation of Air Pollution Emission Factors, Fourth Edition, AP-42.

7. McGowin, C.R. Alternate Fuel Co-Firing with Coal in Utility Boilers. Presented at the EPRI Conference: Waste Tires as a Utility Fuel. San Jose, CA. January 28, 1991.

8. Horvath, M. Whole Tire and Coal CoFiring Test in a Pulverized Coal-Fired Boiler. Presented at EPRI Conference: Waste Fuels in Utility Boilers. San Jose, CA. January 28, 1991.

9. Stopek, D.J., A.K. Millis, J.A. Stumbaugh, and D.J. Diewald. Testing of Tire-Derived Fuel at a 560 MW Cyclone Boiler. Presented at the EPRI Conference: Waste Tires as a Utility Fuel. San Jose, CA. January 28, 1991.

10. U.S. Environmental Protection Agency. APTI Course SI:428A, Introduction to Boiler Operation. Self-Instructional Guidebook. EPA-450/2-84-010. December 1984.

11. Granger, John E. Fuel Characterization of coal/Shredded Tire Blends. Presented at EPRI Conference: Waste Fuels in Utility Boilers. San Jose, CA. January 28, 1991.

12. Hutchinson, W., G. Eirschele, and R. Newell. Experience with Tire-Derived Fuel in a Cyclone-Fired Utility Boiler. Presented at EPRI Conference: Waste Fuels in Utility Boilers. San Jose, CA. January 28, 1991.

13. Telecon. Clark, C., Pacific Environmental Services, Inc. (PES), with Bosar, L., Fort Howard Corporation, Green Bay, WI. February 27, 1991. TDF used at Fort Howard.

14. Pope, Kent M. Tires to Energy in a Fluidized Bed Combustion System. Presented at EPRI Conference: Waste Fuels in Utility Boilers. San Jose, CA. January 28, 1991.

15. Phalen, J., A.S. Libal, and T. Taylor. Manitowoc Coal/Tire Chip-Cofired Circulating Fluidized Bed Combustion Project. Presented at EPRI Conference: Waste Fuels in Utility Boilers. San Jose, CA. January 28, 1991.

16. Murphy, M.L. "Fluidized Bed Combustion of Rubber Tire Chips: Demonstration of the Technical and Environmental Feasibility." Energy Biomass Wastes. 1988 11:371-380

3. DEDICATED TIRES-TO-ENERGY FACILITIES

Most facilities that burn tires or TDF use the rubber to supplement a primary fuel such as coal, gas, or waste wood. One company, however, the Oxford Energy Company, is operating two electric power plants using tires as the only fuel, and is planning several more.

3.1 INDUSTRY DESCRIPTION

Two dedicated tires-to-energy facilities, are currently operational in the United States: the Modesto Energy Project in Westley, California, and the Exter Energy Company in Sterling Connecticut. The Modesto Energy Project is a subsidiary of The Oxford Energy Company (Oxford Energy), which was founded in 1985, and is the only commercially operating electric power plant using only tires for fuel. The plant, which cost about $40 million to build, has a potential generating capacity of 15.4 megawatts (MW) of electricity per year and an actual capacity of 14.5 MW.[1] It was designed specifically to burn whole scrap tires as its sole fuel. Although tire-derived fuels have been tried on a smaller scale elsewhere in the world, the Modesto Energy Project is apparently the first to operate successfully on a large scale.[2]

The location of the Modesto Energy Project is directly adjacent to the country's largest tire pile, which contained at its maximum, somewhere between 30 and 40 million tires. The tires in this pile are piled up to 40 feet high, and initially covered a canyon 1/4 mile wide for about a mile in distance.[1]

The technology used for the Modesto Energy Project was developed and licensed by the German company Gummi-Mayer in the late 1970's. The prototype facility on which Modesto was based has been operating successfully since 1973,[3] but is only generating about 1 to 2 MW. Oxford Energy has exclusive licensing rights for the technology for the entire United States.[4]

In August 1991, Oxford Energy began start-up operations of another dedicated tires-to-energy electric power plant, called The Exeter Energy Company. Exeter, located in Sterling, Connecticut, is a $100 million, 30 MW facility, which is twice as large as the Modesto Energy Project.[1] When commercial operation begins, power will be sold to Connecticut Light and Power.[5] No tire pile exists near the Connecticut site, and Exter Energy Company uses a tire collection system. A tire sorting center will be located in Plainfield, Connecticut. The boilers can combust both whole and shredded tires.[6] An anticipated 10 million tires per year will be used.[1] The facility is anticipated to produce a greater cash flow than the Modesto Energy Project because all tires will come from the "flow", generating greater tire tipping fees; the fuel feed system is less complicated (no 420-foot incline is needed); and the same size workforce is used in generating twice the amount of electricity.[1]

Oxford Energy has also announced plans to build the Erie Energy Project, to be located in Lackawanna, New York. This facility is a 30 MW, 10 million tire/yr, plant that is in the last stages of planning for construction. The plant is planned to be constructed in an Economic Development Zone, which gives tax benefits to the company. Power sales will be to New York State Electric and Gas. Construction is anticipated to begin by the late 1991, with operation beginning in 1993. The plant will not be required to obtain a PSD permit, and a draft air permit and draft EIS have been submitted.[1]

A fourth facility, the Moapa Energy Project, is planned for construction in Moapa, Nevada, about 50 miles northeast of Las Vegas. The plant would require 15 million tires per year to generate 49 MW per hour, and would sell power to Nevada Power. The environmental impact statement and air emissions permits for this facility have been accepted, and public hearings are upcoming. Construction may begin in 1992, with operation commencing in 1993.[1]

3.2 PROCESS DESCRIPTION

This section of the report describes the process used at the Modesto Energy Project.

Tires for the boilers are obtained from the adjacent tire pile and from the community. Altogether, about 4.5 million tires per year are burned. The Modesto Energy Project is required to obtain about half of these tires from the existing tire pile, and is permitted to acquire about half of its fuel from the community (referred to as the "flow"). For example, 2.6 of the 4.8 million tires burned in 1990 at the facility were from the "flow." This arrangement exists to balance the need to reduce the size of the hazardous tire pile with the desire of the company to obtain the most economical source possible of tires. Oxford Energy currently (1991) pays about $0.25 per tire for tires from the tire pile, but receives money for each tire acquired from the flow. The size of the tire pile will be decreased until a tire reserve remains of about 4 million tires.[1]

Modesto has created a subsidiary, Oxford Tire and Recycle, to collect and transport tires from tire dealers. The company sorts the tires to remove good used tires for resale for recapping or retreading. The remaining scrap tires (approximately 80 percent) are fed whole to the boilers.[1]

3.2.1 General Operation

The facility consists of two whole-tire boilers that together generate 125,000 pounds per hour of 930 psig steam.[6] The output steam of the 80-foot high boilers combines to drive a 15.4 MW General Electric steam turbine generator. Figure 3-1 provides a schematic of the process flow at Oxford.

Tires acquired from the "flow" are stored in a specially designated area near the existing tire pile. The tires are fed into a hopper located adjacent to the tire pile. An automated tire feed system singulates tires (spaces them individually) up to 800 tires per hour, to a conveyor belt traveling 420 feet up a hill to the power plant. Tire feed rate averages 350 to 400 tires per hour to each boiler.[1]

The boilers and feed system can accommodate tires made of rubber, fiberglass, polyester, and nylon, and as large as 4 feet in diameter. Tires larger than four feet must be chipped or used in other ways. Assuming each tire weighs about 20 pounds, total weight of the tires fed to each boiler is about 7,000 to 8,000 lbs per hour. (Total energy input is estimated to be 190 million (MM) Btu's.[1]) Tires are weighed by automated scales and information is fed to the computer to facilitate appropriate tire feed to the boilers. Tires are fed onto the grate in the combustion chamber located at the bottom of one of the two 80-foot high boilers. The 430 square-foot reciprocating stoker grates are composed of several thousand steel bars made of a stainless steel alloy to prevent slag from adhering to the metal.[1] This prevents plugging of the air distribution system by viscous liquids resulting from tire combustion. The grate configuration allows air flow above and below the tires, which aids in complete combustion. The bars resemble a series of steps sloping downward that move back and forth,

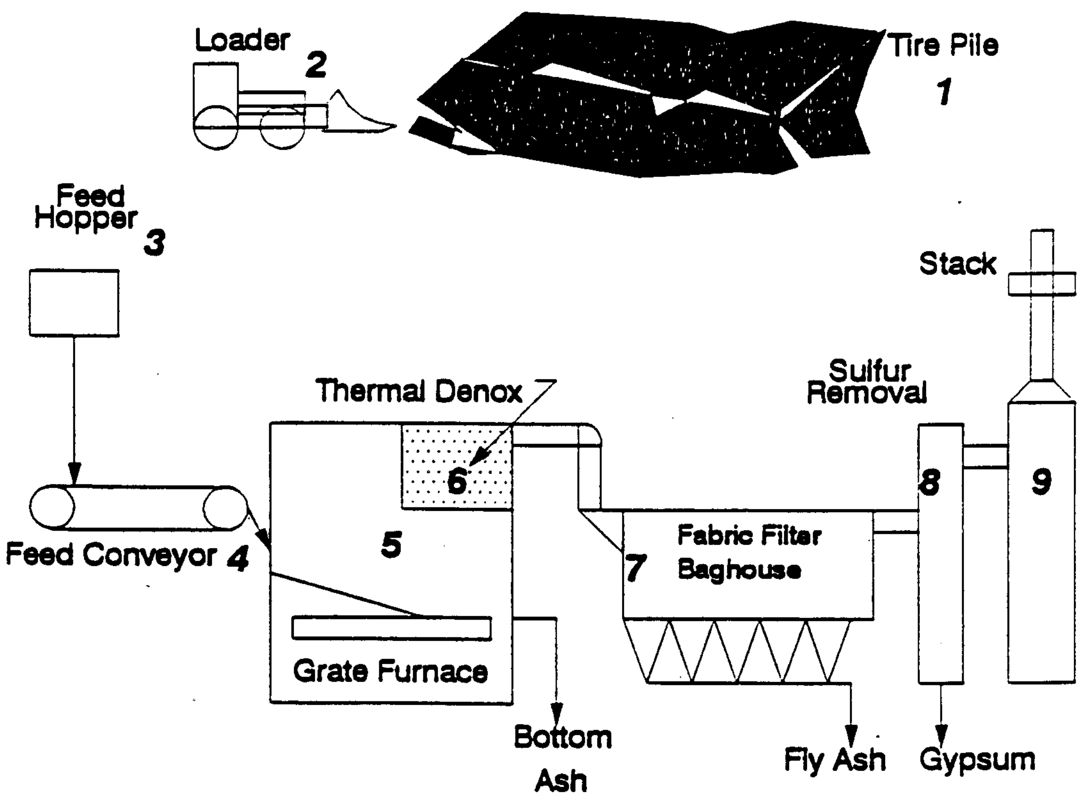


Figure 3-1. Oxford Energy Process Flow Sheet.[1]

pushing the burning tires through the boiler. Essentially all of the slag and ash is moved along the reciprocating grates. At the end of the grates, the slag and ash fall into a water quench on a submerged conveyor, which then transports the ash and clay to storage hoppers,[1] for sale as by-products.[3]

Although tires begin to ignite at about 600°F, the boilers are operated above 2000°F to ensure complete combustion of organic compounds emitted by the burning tires.[2] The heat generated by the burning of the tires rises into the radiation chamber, which is constructed of refractory brickwork.[6] This heat causes water contained in pipes in the refractory to turn to steam. The high-pressures steam is forced through a turbine, causing it to spin. The turbine is linked to a generator that generates power, which is then sold to the Pacific Gas and Electric Company. After passing through the turbine, the steam is condensed to water in a cooling system, and is recycled to the boiler to be reheated.[2]

To meet emissions limits, the Modesto Project had to install state-of-the-art emission control devices. Detailed descriptions of all air pollution control equipment is contained in Section 3.3.

3.2.2 Operational Difficulties

Oxford Energy has had to make significant modifications to the Modesto Energy Project to operate successfully. Because power is being sold to a utility (California Edison), power generation must be consistent. If tire feed problems prevent enough fuel from being combusted to maintain consistent power generation, gas-firing of the boilers is used to maintain power. This is an expensive solution. Therefore, successful and reliable tire feed is imperative.

Inconsistent tire feed also yields variable temperatures in the boiler, and the plant experienced some operational problems that resulted from temperature fluctuations. Therefore, the plant had to make modifications to the facility to ensure consistent power generation.

The prototype facility on which Modesto was based uses manual tire feed.[6] Modesto personnel felt it necessary to automate the tire feed system. The initial system, however, did not deliver a consistent feed of tires to the furnaces. The one weigh station, located near the tire pile, could not make allowances for the variability in size and type of tire entering the conveyor apparatus.[6] Inconsistent power generation resulted.

Tire handling also provided another challenge. Because the tires are whole, timing of their entrance to the boilers is critical to ensure a steady Btu input to the boilers. During rain, mud and sand from the tires acquired from the pile would accumulate on the conveyor belt. The length and steepness of this conveyor caused tires to slide off the belt.[1]

Another initial problem encountered was several grate bars popped out of place, exiting at the end of the inclined floor of the boiler. Engineers determined that the fluctuations in steam load and on/off cycling of the furnace were allowing ash and slag to be wedged in the spaces between bars and to lift the bars out of place.[6]

To enhance consistent tire feed, four tire weigh scales were installed where tires are fed into the two combustion chambers. Each furnace is fed by two weigh scales. The goal of the new system is to feed 80 to 90 pounds of tires in a batch to maintain the desired heat input to the system.[6] The new system has allowed consistent boiler operation. At the same time, the new system has minimized the grate problem. The speed of tire delivery overall was increased.[6] Finally, a special belt washing system was installed to solve the problem of tire slippage on the conveyor. The belt washing system is now used in particular before a rain storm.[1]

Another problem initially encountered was the disintegration of the refractory brick initially installed in the boilers. This was caused by the high boiler temperatures. The refractory was removed, and Modesto has experimented with two different solutions, one in each boiler. In Boiler No. 1, the 3-foot thick refractory was replaced with a high thermal conductivity brick that transmits the heat to the boiler skin. This facilitates cooling of the inner boiler walls, causing slag to solidify on the inner refractory as a protective layer. This has increased the fuel need for this boiler, but is still a satisfactory solution. For boiler No. 2, a different approach was used. In this case, the water walls, which initially ran down the boiler sides to a level about 20-feet above the grates, were extended down to grate level. Water walls (tubes filled with water) generate steam and deliver it to the drum. The economizer preheats the feed water. This approach has protected the new refractory very well.[1]

Problems with the air pollution control equipment also had to be addressed. These are discussed in Section 3.3.

3.3 EMISSIONS, CONTROL TECHNIQUES AND THEIR EFFECTIVENESS

3.3.1 Emissions

Pollutant emission levels for criteria pollutants as listed in the permit for the Modesto facility are summarized in Table 3-1. Annual compliance tests are required and have

Table 3-1. Permitted Emission Levels
The Modesto Energy Project,
Westley, CA[7]

Pollutant	lbs/day
CO	346.4
NO_x	500.0
PM	113.0
SO_x	250.0
HC	148.4

Note: Based on 700 tires per hour, 300,000 Btu's per tire, and 24 hours per day, these permitted emission levels are equivalent to: 0.069 lbs/MMBtu for CO; 0.099 lbs/MMBtu for NO_x; 0.022 lbs/MMBtu for PM; 0.050 lbs/MMBtu for SO_x; and 0.029 lbs/MMBtu for HC.

Table 3-2. Permitted Emission Limits for Each Boiler
Exeter Energy Project, Sterling, CT

Pollutant	gr/dscf	lb/MMBtu
PM_{10}	0.0150	
SO_2		0.1090
NO_x		0.1200
CO		0.1670
VOC		0.0300

been conducted on the facility since 1987. Table 3-2 contains permitted limits for the Exeter Energy Project in Sterling, CT. Table 3-3 contains a summary of test data for criteria pollutants and metals for Modesto in 1988 and 1990. Table 3-4 shows organic compound emissions from Modesto. Testing of emissions from Modesto has been frequent. Comparison of these emissions to baseline (no TDF use) is not appropriate, but they can be compared to coal-fired utility emissions on a lb/MMBtu basis. Such a comparison is provided in the Chapter 6, which covers utility boilers, in Figures 6-1 through 6-4.

3.3.2 Control Techniques

Three air pollution control systems are used at the Modesto Project. These systems are used in series to control NO_x, particulate matter, and SO_x. An Exxon thermal de-NO_x system is uesd to control NO_x emissions; a fabric filter is used to control particulate matter; and a wet scrubber is used to control SO_x emissions. The following paragraphs describe these three air pollution control systems and any operational problems associated with their use.

3.3.2.1 De-NO_x System. At the Modesto Energy Project, NO_x is reduced by use of a selective non-catalytic ammonia injection system manufactured by Exxon, which is designed to operate at the top of the combustion chamber. Rising gases are injected with a fine spray composed of compressed air and 20 pounds per hour of anhydrous ammonia per boiler. The NO_x is converted to inert nitrogen gas and water. Each boiler has two injection zones, each of which operates at 300 scf/hr of air flow. Design efficiency is 35 percent, and plant engineers estimate actual efficiency varies between 25 and 35 percent.[1]

Table 3-3. Criteria Pollutant and Metals emissions, by year, The Modesto Energy Project[5,8]

Pollutant	Limit lb/day	1988 lb/day	October 9-11, 1990[a] lb/day	October 9-11, 1990 lb/million Btu
Criteria				
CO	346.4	247.8	311.5	7.2×10^{-5}
NO_x	500.0	384.3	424.6	9.8×10^{-5}
PM	113.0	31.2	93.12	2.2×10^{-5}
SO_x	250.0	127	61.9[b]	1.4×10^{-5}[b]
HC	148.4	0.646		
Metals				
Lead		0.026	0.006[c]	1.3×10^{-6}[c]
Cadmium		0.0018	0.016	3.7×10^{-6}
Chromium (total)		0.0011	0.020	4.7×10^{-6}
Mercury		<0.00003	0.003	6.7×10^{-7}
Arsenic		0.0026	0.00	0.00
Zinc		7.75	0.623	1.4×10^{-4}
Chromium (hexavalent)			0.0	0.0
Copper		0.015	0.032[c]	7.5×10^{-6}
Manganese		0.023	0.007	1.6×10^{-6}[c]
Nickel			0.027[c]	6.3×10^{-6}[c]
Tin			0.018	4.2×10^{-6}
Aluminum		0.28	0.101[c]	2.3×10^{-5}[c]
Iron		0.62	0.316[c]	7.3×10^{-5}[c]
Beryllium			0.00	0.00

[a] Assumed 24 hr/day operation
[b] As sulfur trioxide; sulfur dioxide not reported
[c] MQL or trip blank showed significant measurement.

Table 3-4. Organic Compound Emissions by year, The Modesto Energy Project[5,8]

Pollutant	Limit lb/day	1988 lb/day	October 9-11, 1990[a] lb/day	October 9-11, 1990 lb/million Btu
HCl		<22.3		
Dioxin and Furan		4.2×10^{-7}		
PAH		0.012		
PCB		5.71×10^{-4}		
Naphthalene			0.005[c]	1.2×10^{-6c}
Acenaphthylene			0.000	0.000
Acenapthene			2.4×10^{-5c}	5.6×10^{-9c}
Fluorene			7.2×10^{-5c}	1.7×10^{-8c}
Anthracene			4.8×10^{-5c}	$1^{1} \times 10^{-8c}$
Flouranthene			7.2×10^{-5c}	1.7×10^{-8c}
Pyrene			9.6×10^{-5c}	2.2×10^{-8c}
Benz(a)anthracene			0.000	0.000
Chrysene			0.000	0.000
Benzo(b)flouranthene			2.4×10^{-5c}	5.6×10^{-9c}
Benzo(k)flouranthene			0.000	0.00
Benzo(a)pyrene			0.000	0.00
Indeno(1,2,3-cd)pyrene			0.000	0.00
Dibenzo(ah)anthracene			0.000	0.00
Benzo(ghi)perylene			0.000	0.00
Phenanthrene			2.4×10^{-4c}	5.6×10^{-8c}
Phenol			0.000	0.00
Formaldehyde			0.735[c]	1.7×10^{-4c}
Benzene			0.000	0.000
Monochlorobiphenyl			0.000	0.000
Dichlorobiphenyl			0.000	0.000
Trichlorobiphenyl			0.000	0.000
Tetrachlorobiphenyl			0.000	0.000
Pentachlorobiphenyl			0.000	0.000
Hexachlorobiphenyl			0.000	0.000
Heptachlorobiphenyl			0.000	0.000
Nonachlorobiphenyl			0.000	0.000
Decachlorobiphenyl			0.000	0.000
Vinyl chloride			0.000	0.000

[a] Assumed 24 hr/day operation
[b] As sulfur trioxide, sulfur dioxide not reported
[c] MQL or trip blank showed significant measurement.

Initially, NO_x emissions were problematic, but now seem to be under control. First, the amount of ammonia needed was discovered to be less than originally thought.[1] Although tests performed in early 1988 showed a 3-day NO_x average that was below the permitted level of 500 lb/day, Modesto was forced to use previously purchased offsets.[3] Initially, much breakthrough of unreacted ammonia (ammonia "slip") from the boilers into the wet scrubber occurred, causing emissions to exceed the ammonia limit on some runs.[3] Reduced ammonia levels stopped the breakthrough, and NO_x emission levels were still within required limits.

Second, mixing of the flue gas and reagent had to be improved. Reduction efficiency is limited primarily by amount of mixing within the chamber; increased mixing aids in contact between reagent and pollutant, and stabilizes the air temperature, further optimizing the reaction. Therefore, negative pressure was decreased to reduce tramp air. Also, the operational reciprocating compressor was replaced by a centrifugal rotary screw type compressor. Further, ash build up on the boiler superheater tubes was a problem, impeding heat transfer to cool down the flue gas. This problem was resolved by using acoustics to cause the ash to fall off the superheater and economizer tubes. This allowed lower fuel consumption, resulting in decreased NO_x emissions.[1]

NO_x reduction at the Exeter Energy facility is planned to be somewhat different than that at Modesto. Specifically, urea will be sprayed into the combustion chamber instead of ammonia. The advantages of using urea are numerous: urea is more efficient, not hazardous, less corrosive, and easier to handle. In addition, urea is a liquid, so compressed gas is not needed. Disadvantages of urea, however, include the extreme sensitivity of the system to urea concentration. At low urea concentrations (less than 50 percent), rampant biological growth occurs, which plugs the lines. At urea concentrations over 50 percent, the urea itself can plug lines. Further developments may include the use of ammonium hydroxide. The initial installation cost of using urea may be comparable to, or even less than, using ammonia. Since the urea itself is less expensive than ammonia, the cost per ton of NO_x removed using urea is likely to be less. This type of system was not fully developed when the Modesto plant was under construction, and the cost to retrofit the existing plant is not economical.[1]

3.3.2.2 Fabric Filter. After exiting the boiler chambers and the de-NO_x system, exhaust gases pass through a large fabric filter. A fabric filter was chosen over an electrostatic precipitator (ESP), because a fabric filter was believed to provide a higher particulate reduction efficiency, and because this fabric filter design was BACT.[1] The fabric filter uses Gore-Tex® bags to avoid problems with sticky particulates or acid sprays.[6] The acid spray results from the temperature controlling spray system located upstream of the fabric filter to protect against temperature excursions and to agglomerate the ash for easier removal.[6]

Staff at the Modesto Energy Project believe this particular baghouse was somewhat oversized, because the emissions from the plant were of such concern during permitting and construction.[1] Modesto personnel are required to keep 25 percent of the bag requirement as spares on site.[1]

Dust from the fabric filter collection system has tended to accumulate on the sides of the hopper in a problematic manner. Noting the success of acoustics on the boiler ash that collected on the superheater and economizer tubes, plant personnel successfully transferred that technology to the fabric filter hoppers; periodic sonic blasts now maintain clean hopper sides.[1]

3.3.2.3 Scrubber. After exiting the fabric filter, exhaust gases pass to a wet scrubber manufactured by General Electric (GE) Environmental Services for SO_x removal. The system uses a lime mist to remove sulfur compounds, producing gypsum. The lime is purchased as calcium oxide in pebble form, and is slaked to form a calcium hydroxide solution (11 percent by weight) used at a rate of 5,000 gallons per day. Exhaust gases enter the scrubber at a temperature of about 375°F and exit at a temperature of about 125°F. The gas is reheated to about 180°F before exiting the stack. About 3 to 5 million BTU per hour are required to operate the scrubber system.[1] The gypsum is sold as an agricultural supplement.[2]

Personnel at Modesto noted many problems that have had to be overcome to operate the scrubber system successfully. First, GE installed a vacuum type technology to remove scrubber sludge. This system was undersized and could not handle the sludge volume. A larger vacuum pump system has been ordered. Second, personnel have experimented with moving the lime injection location from the top of the scrubber to the bottom. Adding lime near the bottom encourages better mixing and a quicker response in increasing the pH. This has resulted in a more consistent SO_x emissions rate. However, a permanent injection system for the bottom of the scrubber has not been designed yet. Third, because the spray nozzles were plugging continuously, a filter grate was installed before the recycle pumps in the system. Fourth, the two mist eliminators are problematic. The vendor installed small hooks on the mist eliminator to increase the efficiency from 11 feet per second (fps) of gas to 21 fps. However, the gypsum gets caught on the hook, filling it up, reducing the efficiency to the normal 11 fps, and allowing gypsum carryover from the unit. Maintenance personnel must clean the hooks about every 3 months to minimize gypsum carryover. Last, the closed loop heat exchange system was initially made of carbon steel and corroded. It has been replaced with a stainless steel system using turbine extraction.[1]

3.3.3 Permit Conditions and Issues

The Modesto Energy Project is overseen locally by the Stanislaus County, California, Department of Environmental Resources, Air Pollution Control District (APCD). The Modesto Energy Project has numerous permit conditions the facility must meet. Limits are set for all criteria pollutants (see Table 3-1) and ammonia. In addition, the plant must not exceed 20 percent opacity. The Modesto Energy Project must perform an annual source test. On-site inspections are performed weekly. The plant operates and maintains continuous emissions monitoring systems for NO_x, SO_x, CO, CO_2, O_2, and opacity, and the resulting data are submitted to Stanislaus County on a weekly basis. Both boilers are required to use Best Available Control Technology (BACT). Under California Law A2588, the Air Toxics "Hot Spots" Information and Assessment Act of 1987, the plant must report emissions of 24 hazardous air pollutants including such pollutants as dioxins, PCB's formaldehyde, arsenic, hexavalent chromium, mercry, iron, nickel, lead, and zin.[1] The most recent stack test results are presented earlier in Tables 3-3 and 3-4.

Other selected permit requirements are listed below.[7]

1. Modesto must report emissions of SO_x, NO_x, and CO on a lb/day basis from midnight to midnight; a summary of these data shall be provided weekly to the APCD.

2. Ammonia breakthrough of the exhaust shall not exceed 50 ppmv, except for the first 2 hours of start-up and the last hour of shutdown.

3. Trace metals, dioxin and furan emissions shall not exceed the estimated emission levels as listed in the Modesto Energy Company's District approved risk

assessment. If these levels are exceeded, explicit procedures for performance of new risk assessment and curtailment of operations are set forth.

4. Gross electrical output shall not exceed 14.4 MW, averaged over 24 hours.

5. The exhaust stack must be equipped with CEMS for opacity, NO_x, SO_2, CO, O_2, and volume flow rates.

6. If control equipment failure occurs, tire input is to be immediately curtailed, and furnace temperature is to be maintained at 1800°F until all tires in the incinerator are combusted. Auxiliary burners must be used, if necessary, to maintain the minimum temperature.

Plant personnel state that, three times in the past, they have shut down all or part of the plant rather than exceed their permitted NO_x levels. In 1988, one boiler was shut down on one occasion, and the whole plant was shut down on another occasion when NO_x limits might have otherwise been exceeded. Since that time, no shut downs have occurred for that reason. Most recently, a shut-down occurred to avoid a NO_x exceedance in October of 1991.[1]

3.4 OTHER ENVIRONMENTAL AND ENERGY IMPACTS

Other environmental impacts include solid waste (slag, dust, etc.) and water. The facility recycles all solid wastes generated as described below.

Byproducts of the boilers (slag) and of the pollution control devices are almost wholly recycled. The boiler generates about 24 tons per day of slag, which has a high steel content from the metal in the tires, mainly radial and bead wiring. Oxford has an agreement to sell the slag to a cement company at a cost of $10/ton. However, transportation to the cement company has proven a problem; estimated costs are higher than the sales price. Currently, Modesto is negotiating a more cost-effective hauling arrangement where a trucking company would backhaul the slag to the Nevada cement plant in trucks emptied in the Westley area that would otherwise be returning empty. The slag provides some of the iron content required of raw materials in the cement production process.[1]

The particulate matter collected from the fabric filter has a high zinc oxide content, and is sold to a metal refiner to recover the zinc. The fabric filter generates dust at a rate of 18 bags/day,each bag weighing approximately 1300 pounds. Zinc content of the bag ranges from 25 to 40 percent. The bags are sold on a sliding scale price range, depending on the zinc content of the bag. The rate is based on a zinc cost of about $20/ton. Budgeted revenues last year for fabric filter dust were $174,000.[1]

The gypsum produced by the alkali scrubber is sold as an agricultural supplement or soil conditioner to California farmers. It is generated at a rate of 10 tons/day and sold for $5 per ton.[1]

The facility's original waste water treatment and evaporation system was too small to handle the required volume, and some wastewater had to be treated offsite.[9]

One of the initial requirements made of the Modesto Project was installation of a comprehensive fire system. The large and unwieldy tire pile was surrounded by an underground sprinkler system and fire hydrants. Further, tire removal from the pile follows a carefully drafted plan to result in optimal fire lanes among the tires.[1]

3.5 COST CONSIDERATIONS

As noted earlier, the company must pay the landowner (who also owns the tire pile) a varying amount, approximately $27 per ton (about $0.25 for each tire removed) at the present time, but Modesto receives money for each tire acquired from the "flow".[1]

The Modesto Energy Project is designated as a "qualifying facility" under PURPA, the Public Utilities Regulatory Policies Act of 1978. This act makes companies eligible for long-term power sales agreements with public utilities. The projects are exempt from the rate of return regulations that plants must use that burn conventional fuels. Further, the California Alternative Energy Law guarantees long-term revenues to companies burning waste or renewable energies at a rate equal to wholesale cost of power plus the avoided cost of power. (Avoided cost means the cost for a utility burning conventional fuels to add the amount of potential power being provided by the alternative fuel user.) Effectively, this yields a very attractive power cost for the power producer coupled with a long-term (15-year) promise that the utility will buy at that rate. In California, that rate is about $0.08 per kilowatt-hour in the current contract. Although the power contract guarantees the revenue stream, the plant must guarantee output. Therefore, whenever tire feed became a problem power had to be generated using gas, which hurt profitability.[1]

The Modesto Energy Project has sustained overall financial losses since the plant commenced construction. A local California newspaper reported that, in 1987, the Company posted a loss of $678,502. In 1988, the loss had grown to $2.1 million, although the company's revenues for 1988 had increased from $1.5 million to $7.9 million. The article reports net income of $1 million for the first 9 months of 1989.[10]

As the plant worked out operational problems, the power generated had to be consistent, because the long-term power contract requires dependable power for sale. Therefore, when tire-feed was a problem, the company had to keep the boilers operating using natural gas, at considerable company expense.

3.6 CONCLUSIONS

The generation of electricity at dedicated tire-to-energy facilities appears to be very promising from both an air pollution and a financial perspective.

Oxford experienced difficulties at first with several of their emission control devices. These difficulties have been overcome. Based on Oxford Energy's experiences, controlled emissions from their Modesto Energy Project compare extremely favorably to controlled emissions from electric utility plants powered by traditional fuels. Most emission rates (lbs/MMBtu) at Oxford are below those at other electric generating plants burning traditional fuels.

Dedicated tire-to-energy facilities must be able to supply consistent power generation to the utility. Thus, it is extremely important that a consistent source of tires be in place. A tire acquisition system must be developed for each plant.

As with any new venture, Oxford has had a number of operational difficulties that have affected the financial viability of their original facility. These difficulties appear to have been overcome, and with new, larger facilities, dedicated tire-to-energy plants appear to have a very good financial outlook.

3.7 REFERENCES

1. Memorandum from Clark, C., and K. Meardon, Pacific Environmental Services, Inc., (PES), to Michelitsch, D., EPA/ESD/CTC. November 19, 1991. Site Visit--Modesto Energy Project, The Oxford Energy Company.

2. Sekscienski, G. Meltdown for a Tough One. EPA Journal. Office of Communications and Public Affairs. 15:6. November/December 1989.

3. U.S. Environmental Protection Agency. Markets for Scrap Tires. EPA/530-SW-90-074B. September 1991.

4. Alternate Sources of Energy, Volume 90, April 1987. p. 43.

5. Ohio Air Quality Development Authority. Air Emissions Associated with the Combustion of Scrap Tires for Energy Recovery. Prepared by: Malcolm Pirnie, Inc. May 1991.

6. Oxford Meets Performance Goals Firing Whole Tires. Power. October, 1988. pp. 24, 28.

7. Stanislaus County Department of Environmental Resources Air Pollution Control District. Permit for Modesto Energy Company. Issued 3/9/88. Permit No. 4-025.

8. The Almega Corporation. Source test data for Modesto Energy Project, Westley, CA. The Oxford Energy Company. October 9-10, 1990.

9. "Tires, Tires Everywhere...Oxford Energy Offers a Solution," Environmental Manager. 1(4) November 1989.

10. Phillips, D. "Out to Confound the Skeptics". The Press Democrat. Santa Rosa, California. January 7, 1990. pp. E1,E6.

4. TIRE AND TDF USE IN PORTLAND CEMENT KILNS

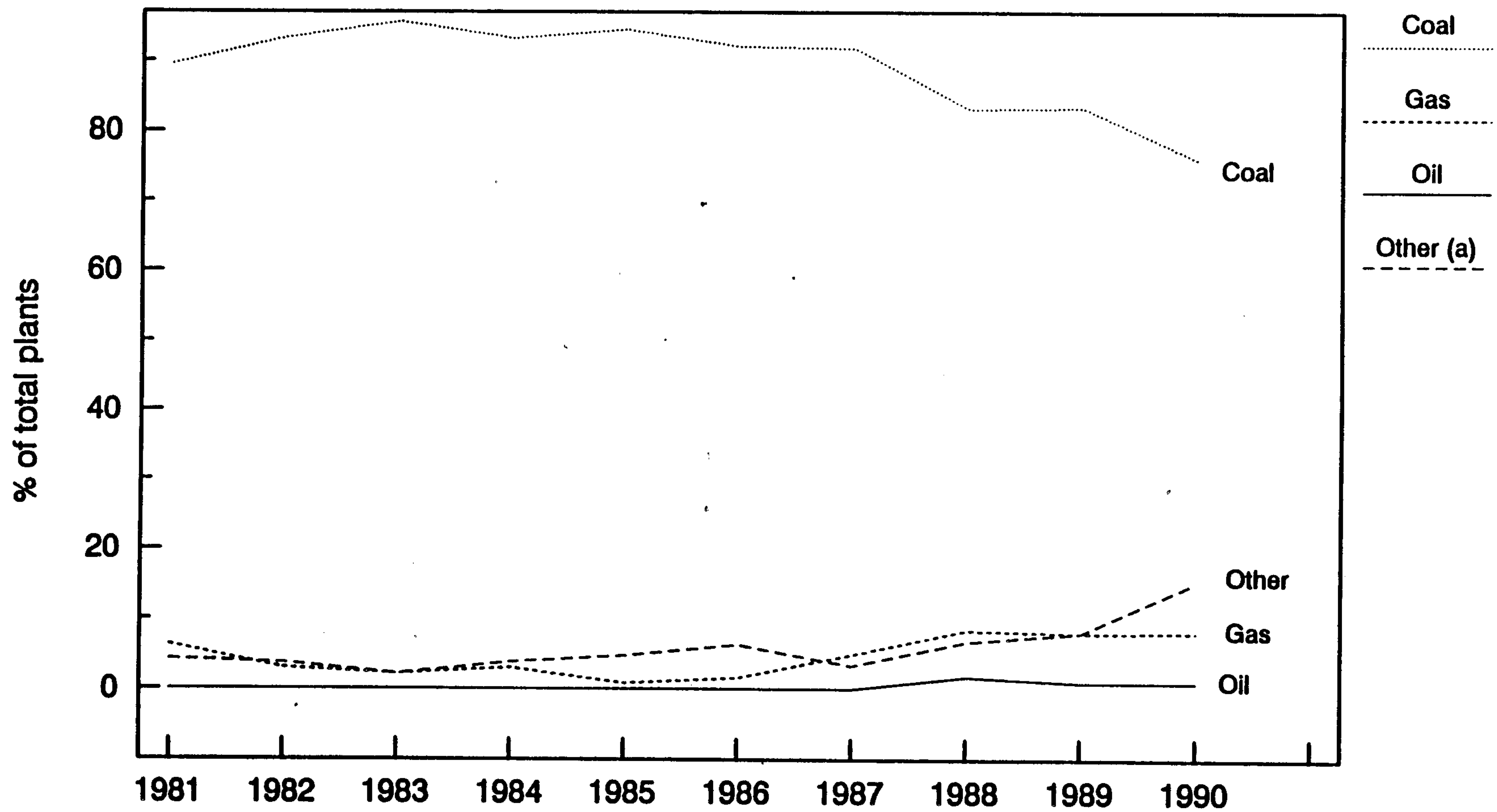
The portland cement production process is extremely energy intensive (from 4 to 6 million Btu's (MMBtu's) are required to make a ton of product); therefore, alternative and cost-effective fuel options are of great interest. Waste tires have been tried as a supplemental fuel in well over 30 cement kilns and in at least one rotary lime manufacturing kiln. Currently, tires are in use, either on a trial or permanent basis, in 11 cement kilns and one lime kiln.

A cement kiln provides an environment conducive to the use of many fuel substances, such as tires, not normally included in the fuel mix. Specifically, the very hot, long, inclined rotary kiln provides temperatures up to 2700°F, long residence time, and a scrubbing action on kiln materials that allows a kiln to accommodate and destroy many problem organic substances. Also, the rock-like "clinker" formed in the kiln can often incorporate the resulting ash residue with no decrease in product quality. Tires are a compact fuel, with very low moisture. Tires have some iron and zinc content, both desirable materials in the raw material mix for cement manufacturing. Further, the materials handling operations already in place at many cement plants require only minimal modification to accommodate TDF feed. For these reasons, cement kilns are one of the most common methods by which energy in waste tires is recovered.

Cement plants attract favorable power rates because the process is so energy intensive; TDF cost per Btu is thus less of a savings. Second, cement kilns can accommodate many alternate fuels,[1] such that regional availability and price for these may affect the marginal savings of TDF. For example, on the Southeast Gulf coast, petroleum coke is often less expensive than TDF. Whole tires are cheaper than TDF, but feeding and handling equipment for whole tires is expensive.[1]

Other alternative fuels of interest to the industry have included organic hazardous waste (e.g., solvents), waste oil, and wood chips. In 1990, seven cement plants reported to the Portland Cement Association (PCA) that their primary fuel included waste; three reported using a combination of coal and waste as primary fuel.[2] The type of waste was not specified and, therefore, the number burning tires or TDF specifically could not be determined. The PCA reported that 31 plants utilized waste fuel as an alternate fuel in 1990.[2] The number of kilns reporting use of waste fuels is 40 percent higher in 1990 than in 1989.[2] There is no record of waste fuel being burned in cement kilns at all in 1972.[3] Overall, the number of cement plants with kilns fired by fuels other than coal, natural gas, or oil, has risen from 2.2 percent in 1983 to 15.2 percent in 1990. Figure 4-1 graphs this change.

This chapter describes the use of whole tires and TDF in the cement industry in five sections. First, an industry description is provided. Second, the cement production process is described, including traditional fuel use and use of both whole tires and TDF as supplemental fuel. Third, air pollution implications are discussed in detail, including emissions, control techniques, and control effectiveness. Fourth, other environmental and energy impacts are evaluated. Last, cost considerations of tire use are described.



(a) The types of fuels were not specified for "other".

Figure 4-1. Fuel use at cement kilns, 1981-1991.[2]

4.1 INDUSTRY DESCRIPTION

As of the Summer of 1991, 112 cement plants were operational in the United States.[2] Annual U.S. production of clinker in 1990 was approximately 81 million tons per year. Using an average of 5 MMBtu's per ton of clinker produced, some 400×10^{12} Btu's are required nationally by the industry each year. One source estimated that, theoretically, if all waste tires went to the cement industry, waste tires could provide approximately 11 percent of the fuel requirements for the cement industry.[4]

Many industry-wide changes over the last decade have dramatically affected fuel use and efficiency in the cement industry. First, a trend toward more prevalent use of the dry process of cement manufacture rather than the wet process continues. New technology in conjunction with fuel savings provided by the dry process have made it the process of choice. In fact, no new wet process kilns have been built in over 15 years.[2] Second, over the last decade, many plants have converted their kilns to coal firing because of coal's cost effectiveness in comparison to oil and gas. Although both of these trends have had a considerable effect on fuel efficiency and cost in the industry, use of supplemental fuels, such as waste tires, continues to be of high interest to the industry. All fuels are purchased, however, based on regional prices.

Table 4-1 provides a list of cement facilities in the United States that have been reported to be burning tires or to have burned tires in the past. Test data on air emissions while burning tires were obtained for three cement facilities and one lime plant. These facilities comprised both wet and dry process plants, and plants that burned whole tires and TDF. A summary of this test data is presented in this report in section 4.3 below.

Table 4-1. Portland Cement Facilities that have been, or are, Burning TDF or Whole Tires

COMPANY AND LOCATION	KILNS DESCRIPTION[a]	TDF OR TIRE EXPERIENCE	AIR EMISSIONS TEST DATA	COMMENTS/REFERENCES
Allentown Cement (LeHigh Portland Cement Co.) Allentown, PA	2 dry kilns; coal/coke fired			References 2 and 5
Ash Grove Cement Co. West Plant Durkee, OR	Dry/1980; PH; ESP; natural gas/oil co-fire; one four-stage preheater; 500,000 tpy.	Current use; burned since 6/90, 2"x2"; fed pneumatically into feed end of kiln; permitted to burn up to 10% TDF; currently running 8%	Extensive testing for PM, SO_x, metals, HC; showed no significant increase	References 2, 6, and 7
Blue Circle, Inc. Atlanta, GA	2 dry kilns; coal/coke fired	Past use		References 2 and 5
Box Crow Cement Co., Box Crow Plant Midlothian, TX	1 dry kiln; PH/PC; coal-fired; baghouse; 310,000 tpy	Past use; 2"x6" TDF; 10-12% TDF	CEMS only; test burn planned soon	References 2, 5, and 7
Calaveras Cement Co. Redding, CA	1 kiln; PH/PC; FF; coal fired, 650,000 tpy	Current use; burned since 1985, 2"x2" TDF, wire-free now; whole by mid-1991; about 20% Btu; 65 tons TDF per day (6,000 tires); TDF into riser duct just above kiln feed housing	Yes; emission not significantly different than burning coal	Use permit modification from local agency. References 1, 2, 7, and 8
California Portland Cement (Arizona Portland) Rillito, AZ	4-dry kilns; 1 with PH/PC; coal-fired; 2 kilns inactive in 1990.	Past use; 2"x2" 10% of energy from TDF; TDF since 1986	No	References 1 and 2
California Portland Cement Mojave, CA	1 dry kiln; PH/PC; FF; coal-fired; 3,250 tpd	2.5"x 2.5"; 30% TDF of total fuel	No	References 2 , 5, and 7
Centex Illinois Cement Co. LaSalle, IL	1 dry kiln; PH; FF; coal fired.	Test use; anticipate 4/91 test burn	Applied for test burn permit; plant 4/91 test burn.	Completed permit application; plans April 1991 test burn. References 2 and 9
Essroc Materials, Inc. Nazareth, PA	1 planned dry kiln; PC; to be completed 1991		Test burn in November	References 2, 5, and 7

Table 4-1. (Continued)

COMPANY AND LOCATION	KILNS DESCRIPTION[a]	TDF OR TIRE EXPERIENCE	AIR EMISSIONS TEST DATA	COMMENTS/REFERENCES
Florida Crushed Stone Co. Brookville, FL	1 dry kiln; PH; FF; ; coal fired	Past use; fed TDF into preheater; stopped because of preheater plugging problems; installing whole tire feeder; Test data (10/90) not valid, but tested for PM, SO_2, VOCs, furans, dioxins, metals.	Incomplete	References 2 and 10
Giant Resource Recovery Harleyville, SC	4 wet Kilns; ESP; coal fired			References 2 and 5
Gifford Hill Cement Co. Harleyville, SC (now Blue Circle)	1 dry kiln; PH; FF; coal fired	Past use; whole tires; 20% of energy from TDF during testing; in process of making modifications to install feed equipment.	No	References 2 and 11
Holnam/Ideal Cement Dundee, MI	2 wet kilns; coal/coke-fired	2"x2"		References 2 and 5
Holnam/Ideal Cement Seattle, WA	1 wet kiln; ESP; coal/coke fired	Current use; 2" wire-free; test permit is for up to 25%; first used TDF in 1986; discontinued because TDF not price competitive with coal; reinstated TDF use in 1990; 20% of energy is from TDF.	Yes; using 0%, 11%, and 14% TDF; complete data for PM, SO_2, NO_x, heavy metals, PNA's, and VOC's.	References 2, 5, 12, and 13
Kosmos Cement Co. Kosmosdale, KY	1 dry kiln; PH; FF; coal fired, 2,160 tpd	Past use; shredded TDF	Yes (PM, SO_2, CO, HC, HCl)	References 2, 5, and 7
La Farge Corp., Balcones Plant New Braunfels, TX	1 dry kiln; PH/PC	Current test use; 2" wire-free. Used TDF experimentally for 2 yrs; completed trials for emission testing; permit being issued to limit TDF to 25% of energy used; planning to test VOC, PAH's, PCDD/PCDR.	planned	Investigating tire burning on corporate level. References 2, 5, and 7

Table 4-1. (Continued)

COMPANY AND LOCATION	KILNS DESCRIPTION[a]	TDF OR TIRE EXPERIENCE	AIR EMISSIONS TEST DATA	COMMENTS/REFERENCES
Lone Star Cement, Cape Girardeu, MO			Test burn soon	Reference 7
Medusa Concrete Clinchfield, GA	1 Wet Kiln inactive in 1990; 1 dry kiln w/PH; FF; coal fired.			References 2 and 5
Medusa Cement Charlevoix, MI	1 dry kiln; PH/PC; coal-fired			References 2 and 5
Monarch Cement Co. Humboldt, KS	3 dry kilns; 2 with PH; FF; coal/coke			References 2 and 5
River Cement Co., Selma Plant Festus, MO	2 dry kilns; FF; coal fired.			References 2 and 5
RMC Lone Star Davenport, CA	1 dry kiln; PH/PC; ESP; coal fired	Current use		References 2 and 14
Roanoke Cement Co. Cloverdale Plant Roanoke, VA	5 dry kilns; 1 with PH; coal fired; TDF planned in kiln with PH	Test use; planning use of whole tires, beginning with 4% and increasing to 20% tires; tires from retailers and maybe from dumps.	Yes, winter 1991; tires at 20%	Have spent $320,000 for equipment and testing; will be paid a disposal fee for taking tires, and perhaps a state subsidy based on $0.50 tax on new tires; currently permitting. References 2 and 15
Southdown, Inc. Southwestern Portland Cement Co. Victorville, CA	2 dry kilns, 1 with PH/PC; FF; coal fired.	Current use; test permit; use not continuous; whole and shredded; TDF added at precalciner; whole added into feed end of kiln by double gate method.	CEMS; new test data	Test permit; final permit pending CEMS data analysis. Whole into kiln feed end; TDF into preheater at precalciner. References 2, 7, and 16
Southdown, Inc. Southwestern Portland Cement Co. Fairborn, OH	1 dry kiln; PH FF; coal fired.	Past permitted use; Whole 36"; 10-15%; use was successful and are renewing alternate fuels permit; tires were slid, not rolled, into feed end of kiln.	CEMS; new emissions tests have been done	Tire burning stopped until renew permit to burn whole tires; public opposition to solvent-derived fuels; working their copy through the permit process References 2, 7, 16, and 17

Table 4-1. (Continued)

COMPANY AND LOCATION	KILNS DESCRIPTION[a]	TDF OR TIRE EXPERIENCE	AIR EMISSIONS TEST DATA	COMMENTS/REFERENCES
Southdown, Inc. (Southwestern) Lyons, CO	1 dry kiln; PH/PC; FF; gas, coal, waste oil; 1,400 tpd	Current use; 3"x3" TDF; dropped on to feed shelf by screw conveyor; 1/2 ton/hr @ 5%; some feeding problems; plugging of rubber shreds to hopper if shreds have belts and beads.		References 2, 5, 7, and 16
St. Mary's Peerless Cement Detroit, MI	1 wet kiln; coal-fired			References 2 and 5
Lime Manufacture				
Boise Cascade Wallula, WA	1 rotary lime kiln; freed by gas, oil, and tires; venturi scrubber controlled.	TDF up to 15%	Yes; 5/86; baseline gas fired; TDF 15% with gas; measured PAH's and metals	Lime manufacturing rotary kiln. Reference 18

[a] PH = Preheater, PC = Precalciner, ESP = electrostatic precipitator, FF = fabric filter

4.2 PROCESS DESCRIPTION

In the portland cement manufacturing process, three steps occur. First, raw materials are crushed and mixed. The raw materials are powdered limestone, alumina, iron, and silica. Second, the raw materials are fed to an inclined rotary kiln in which they are heated to at least 2700°F. A rock-like substance called clinker is formed, which exits the kiln and is cooled. Third, the cooled clinker is finely crushed, and about 5 percent gypsum is added to produce finished cement. Details of the process are explained below.

4.2.1 Mixing and Grinding

Cement may be made via a wet or a dry process. In the wet process, water is added to the mill while grinding raw materials to form a slurry before entering the kiln. Much of the fuel must be used to evaporate this water from the feed. In the dry process, raw materials are also ground finely in a mill, but no water is added and the feed enters the kiln in a dry state. Therefore, much less fuel is needed in the kiln. Many older kilns use the wet process; in the past, wet grinding and mixing technologies provided more uniform and consistent material mixing, resulting in a higher quality clinker. Dry process technologies have improved, however, to the point that all of the new kilns since 1975 use the dry process. Figure 4-2 diagrams typical wet process material handling, and Figure 4-3 shows typical dry process material handling. Fuel type, or use of tires, does not affect this part of the operations, except that tire use may allow less iron to be added from raw materials. Usually, without an iron supplement, raw materials would contain about 2 percent iron; cement requires about 3 to 3.5 percent iron. Metal in tires is mostly steel and iron. One cement plant estimated that, in one test using whole tires, iron content was raised 0.1 percent by the tires.[16]

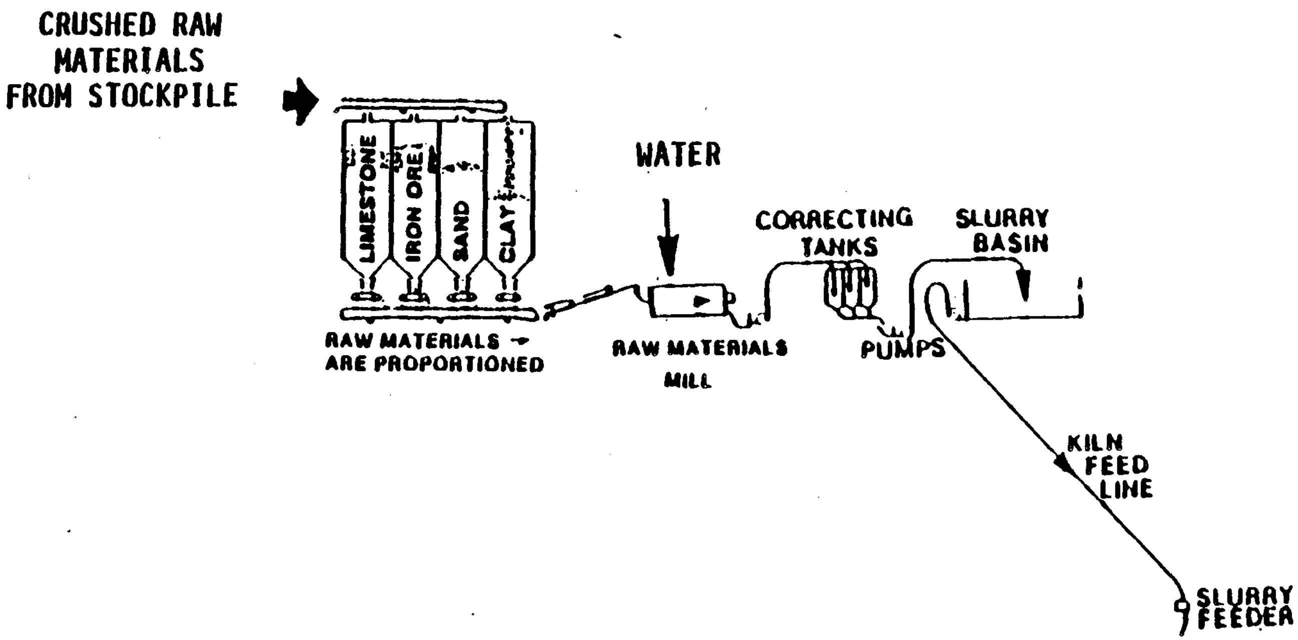


Figure 4-2. Typical wet process material handling during Portland Cement manufacture.[3]

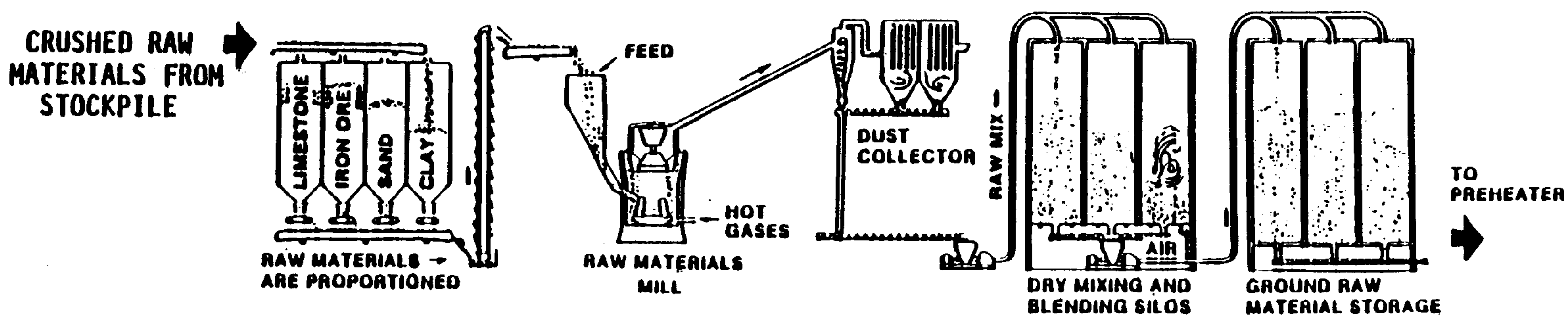


Figure 4-3. Typical dry process material handling during Portland Cement manufacture.[3]

4.2.2 Calcination

As stated in Chapter 2, cement kilns incline slightly toward the discharge end and rotate slowly. Feed materials slowly progress to the exit of the kiln by gravity. The majority of the fuel is burned at the discharge end of the kiln, so that the hot gases pass countercurrent to the descending raw feed material. Wet process kilns are typically over 500 feet long, and evaporation of water from the feed occurs in the first 20 to 25 feet of the kiln. Dry process kilns can be 20 to 25 percent shorter than wet process kilns because little or no residence time is needed to evaporate water from the feed and the feed heats faster. After evaporation, the temperature of the feed material increases to about 2700°F during passage through the kiln, and several physical and chemical changes occur. The water of hydration in the clay is driven off, the magnesium carbonate calcinates to MgO and CO_2, the calcium carbonate calcinates to CaO and CO_2, and, finally, the lime and clay oxides combine at the firing end of the kiln to form clinker. Figure 4-4 provides a schematic drawing of the typical clinker production process. Section 4.2.6 below discusses the various methods by which tires and TDF are being added to supplement kiln fuel.

4.2.3 Preheaters and Precalciners

Dry process cement production facilities often have several other types of manufacturing equipment designed to increase fuel efficiency. First, many dry process kilns add a preheater to the feed end of the kiln to begin heating of the feed prior to its entrance to the kiln. Two main types of preheaters exist, the suspension preheater and the traveling grate preheater; both use hot, exiting kiln air to facilitate a more efficient heat transfer to the feed than could occur in the feed end of the kiln itself.[1] This

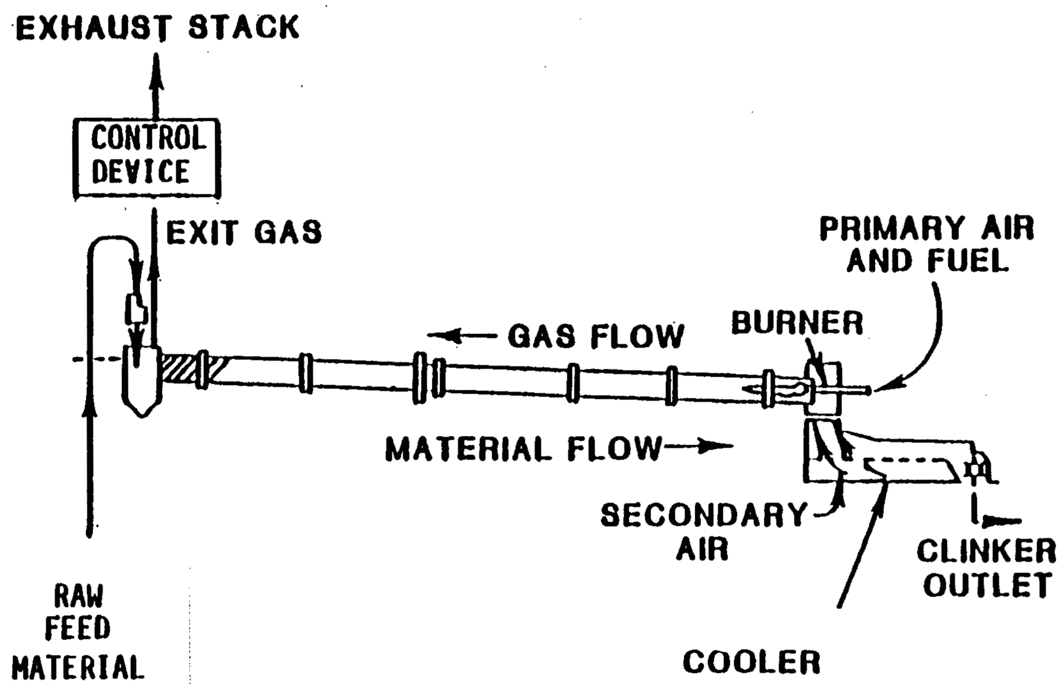


Figure 4-4. Typical clinker production process during Portland Cement manufacture.[3]

addition decreases the amount of fuel needed to form one ton of clinker. Compared to a wet process kiln, a dry process kiln with a preheater system can use 50 percent less fuel.[3]

The second development to increase fuel efficiency in a dry process kiln is a precalciner. For this system, a vessel called a flash precalciner is located between the preheater and the kiln, and is fueled by a separate burner. A discussion of tire use to supplement precalciner fuel is discussed in section 4.2.6 below.

Figure 4-5 shows a four-stage suspension preheater with a precalciner. Feed is blown from stage to stage by the rising countercurrent air, reaching the precalciner after Stage 3 and before being blown into Stage 4. Figure 4-6 shows a traveling grate preheater. About 95 percent of the calcining of the feed occurs in the precalciner. The calciner may use preheated air either from the kiln or the clinker cooler. Precalciners allow several operating advantages. Because calcination is rapid, adjustment to the calcination rate can be made quickly to yield uniform feed calcination. A kiln with a precalciner is shorter, because less distance is needed for calcination. Also, production capacity can be increased over a kiln of identical diameter without a precalciner, because the shorter kiln can be rotated at a higher rate while still maintaining proper operating characteristics of feed residence time and bed depth.

4.2.4 Finished Cement Grinding

Calcined clinker is ground in ball mills, mixed with gypsum, and shipped in bags or bulk. Figure 4-7 depicts finish mill grinding and cement shipping. The type of fuel used to make clinker does not affect these operations.

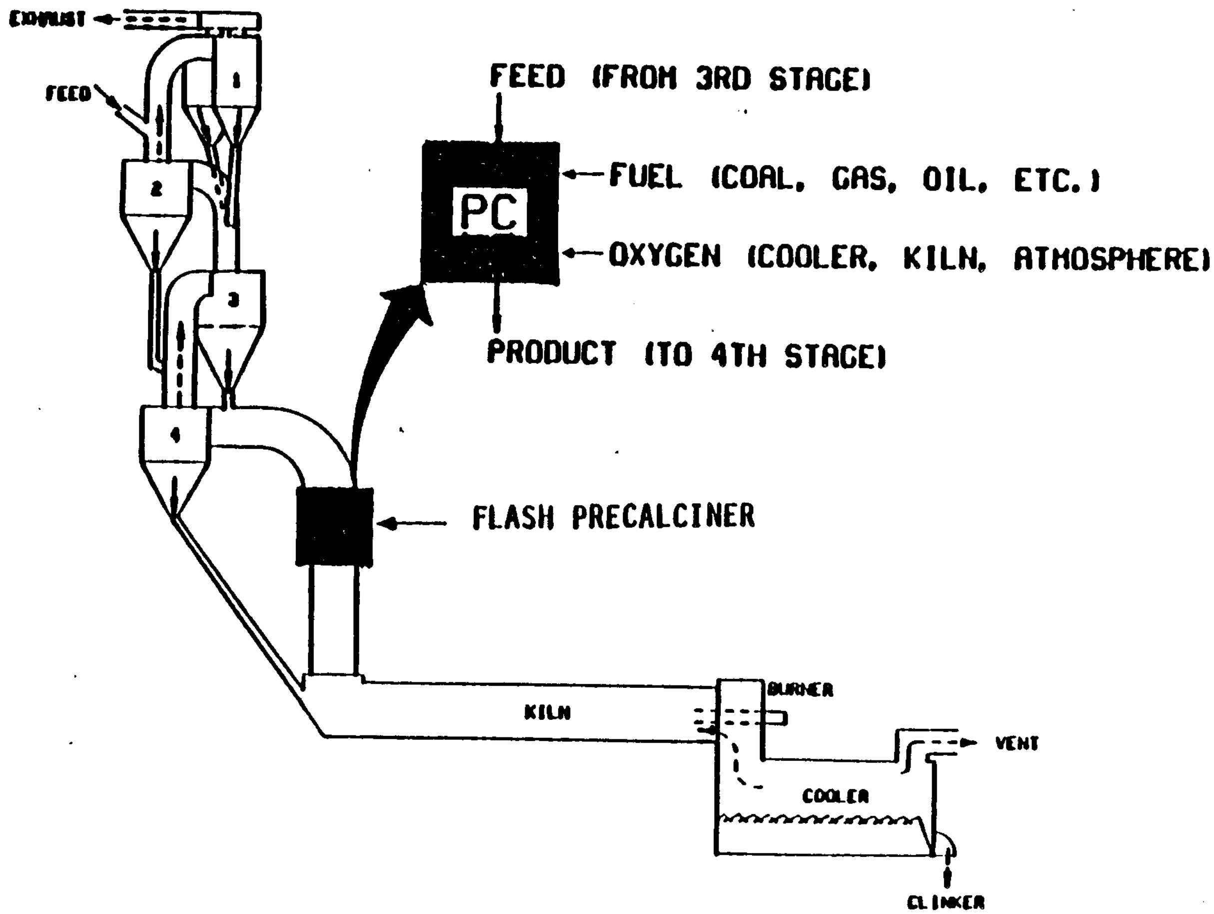


Figure 4-5. Four-stage suspension preheater with a precalciner at a Portland Cement plant.[3]

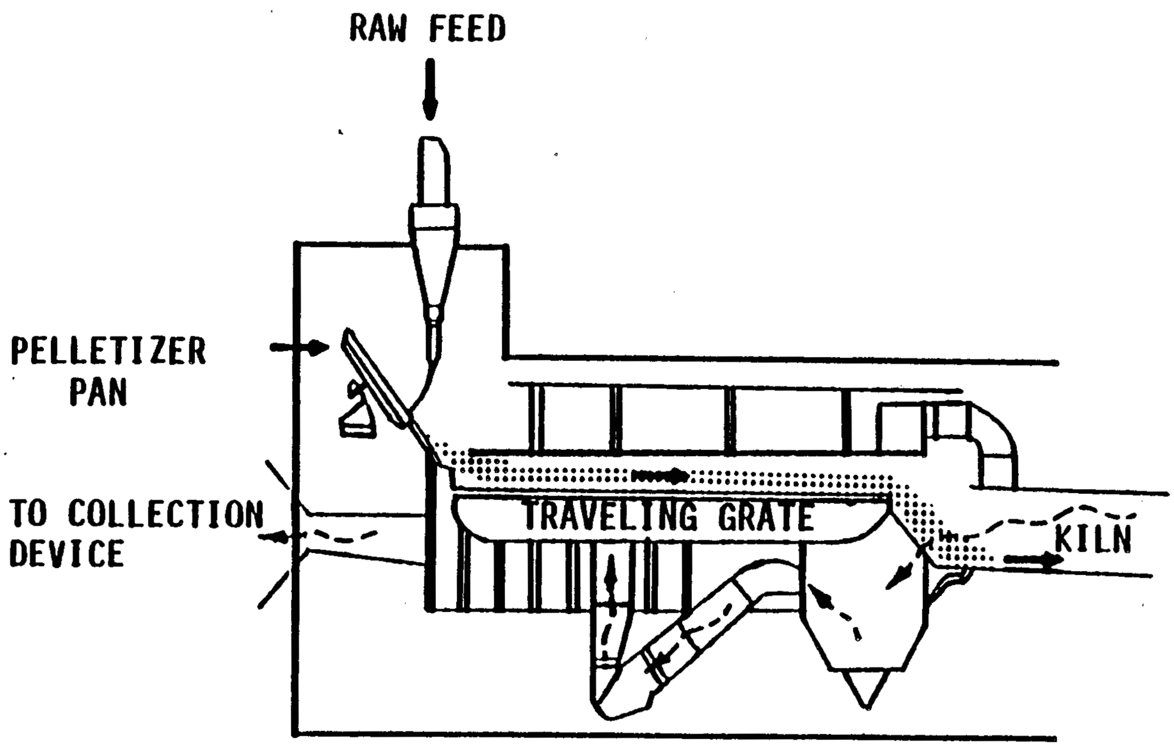


Figure 4-6. Traveling grate preheater system at a Portland Cement plant.[3]

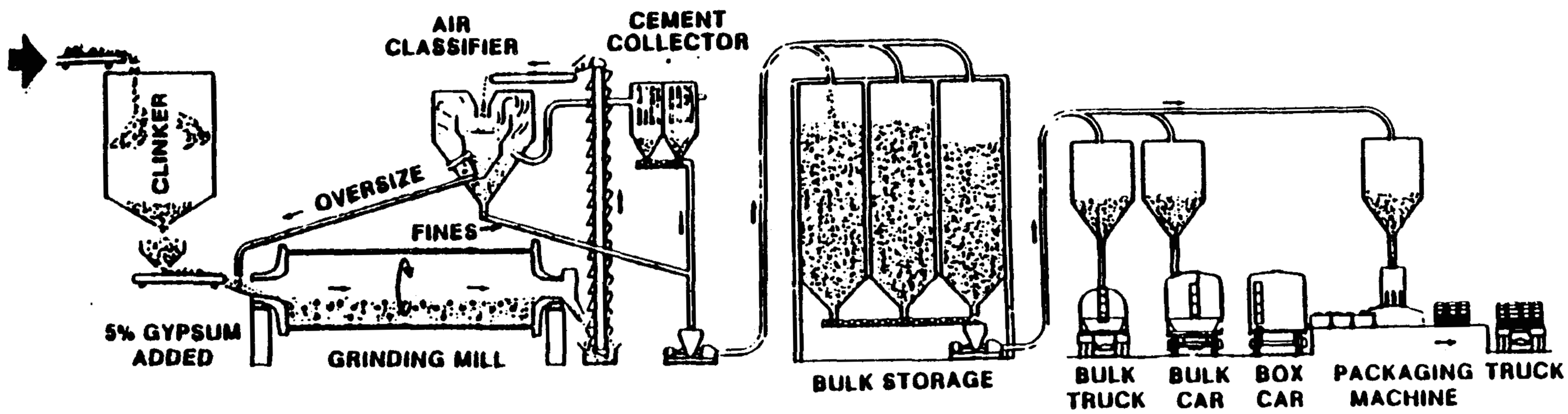


Figure 4-7. Finish mill grinding and shipping during Portland Cement manufacture.[3]

4.2.5 Tires as Fuel in the Kiln

Tires or TDF can be used to supplement the kiln fuel and/or the precalciner fuel. When TDF is added to the kiln fuel mix, it is often added at the burner (lower) end of the kiln, near, but not mixed with, the coal feed. At one plant (Holnam/Ideal), TDF is fed in above the coal flame.[19] This arrangement permits the chips to be blown further into the kiln and causes the chips to fall through the coal flame to produce much better combustion. In most cases, TDF is added at the feed end (high end) of the kiln. Several kilns have added whole tires at the feed end of the kiln so that burning occurs as the tires move down the kiln; this method is common in Europe.[4] However, many kilns in the U.S., particularly wet process kilns, have chains hanging down in the feed end of the kiln to enhance heat exchange. Such equipment forms a barrier to everything but finely ground materials, and precludes use of whole tires at the feed end. Kilns with preheaters provide the best environment for adding TDF or tires at the feed end, because significant preheating of the dry feed has occurred before the feed contacts the tire chips.

Tires have occasionally been used to supplement the primary precalciner fuel (usually coal), with mixed results. Florida Crushed Stone in Brookville, Florida, was feeding TDF into the preheater, but had to discontinue use because of plugging of the preheater (most likely due to oil condensate from the incomplete combustion of the tire chips). The company is in the process of installing a whole tire feeder with weight-belt, computer, variable rate belt, and triple gate chute to feed tires into the kiln.[10]

Southwestern Portland Cement in Victorville, California, not only adds TDF successfully to the preheater, but concurrently supplements the primary kiln fuel by mixing whole tires in the kiln feed.[16] Tire chips are added in the preheater, at the pyroclone (precalciner) unit, right after the tertiary air duct that brings hot air from the clinker cooler.[16] The chips burn quickly and go up the air stream into the preheater. Concurrently, whole tires are introduced into the feed end of the kiln with a double gate method. First, the tire is fed upright into a downward chute that slopes 30 to 40 degrees, so that it rolls down and stops at the second gate. The first gate closes and the second gate opens. The tire then rolls across the feed shelf and into the kiln. The double gate method reduces excess air introduction to and heat loss from the kiln.[16] Using both kinds of tires concurrently helps maximize the percent of fuel provided by tires. Whole tire use reduces coal used at the firing end of the kiln, but too many whole tires would provide too much heat in the kiln feed end. The TDF replaces coal used in the precalciner, but would not be used in the kiln, because they are more expensive than the whole tires.[16]

4.3 EMISSIONS, CONTROL TECHNIQUES AND THEIR EFFECTIVENESS

Testing results from three cement facilities and one lime kiln were evaluated for this report. The four facilities are: Ash Grove Cement, Durkee, Oregon; Holnam/Ideal Cement, Seattle, Washington; Calaveras Cement, Redding, California; and Boise Cascade Lime, Wallula, Washington.

Testing performed at Ash Grove Cement in Durkee, Oregon, on October 18 to 20, 1989, evaluated criteria pollutants, aliphatic and aromatic compounds, metals, and specifically examined chloride emissions to assess the possibility of dioxin formation.[20] Ash Grove's normal fuel is a mixture of gas and coal. As seen in Table 4-2, emissions of chloride were lower burning some TDF than with normal kiln firing, and; therefore, the Oregon Department of Environmental

Table 4-2. Effect of Burning 9 to 10 percent TDF in a Gas and Oil Co-fired Dry Process, Rotary Cement Kiln Controlled by an ESP[20]
Ash Grove Cement, Durkee, Oregon

Pollutant	Baseline, 0% TDF	9-10% TDF	Percent Change
Particulate, lb/MMBtu	0.969	0.888	-8
SO_2, lb/MMBtu	0.276	0.221	-20
CO, ppm	0.049	0.036	-27
Aliphatic compounds, lb/MMBtu	0.0011	0.0009	-18
Nickel, μg	30	DL[a]	NA[b]
Cadmium, μg	3.0	2.0	-33
Chromium, μg	30	DL[a]	NA[b]
Lead, μg	DL[a]	DL[a]	NA[b]
Zinc, μg	35	35	0
Arsenic, μg	0.2	0.2	0
Chloride, lb/hr	0.268	0.197	-26
Copper, μg	37	13	-65
Iron, μg	400	200	-50

[a] Below detection limit (DL).
[b] NA = not applicable.

Quality (DEQ) found that the use of TDF as a supplemental fuel at Ash Grove did not enhance the potential for dioxin formation.[20] The same report described screening tests performed for 17 specific polynuclear aromatic hydrocarbons (PAH's). Only three PAH's were detected (naphthalene, dibenzofuran, and phenanthrene) and each were detected in all eight samples. However, the highest levels of these compounds were detected while firing normal fuel (gas and coal), not when burning TDF.[20]

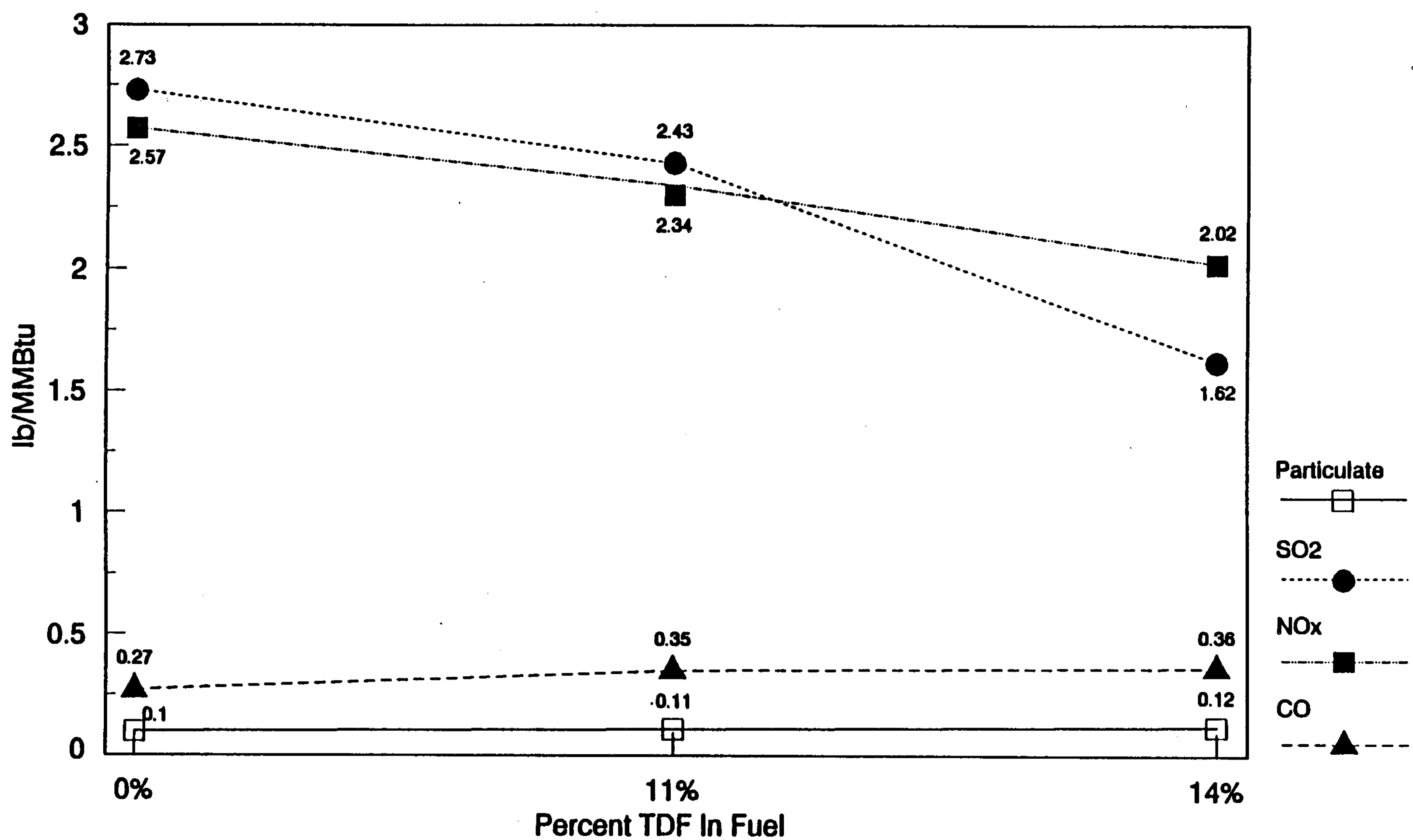
Testing at Ash Grove also examined total hydrocarbons, vaporous heavy metals, and approximately 115 other PAH's. Emission testing for total hydrocarbons showed results similar when burning TDF and under conditions when TDF was not burned. Since there are no permit limitations on total hydrocarbons, these were not addressed further in the report. For the ten metals tested, emissions during the tire chip burning were equal to or less than emissions when tire chips were not being burned. The report states that there is no evidence that the emission concentrations found for any of the 10 metals warrant concern. Finally, the screening of the other PAH's did not identify any other compounds of significance. For all PAH's, none of the compounds detected are listed as human carcinogens or possible human carcinogens.[20] The Oregon DEQ is requiring Ash Grove in Durkee to conduct a one-year ambient monitoring program for particulate emissions.[20]

In October, 1990, testing at Holnam/Ideal Cement, in Seattle, Washington, was performed at baseline (100 percent coal-fired), 11 percent TDF, and 14 percent TDF.[12] Holnam is a wet process cement plant. The kiln emissions are controlled with an ESP. Particulate, SO_2, NO_x, VOC, and semi-volatile organic compound emissions decreased significantly from baseline for both 11 and 14 percent TDF use rates. CO emissions increased 30 and 36 percent, respectively, for the 11 and 14 percent tests. Several metals were tested, including cadmium, chromium, copper, leak, and zinc. These also exhibited decreased emissions with the exception of chromium emissions during the 11 percent TDF test, which showed increased emissions.

Figure 4-8 graphs criteria pollutant emissions for each TDF level tested at Holnam's kiln.[12] The percent change in emissions of metals at Holnam is shown in Figure 4-9, and the percent change of VOC emissions is shown in Figure 4-10.[12] Table 4-3 summarizes the results of hazardous air pollutant (HAP) emission testing performed at Holnam.[12]

One lime manufacturing plant, Boise Cascade, in Wallula, Washington, burns 15 percent TDF supplementally to natural gas in their rotary kiln.[18] Testing was performed in 1986 for metals and organics only. Most significant were the dramatic increases in zinc, chromium, and barium emissions when burning TDF during the test.[18] The kiln emissions are controlled by a venturi scrubber, which would not be effective for collecting small metallic particles like zinc oxide. (The collection efficiency of venturi scrubbers decreases as particle size decreases.) Table 4-4 lists results of this test, and Figure 4-11 graphs the percent change in emissions of metals and organics from this kiln.[18]

Because of the extensive reuse of combustion air in the process at Calaveras' facility, the fabric filter exhaust is the only point of emissions for the kiln, clinker cooler, and raw mill. Exhaust gases from the fabric filter are monitored continuously for carbon monoxide, nitrogen oxides, and hydrocarbons. Calaveras has tested toxic pollutants while burning 20 percent TDF. Table 4-5 summarizes these test results, giving emission factors for metals, hazardous air pollutants, polyaromatic hydrocarbons, dioxins and



Note: A wet process coal-fired cement kiln controlled by an ESP.

Figure 4-8. Effect of burning TDF on criteria pollutant emissions from Holnam/Ideal Cement, Seattle, WA.[12]

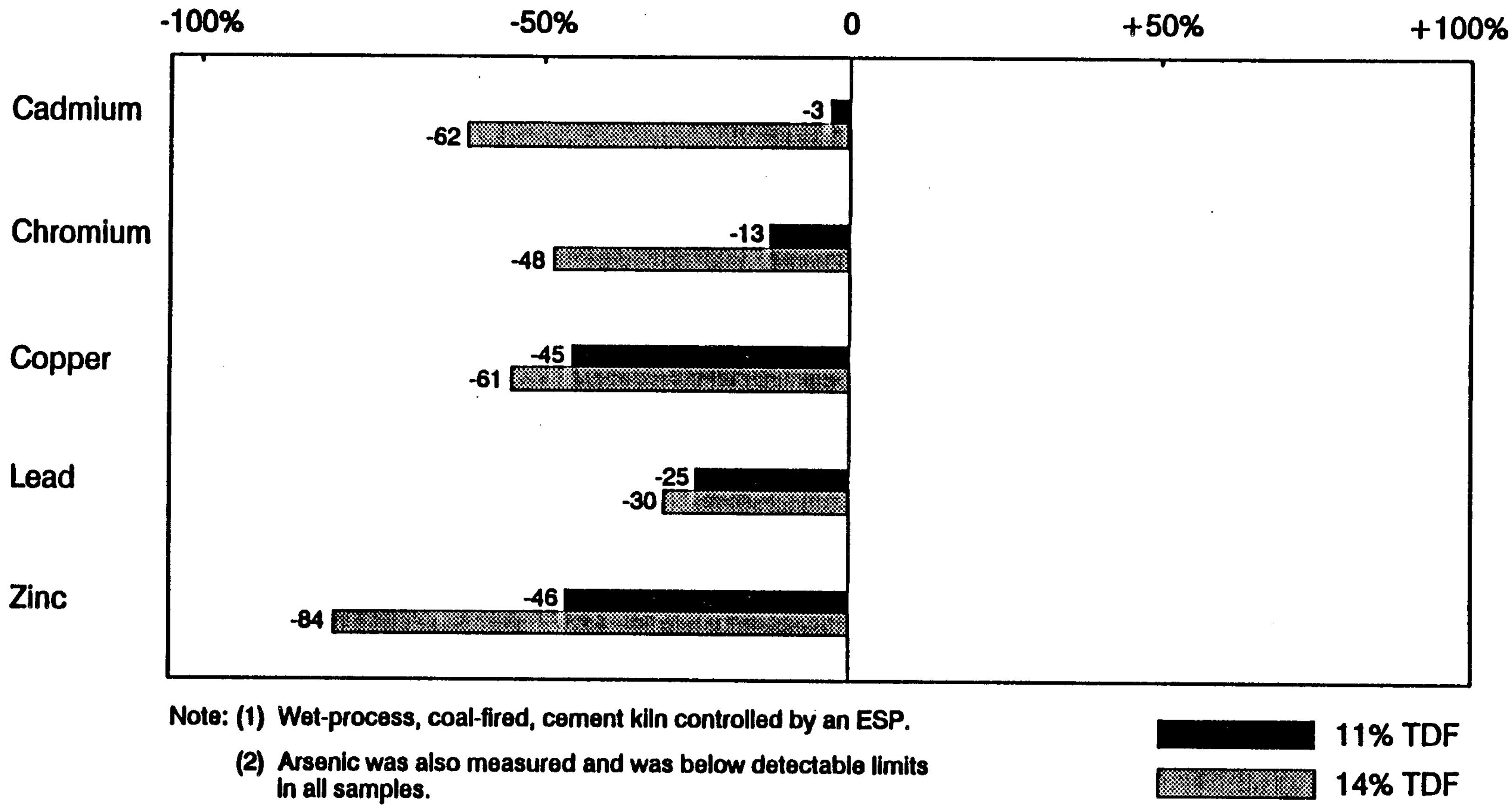
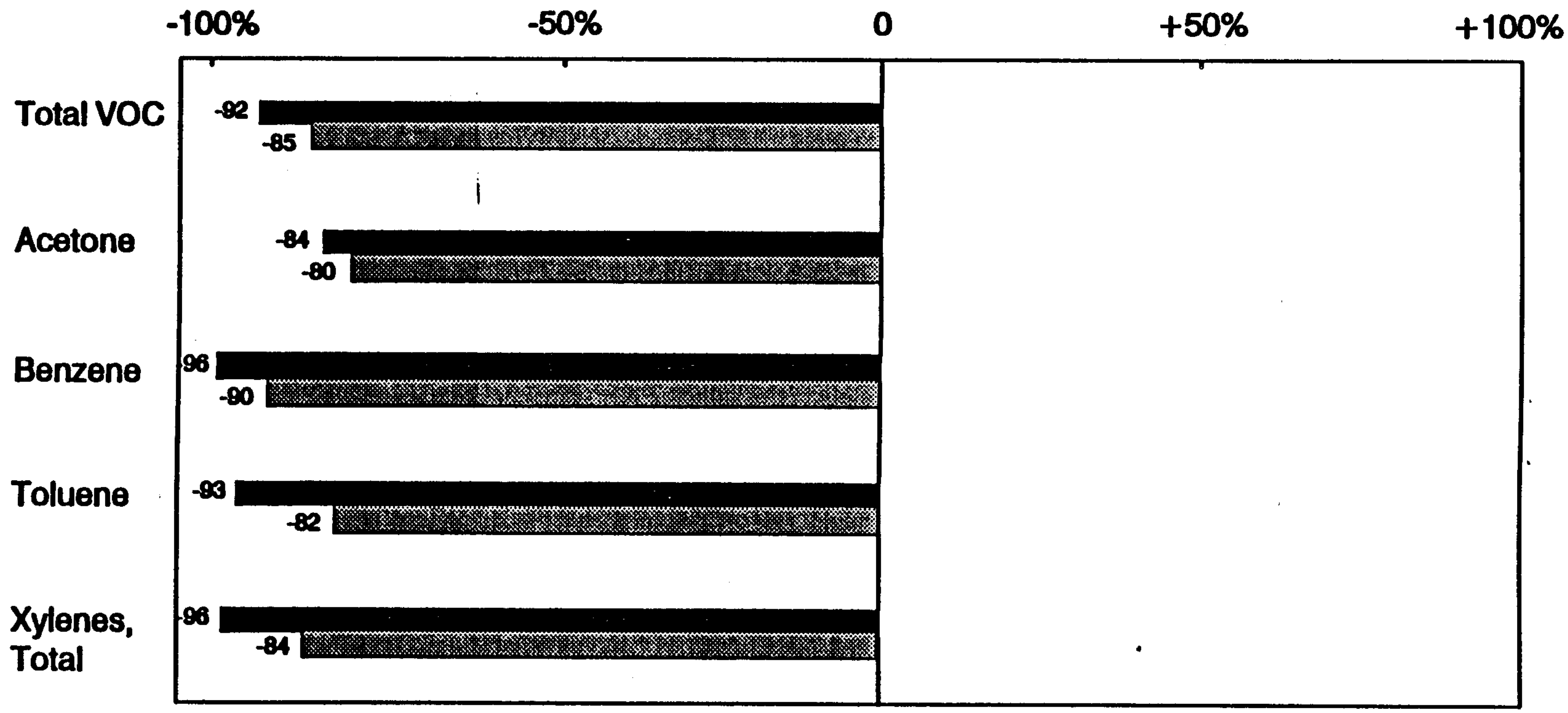


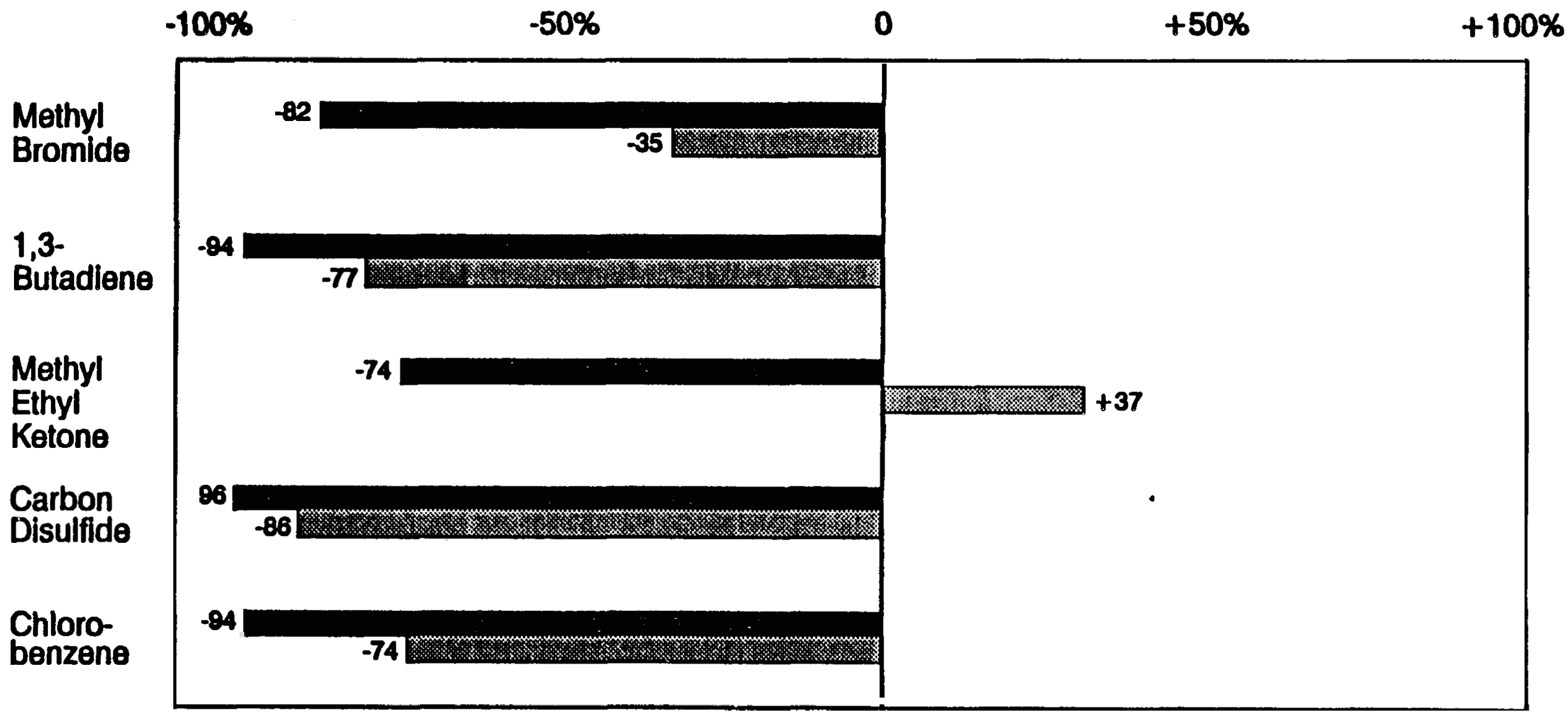
Figure 4-9. Percent change in emissions of metals when burning TDF at Holnam/Ideal Cement, Seattle, WA.[12]



Note: (1) Wet-process, coal-fired cement kiln controlled by an ESP.

(2) Carbon tetrachloride was measured also. Emissions increased from 0 gm/day at baseline to 0.81 gm/day and 6.6 gm/day at 11% and 14%, respectively.

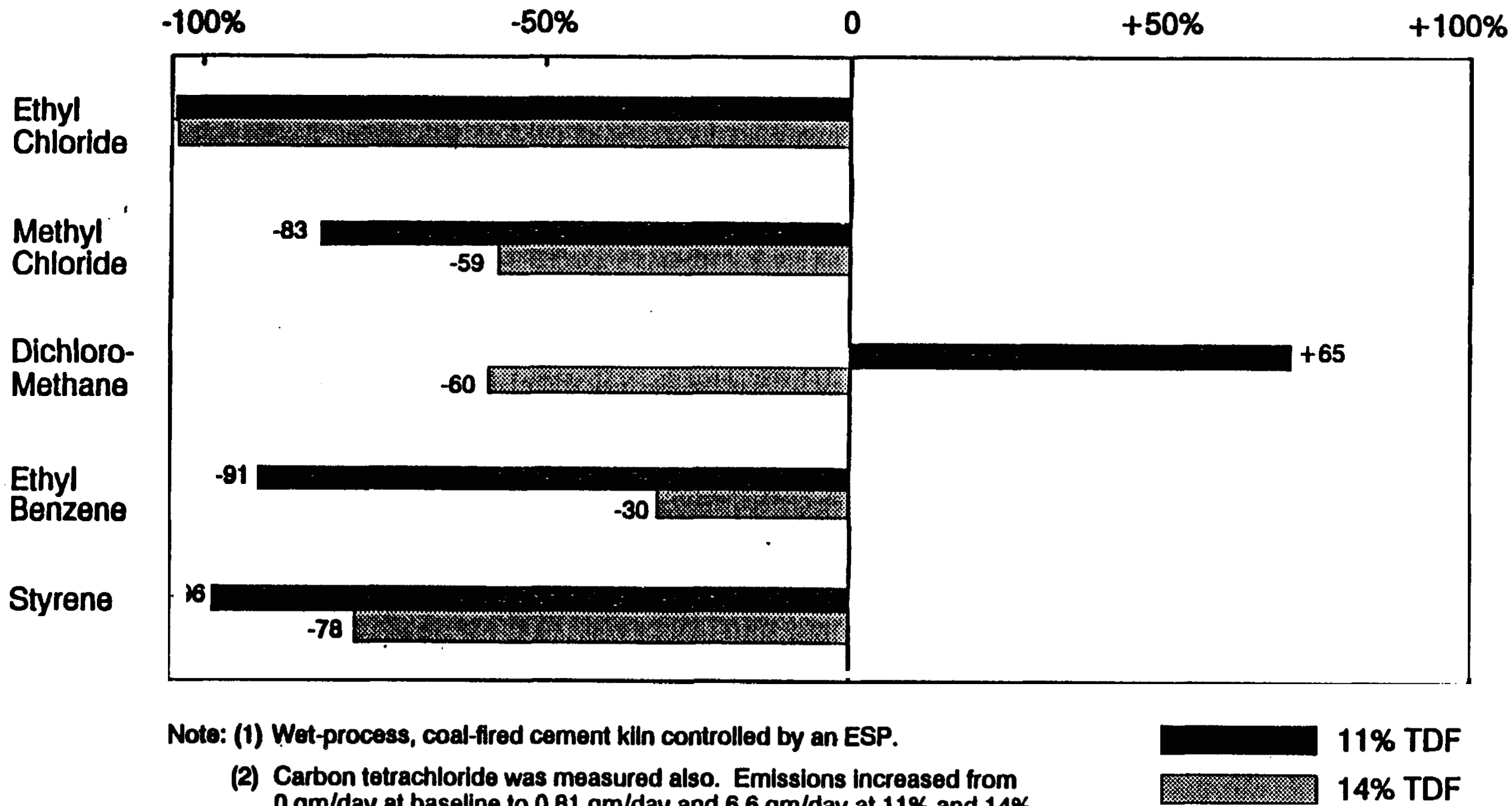
Figure 4-10. Percent change in VOC emissions when burning TDF at Holnam/Ideal Cement, Seattle, WA.[12]



Note: (1) Wet-process, coal-fired cement kiln controlled by an ESP.

(2) Carbon tetrachloride was measured also. Emissions increased from 0 gm/day at baseline to 0.81 gm/day and 6.6 gm/day at 11% and 14, respectively.

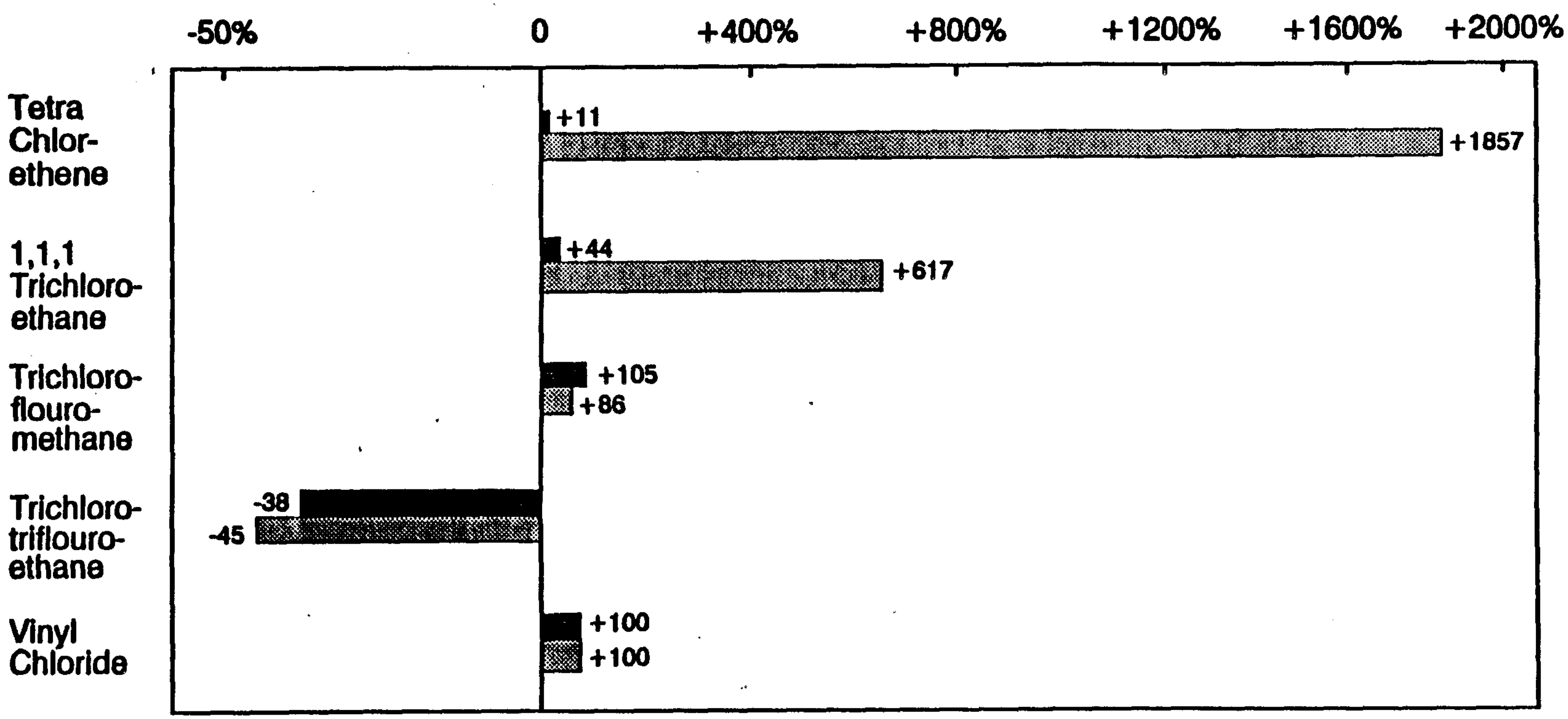
Figure 4-10. Percent change in VOC emissions when burning TDF at Holnam/Ideal Cement, Seattle, WA.[12] (Continued)



Note: (1) Wet-process, coal-fired cement kiln controlled by an ESP.

(2) Carbon tetrachloride was measured also. Emissions increased from 0 gm/day at baseline to 0.81 gm/day and 6.6 gm/day at 11% and 14%, respectively.

Figure 4-10. Percent change in VOC emissions when burning TDF at Holnam/Ideal Cement, Seattle, WA.[12] (Continued)



Note: Carbon tetrachloride was measured also. Emissions increased from 0 gm/day at baseline to 0.81 gm/day and 6.6 gm/day at 11% and 14%, respectively.

11% TDF
14% TDF

Figure 4-10. Percent change in VOC emissions when burning TDF at Holnam/Ideal Cement, Seattle, WA.[12] (Concluded)

Table 4-3. Effect of Burning TDF on HAP Emissions from Holnam/Ideal Cement, Seattle, WA[12,a]

Pollutant	Baseline 100% Coal, 0% TDF lbx10^{-6}/MMBtu	11% TDF		14% TDF	
		lb x 10^{-6}/MMBtu	% Change	lb x 10^{-6}/MMBtu	% Change
Acenaphthene	2.76	2.01	-27	2.06	-26
Acenaphthylene	0.22	0.00	-100	0.00	-100
Anthracene	2.46	0.00	-100	0.00	-100
Benzo(b)Anthracene	9.88	0.00	-100	0.00	-100
Benzoic Acid	10.46	0.00	-100	0.00	-100
Benzo(a)Pyrene	2.04	0.00	-100	0.00	-100
Benzo(g,h,i)Perylene	0.00	3.11	NA	10.33	NA
Bis(2 Chloroethoxy) Methane	222.42	173.45	-22	275.75	+24
Butyl benzyl Phthalate	5.98	0.00	-100	0.00	-100
Dibenz(g,h) Anthracene	106.69	47.67	-55	67.17	-37
Di-N-Butylphthalate	2.23	0.00	-100	0.00	-100
1,2-Dichlorobenzene	3.21	0.00	-100	0.00	-100
2,4-Dinitrotoluene	13.37	9.97	-25	9.00	-33
Fluorene	7.65	7.03	-8	7.12	-7
Hexachlorobenzene	73.49	40.42	-45	53.46	-27
Naphthalene	340.00	178.94	-47	159.20	-53
2-Nitroanaline	4.67	0.00	-100	5.02	+7
N-Nitrosodiphenyl-amine	90.81	47.60	-48	49.92	-45
Pyrene	4.97	2.38	-52	2.23	-55
1,2,4-Trichloro-benzene	17.45	2.57	-85	0.00	-100
4,6-Dinitro-2-Methyl phenol	5.53	0.00	-100	0.00	-100
4-Methyl Phenol	19.55	9.13	-53	15.28	-22
2-Nitrophenol	194.99	169.18	-13	172.12	-12
4-Nitrophenol	0.00	49.62	NA	29.77	NA
Pentachlorophenol	0.00	0.00	NA	0.00	NA
Phenol	320.95	161.04	-50	306.71	-4
2,4,5-Trichloro-phenol	0.00	0.00	NA	0.00	NA

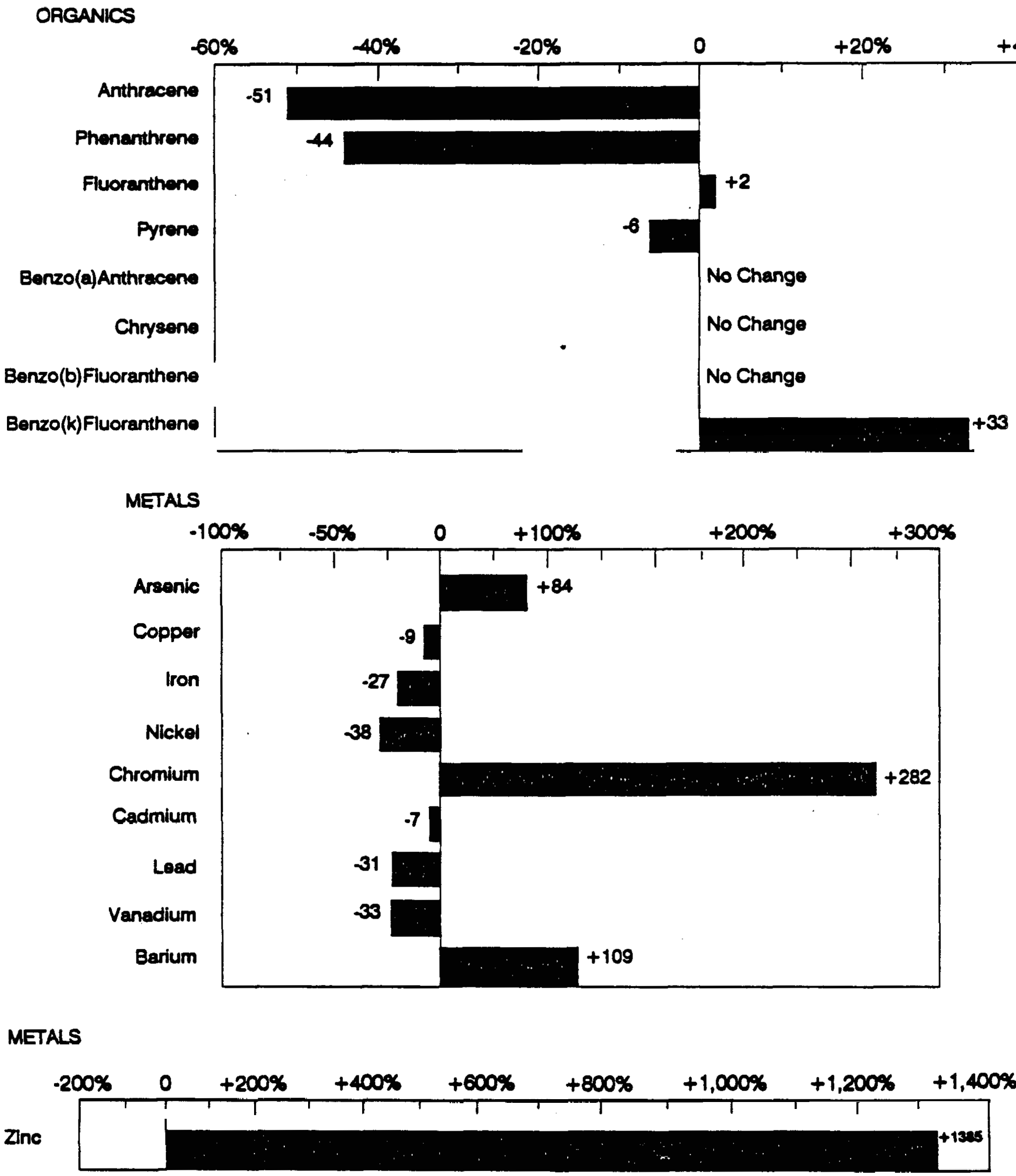
[a] Wet process, coal-fired, cement kiln controlled by an ESP.

Table 4-4. Effect of Burning 15 Percent TDF in a Gas-fired Rotary Lime Kiln Boise Cascade, Wallula, WA[18,a]

Pollutant	100% Gas-Fired lbx10^{-6}/MMBtu	85% Gas, 15% TDF lbx10^{-6}/MMBtu	% Change
Organics[b]			
Anthracene	3.7	1.8	-51
Phenanthrene	51.9	29.1	-44
Fluoranthene	8.6	8.8	+2
Pyrene	6.6	6.2	-6
Benzo(a)-Anthracene	1.1	1.1	0
Chrysene	1.1	1.1	0
Benzo(b)Fluor-anthene	0.8	0.8	0
Benzo(k)Fluor-anthene	0.3	0.4	+33
Metals			
Arsenic	1.9	3.5	+84
Copper	3.2	2.9	-9
Zinc	28.8	427.7	+1,385
Iron	231.7	168.3	-27
Nickel	5.6	3.5	-38
Chromium	83.3	318.6	+282
Cadmium	1.4	1.3	-7
Lead	4.1	2.8	-31
Vanadium	5.7	3.8	-33
Barium	24.9	52.1	+109

[a] Kiln emissions are controlled by a variable throat venturi scrubber, 27-29 in. H_2O.[18]

[b] Also measured, but not detected with or without (TDF) were naphthalene, acenaphthalene, benzo(a)pyrene, dibenzo(a,h)anthracene, benzo(g,h,i)perylene, and indeno(1,2,3-cd)pyrene.



Note: Also measured, but not detected with or without TDF, were naphthalene, acenaphthalene, benzo(a)pyrene, dibenzo(a,h)anthracene, benzo(ghi)perylene, and indeno (1,2,3-cd)pyrene.

Figure 4-11. Percent change in emissions when burning 15% TDF in a gas-fired rotary lime kiln controlled by a venturi scrubber.[18]

Table 4-5. Emissions Estimates for Calaveras Cement Kiln Stack While Burning Twenty (20) Percent TDF[21]

Compound	Emission Factor		Emission Rate (lbs/hr)
	grams/ton clinker	grams/MMBtu	
Metals			
Arsenic	3.63×10^{-3}		7.4×10^{-4}
Beryllium	5.33×10^{-4}		1.1×10^{-4}
Cadmium	6.63×10^{-3}		1.4×10^{-3}
Chromium (hex)	3.00×10^{-4}		6.2×10^{-5}
Copper	6.20×10^{-3}		1.3×10^{-3}
Lead	1.88×10^{-2}		3.9×10^{-3}
Manganese	4.96×10^{-2}		1.0×10^{-2}
Mercury	4.33×10^{-2}		8.9×10^{-3}
Nickel	8.52×10^{-2}		1.7×10^{-2}
Selenium	2.12×10^{-2}		4.3×10^{-3}
Zinc	3.79		7.8×10^{-1}
Formaldehyde		2.98	1.8
Benzene		0.17	1.0×10^{-1}
Dioxins/Furans		4.2×10^{-7}	2.5×10^{-7}
PAH's (total)		2.9×10^{-1}	1.8×10^{-1}
Phenols		6.8×10^{-2}	4.0×10^{-2}
Chlorobenzenes		2.8×10^{-3}	1.7×10^{-2}
Radionuclides		7.5×10^{-7}	4.5×10^{-7}
Crystalline Silica	4.5×10^{-1}		9.2×10^{-2}
Toluene		3.80×10^{-2}	2.3×10^{-2}
Xylene (p + m)		1.85×10^{-2}	1.1×10^{-2}
Xylene (o)		1.85×10^{-2}	1.1×10^{-2}
Actealdehyde		1.86	1.1
PCB		5.0×10^{-4}	3.0×10^{-4}

Table 4-5. (Concluded)

Compound	Emission Factor grams/ton clinker	Emission Factor grams/MMBtu	Emission Rate (lbs/hr)
Hydrogen flouride	0.04		8.2×10^{-3}
Hydrogen chloride	1.25		2.5×10^{-1}
Vinyl chloride		5.61×10^{-4}	3.4×10^{-4}
Methylene chloride		7.55×10^{-4}	4.6×10^{-4}
Chloroform		4.25×10^{-4}	2.5×10^{-4}
1,2-dichloroethane		3.54×10^{-4}	2.1×10^{-4}
1,1,1-trichloroethane		8.21×10^{-4}	5.0×10^{-4}
1,2-dibromoethane		1.87×10^{-3}	1.0×10^{-3}
Trichloro ethylene		4.70×10^{-4}	2.8×10^{-4}
Tetrachloro-ethylene		5.93×10^{-4}	3.5×10^{-4}
Particulate	18.22		3.7

furans, and particulates. Testing did not include baseline (without TDF in the fuel) conditions.[21]

As seen in Table 4-5, particulate emissions were found to be emitted at a rate of 0.04 lb/ton clinker. In 1981, particulate emissions from the kiln, clinker cooler, and raw mill were estimated to be 0.027 lb/ton clinker burning only coal. When the raw mill was bypassed (i.e., kiln and cooler dust were not recycled), emissions from the kiln and cooler were estimated to be 0.051 lb/ton clinker.[21]

Test results using CEMS at Southwestern Portland Cement in Victorville, California, showed no increase in particulates, a decrease in NOx, and an increase in CO.[16]

4.4 OTHER ENVIRONMENTAL AND ENERGY IMPACTS

No information was found that indicated other environmental impacts for the cement industry as a result of using whole tires or TDF. Often, cement dust is ducted back into the kiln, except in cases where the alkali content of the dust would cause a problem for the quality of the finished cement. In those cases, the dust from the fabric filter or ESP is landfilled. This situation does not change with tire use. At Holnam, plant personnel have experimented with briquetting ESP dust.[19]

Permit conditions were found in several cases that limited the storage and transportation of tires on plant premises,and that mandated safety and emergency procedures and precautions because of the fire hazards.

In one case, the State has limited a cement plant to the sources of its tires. Gifford-Hill in Harleyville, S.C., has a permit condition that the tires must come from a tire dealer, not a landfill or an outside storage facility. This condition was added because the State has had problems with tires contaminated with garbage or were infested with mosquitoes.[11]

4.5 COST CONSIDERATIONS

Use of tires or TDF is economical only in relation to other supplemental or waste fuels in the industry on a regional basis. The kilns most likely to burn TDF are those with preheaters because the introduction of tires into the kiln is more easily accomplished through the preheater (i.e., it is more difficult to feed tires into kilns without a preheater).

Calaveras, which burns approximately 60 tons per day, purchases 2-inch wire-in TDF for approximately $30 per ton. On a dollar per Btu basis, this is approximately one-half the cost of coal. Calaveras will be installing a whole tire feed system, which will cost about $400,000. (In this system, whole tires will be fed by a conveyor into the exhaust of the kiln.) A tipping fee of between $0.50 and $1.00 per tire for whole tires will be charged by Calaveras. Once the whole tire system is in place, Calaveras estimates that the tire fuel will cost one-tenth or less the cost of coal on a Btu basis.[21]

At another cement manufacturer, Holnam/Ideal, TDF costs are 34 percent of their coal costs on a dollar per Btu basis. Fuel costs at Holnam/Ideal are approximately 19 percent of their production costs. Of this 19 percent, coal accounts for 50 percent of the cost; coke, 35 percent; and TDF, 15 percent.[19]

4.6 CONCLUSIONS

The long residence time and high operating temperatures of cement kilns provide an ideal environment to burn tires as supplemental fuel. Results of several tests conducted on cement kilns while burning tires or TDF indicate the emissions are not adversely affected, but in many cases improve when burning tire.

Costs associated with modifying feed equipment to burn TDF in cement kilns is minor in most cases. Cost savings in fuel cost can be 70 to 90 percent of the cost of the primary fuel, depending on location and governmental incentives.

Overall, burning tires or TDF in cement kilns appear to be an economically satisfactory and environmentally sound way of not only disposing scrap tires, but also reclaiming their fuel value.

4.7 REFERENCES

1. U.S. Environmental Protection Agency. Market for Scrap Tires. EPA/530-SW-90-074B. September 1991.

2. Portland Cement Association, U.S. and Canadian Portland Cement Industry: Plant Information Summary. December 31, 1990.

3. U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards. Portland Cement Plants--Background Information for Proposed Revisions to Standards. EPA-450/3-85-003a. May 1985.

4. Scrap Tire Fuel for Cement Kilns. Exchange Meeting Summary. Sponsored by U.S. Department of Energy, Office of Industrial Programs. October 2, 1984. Chicago, Illinois. CONF-8410167

5. Ohio Air Quality Development Authority. Air Emissions Associated with the Combustion of Scrap Tires for Energy Recovery. Prepared by: Malcolm Pirnie, Inc. May 1991.

6. Telecon. Russell, D., Pacific Environmental Services, Inc., (PES) with Hale, C., Ash Grove Cement Co. March 1, 1991. Ash Grove's TDF experience.

7. Memorandum from Clark, C., PES, to Michelitsch, D., EPA/ESD/CTC. Summary of Meeting with Scrap Tire Management Council. October 29, 1991.

8. Telecon. Clark, C., PES, with Siemering, W., Calaveras Cement. February 20, 1991. Calaveras' TDF experience.

9. Telecon. Clark, C., PES, with Justice, A., Illinois Department of Energy and Natural Resources. February 19, 1991. TDF use in Illinois.

10. Telecon. Russell, D., PES, with Lauer, C., Florida Crushed Stone, Brookville, Florida. March 15, 1991. TDF experience.

11. Telecon. Russell, D., PES, with Bunn, L., South Carolina Department of Health and Environmental Control. February 14, 1991. South Carolina TDF experience.

12. Amtest. State of Washington, Department of Ecology. Rubber Tire Chip Trial Burn. Holnam Incorporated Industries. Stack Testing and Chemical Analysis. October 15-19, 1990.

13. Telecon. Clark, C., PES, with Hoard, S., Holnam/Ideal Cement, Inc., Seattle, Oregon. March 5, 1991. TDF experience.

14. Telecon. Russell, D., PES, with Allan, G., California Air Resources Board. February 14, 1991. Facilities burning tires or TDF in California.

15. Campbell, Tom. "Cement Maker Plans to Use Tires as Fuel in Botetourt Kiln." Article in Richmond Times Dispatch, June 6, 1991. p. E-6.

16. Telecon. Clark, C., PES, with McIver, D., Southdown, Southwestern Portland Cement. February 28, 1991. Southdown's TDF experience.

17. Telecon. Clark, C., PES, with Hilkins, T., Ohio EPA, Air Division. February 28, 1991. TDF use in Ohio.

18. Source Test for Boise Cascade Lime Manufacturing Facility, Walluloa, WA. Prepared for Washington Department of Ecology. Test Date: May 20, 1986.

19. Memorandum from Clark, C., PES, to Michelitsch, D., EPA/ESD/CTC. October 28, 1991. Site Visit -- Calaveras Cement Company.

20. Oregon Department of Environmental Quality. Air Contaminant Discharge Permit Application Review Report. Permit Number: 01-0029. Applicaton No.: 12326. Ash Grove Cement West, Inc., Durkee, OR. March 1990.

21. Memorandum from Clark, C., PES, to Michelitsch, D., EPA/ESD/CTC. November 8, 1991. Site Visit -- Holnam, Inc./Ideal Cement.

5. TDF AS FUEL IN WASTE WOOD BOILERS AT PULP AND PAPER MILLS

Pulp mills generate large amounts of waste wood products, such as bark and contaminated wood residues, in the process of making wood chips for the pulp digester. Also, many paper companies operate saw mills adjacent to the wood yard to maximize resources; these mills generate waste wood slabs, logs, trimmings, pellets, shavings, saw dust, etc., that can be a solid waste disposal problem.[1] Heating value of these waste wood ranges from about 7,925 to 9,010 Btu's per pound of fuel, on a dry basis. Tires, as mentioned earlier, generate 15,000 Btu's per pound. Bark is the most common component of waste wood in the pulp and paper industry.[1]

Many mills burn this wood waste in boilers to obtain heat energy for process steam, and to alleviate possible solid waste disposal problems. These waste wood boilers are known as "hog-fuel" boilers. A base load of supplemental fuel of some kind is required in hog-fuel boilers, because the significant variations of the size, moisture content, and heating value of the wood waste may not allow consistent boiler performance. Supplemental fuel facilitates uniform boiler combustion, and ensures that a minimum amount of power is generated regardless of the fuel value of the wood waste at any one time.

Operators traditionally use coal, gas, or oil, whichever is the cheapest fuel in their area, as the supplemental fuel. For the past 15 years, however, some paper mills have used TDF commercially or on a test basis in hog-fuel boilers.[2] The consistent Btu value and low moisture content of TDF in combination with its low cost in comparison to other supplemental fuels make TDF an especially attractive alternative fuel in this industry.

The economic value added by the use of TDF varies by location, and, thus, TDF is not universally the most economical fuel for use in pulp and paper mill hog fuel boilers.

5.1 INDUSTRY DESCRIPTION

As of the Summer of 1991, at least 10 pulp and paper companies are adding tire-derived-fuel (TDF) to their hog fuel boilers as an alternative supplemental fuel. In addition to boilers at pulp and paper plants, one boiler at a silicon manufacturing facility burns TDF supplementally with their primary fuel of waste wood chips. Information and emissions data from this boiler have been included with this section. Table 5-1 contains a list of pulp and paper mills that have burned TDF commercially, or have tested TDF in the past.

The most common type of boiler configuration to burn hog-fuel is the spreader stoker type, although some overfeed stokers also exist. Spreader stoker boilers can burn fuel with high moisture content, are relatively easy to operate, and have relatively high thermal efficiency. Overfeed stoked boilers have lower particulate emissions relative to spreader stoker boilers because less combustion occurs in suspension.[13]

In recent years, environmental concerns over water quality have led to installation of waste water treatment plants at pulp and paper mills. The underflow from the primary clarifier has generated another solid waste disposal problem. To solve this problem, some mills are feeding clarifier sludge to hog fuel boilers. The high moisture content of the sludge in conjunction with its low Btu content creates more difficult operating conditions for the furnace. Comparative composition of TDF, coal, wood waste,

Table 5-1. Pulp and Paper Mills with Experience Burning TDF in Waste Wood Boilers

Company and Location	TDF Use	Air Emissions Test Data	Boiler(s) Description	Comments/References
Augusta Newsprint Augusta, GA	Current	Unknown		
Champion International Bucksport, ME	Shredded; 2" or less, wire free; 2.5 tons/hr (permitted up to 3.5 tons/hr)	Unknown	4 boilers; 3 burn oil only, 4th burns multifuels at 500,000 lbs/hr.	Reference 3
Champion International Sartell, MN	Past	Yes; NO_x, metals, non-methane organics; tests were done with coal at 80% level both for baseline and TDF test, TDF at 1.5%, and rest wood chips.		Reference 3
Crown Zellerbach Port Angeles, WA	Current TDF or oil used with wood;	Yes, PNA's, metals	Oil boiler converted to burn hog fuel; venturi scrubber	Reference 3
Dow Corning Corporation Midland, MI	Current	Yes; PM, PM_{10}, SO_2, NO_x, metals	275,000 lb/hr, ESP	Silicon production facility; TDF used in wood chip boiler. Reference 3
Fort Howard Corporation Rincon, GA	Current			
Fort Howard Corporation Green Bay, WI	Current 3%; 2"x2" and 1"x1"; 30 tons tire/1000 tons coal per day	No; None required	Plant has 6 boilers total: 3 underfeed type that use 2"x2" TDF; 2 spreader-stoker type that use 1"x1" TDF; 1 cyclone fed with no TDF use now, but use planned.	Produce recycled paper; coal other base load fuel. References 3 and 4
Georgia-Pacific Paper Cedar Springs, GA	Current 1.5"x1.5"; 5%	Yes; Test regularly for particulate; also have tested for NO_x and SO_2	Boiler is spreader/stoker traveling grate type; generates 500,000 lbs steam/hr at 880 psig and 900°F. TDF is fed on the bark conveyor.	Used to be Great Southern Paper; have burned TDF for several years; permitted for 100 tpd TDF, but average 60 tpd; coal other base load fuel. References 4 and 6
Georgia-Pacific Toledo, OR	Past		Plant had many violations, even when not burning tires. Given up on tire burning currently	Reference 6

Table 5-1. (Concluded)

Company and Location	TDF Use	Air Emissions Test Data	Boiler(s) Description	Comments/References
Inland-Rome Paper Rome, GA	Current 10 % TDF in 2 of 4 boilers	Yes; opacity, particulate, and NO_x.	Plant has 4 boilers total: 2 burn coal only; 2 burn hog fuel and about 10% (Btu basis) TDF. Both hog fuel boilers are Combustion Engineering boilers rated at 165,000 lbs steam/hr with vibrating stoker grates, 366 ft^2 in size. All 4 boilers are vented together and controlled by multicyclones and one ESP. TDF fed from a hopper with a variable speed screw outflow, and are added to the bark stream.	Have been burning TDF for 3 years; did obtain permit modification. References 2, 3, and 7
Packaging Corp. of America. Tomahawk, WI	Current	Yes; tests performed for criteria, hazardous, and toxic pollutants, including metals and dioxin/furan; testing done on an overall facility basis, with all boilers vented together, some not burning tires.	Three traveling grate spreader/stoker type boilers; all vent to common duct, then separate to two ESP's and stacks.	Formerly Owens Illinois, Nekoosa, and Georgia Pacific; produces corrugated paper materials. Reference 8
Port Townsend Paper Port Townsend, WA	Current; usually 3-8% of fuel is oil or TDF	Yes; Particulates, PNA's, heavy metals	1977; 200,000 lb/hr; venturi scrubber	Reference 3
Rome Kraft Pulp and Paper Mill Rome, GA		Unknown		Reference 3
Smurfit Newsprint Newburg, OR	Current 1% 2"x2"	Yes; boiler # 10, particulate, VOC	Two boilers using TDF; #9 spreader/stoker, 145,000 lb/hr, fixed grates, venturi scrubber; # 10 spreader/stoker, 300,000 lb/hr traveling grate, venturi scrubber just replaced with ESP 6/91	Hope to increase percent TDF limit after ESP operational. References 3 and 9
Sonoco Products Co. Hartsville, SC				Reference 3
Willamette Industries Albany, OR	Current 2% 2"x4" TDF	Yes	Control by wet scrubber; stoker fed type hog fuel boiler. Feed is done with a homemade hopper and feed conveyor. TDF is mixed with the hog fuel after the hog fuel exits a dryer.	References 3, 10, 11, and 12

and clarifier sludge were provided in the introduction in Table 1-2 and is reprinted here.

Table 1-2. Comparative Fuel Analysis, by Weight[3]

Fuel	Component (percent)							Heating Value
	Carbon	Hydrogen	Oxygen	Nitrogen	Sulfur	Ash	Moisture	Btu/lb
TDF	83.87	7.09	2.17	0.24	1.23	4.78	0.62	15,500
Clarifier Sludge	4.86	0.49	2.17	0.47	0.26	3.16	88.69	924
Coal	73.92	4.85	6.41	1.76	1.59	6.23	5.24	13,346
Wood Waste								
Test 1	30.98	3.16	23.33	0.13	0.04	1.31	41.05	5,225
Test 2	28.29	2.37	20.95	0.13	0.03	1.49	46.73	4,676
Test 3	25.67	2.54	19.17	0.12	0.03	1.11	51.36	4,031
Test 4	24.71	2.44	18.46	0.12	0.02	1.13	53.12	4,233

5.2 PROCESS DESCRIPTION

Most waste heat boilers are fairly small, ranging from 100,000 to 200,000 pound of steam per hour (100 to 200 MMBtu's per hour). Overall feed rate of hog fuel averages about 84 tons per hour. The maximum rate of TDF is between 10 and 15 percent of the total Btu's required. The reason for this is that one of the main uses of the hog fuel boiler is to burn hog fuel. Ten to 15 percent TDF is all that is needed to accomplish this.

Varied boiler firing configurations are found in hog fuel boiler applications, including dutch oven, fuel cell, spreader stoker with traveling or vibrating grates, and cyclone stoker types. As stated previously, the spreader stoker is the most widely used of these configurations. Spreader/stoker boilers in the pulp and paper industry often have an air swept spout added to the front of the boiler to feed bark down on top of the coal.[14] Wood is puffed at one-second intervals through the spout so it falls onto the coal base on the grate. The air swept spout can also blow TDF sized up to about 3" x 2", without any additional capital equipment expenditure. However, to retrofit an existing spreader/stoker boiler with an air swept spout to accommodate TDF fuel is not economically feasible.[14]

Alternatively, in the waste heat boiler, bark, wood waste, and sludge are conveyed to an overhead, live-bottom bin. This fuel is then introduced to the boiler furnace by an air jet, which casts the fuel out over the stoker grate in a thin, even layer.[1] The advantage of this type of boiler configuration is that it has a fast response to load changes, has improved combustion control, and can be operated with a variety of fuels.[1]

If coal is the primary base load fuel, it is typically pulverized and fed to separate pneumatic systems that feed individual burners. TDF, when used, is usually fed via a variable-rate weigh belt or variable-speed screw conveyor to the bark conveyor feeding the overhead bin. This configuration permits effective mixing of TDF, bark, wood waste, and sludge.

Figure 5-1 is a schematic diagram of the process flow through Smurfit Newsprint's two hog-fuel boilers. Wood sludge, waste wood chips, and bark are fed into the two boilers. TDF is added as a supplemental fuel, and is currently limited by an air permit to 1 percent of the boiler fuel. Exhaust from the combustion chamber of the boilers exits through multicyclone systems and scrubbers, which collect ash from the exhaust streams.[15]

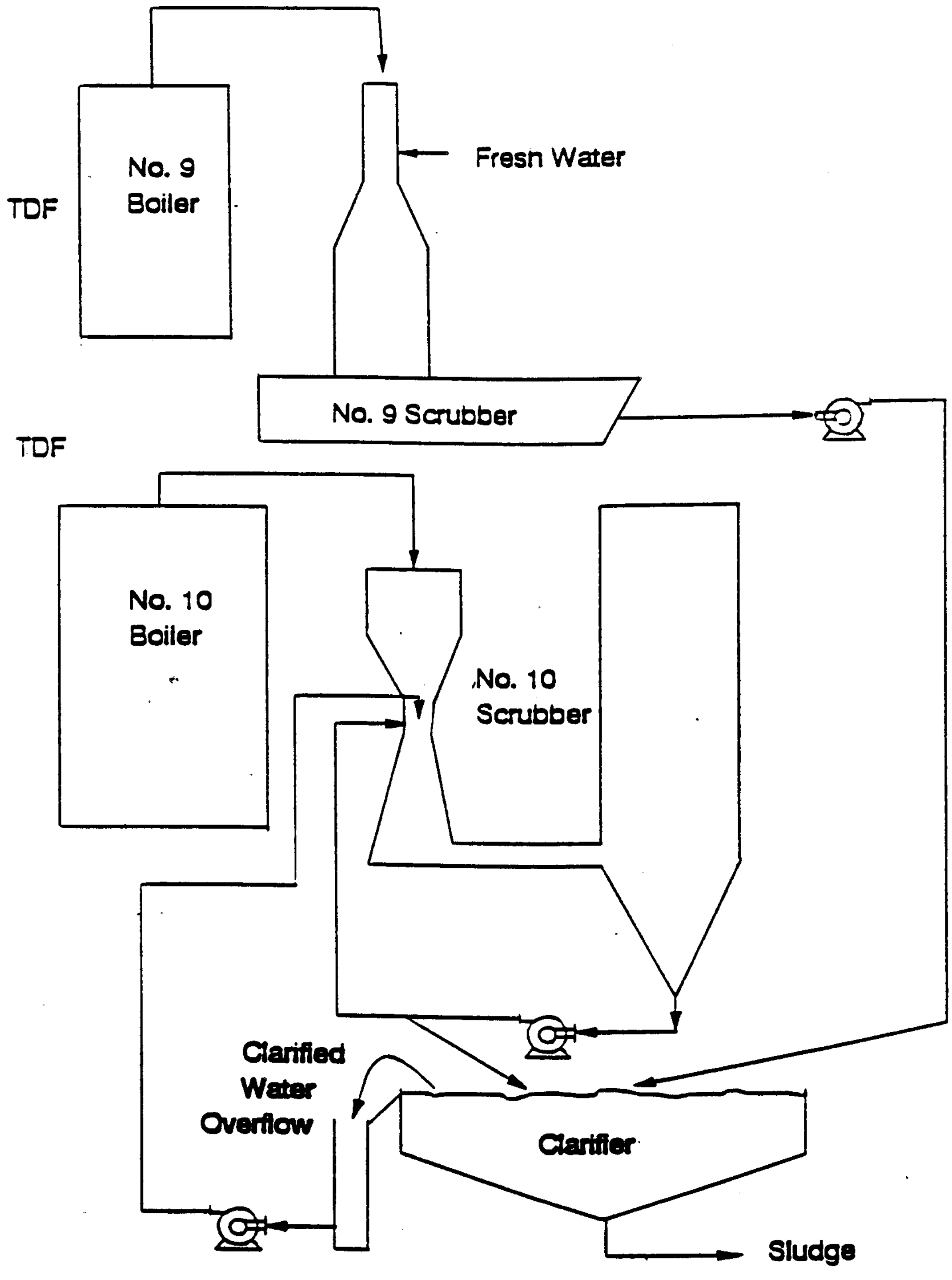


Figure 5-1. Smurfit Newsprint Process Flows[15]

5.3 EMISSIONS, CONTROL TECHNIQUES AND THEIR EFFECTIVENESS

5.3.1 Emissions

This report examined six sets of test data from waste wood boilers at pulp and paper mills (and one at a silicon manufacturing plant). Of the six, control at one is unknown, two are controlled by venturi scrubber, two by ESP's, and one by both a scrubber and an ESP. The State of Washington tested two of these facilities: Port Townsend Paper and Crown Zellerbach Corporation. Table 5-2 presents the particulate, heavy metals, and polynuclear hydrocarbons (PNA) emissions data from these test. Both of these plants use venturi scrubbers for emissions control. Smurfit Newsprint has performed several tests over the last 3 years. Particulate results at Smurfit are summarized in Table 5-3. Results of testing on other criteria pollutants and heavy metals are contained in Table 5-4. Packaging Corporation of America (formerly Nekoosa Packaging) tested criteria pollutants, metals, PCB's, and dioxins and furans at baseline and about 1.5 percent TDF. These results are summarized in Table 5-5. Champion International in Sartell, Minnesota, tested particulate, SO_x, metals, and semi-volatile organics, although the results of the organics testing while burning TDF were lost in a laboratory accident. Results of this test are found in Table 5-6. Dow Corning, a silicon manufacturing facility, burns TDF in their wood chip boiler, and has performed air emissions testing for particulates, SO_2, NO_x, and metals. These data are summarized in Table 5-7. The following paragraphs summarize the test results by pollutant for each plant. Figures are provided that graph the emissions change as TDF percent increased.

Fuel use varied significantly during the six tests evaluated here. Three burned 100 percent wood waste for baseline, and

Table 5-2. Emission of PNA's and Metals from Port Townsend Paper and Crown Zellerbach Corporation[16,17,24] (Venturi Scrubber Controlled)

Pollutant	Port Townsend Paper (2/25/86) Waste Wood + 5% Oil lb/hr	Waste Wood + 5% Oil $lb \times 10^{-6}$/MMBtu	Waste Wood + 7% TDF lb/hr	Waste Wood + 7% TDF $lb \times 10^{-6}$/MMBtu	Crown Zellerbach Corp. (6/10/86) Waste Wood + 12% Oil lb/hr	Waste Wood + 12% Oil $lb \times 10^{-6}$/MMBtu	Waste Wood + 2% TDF + 11% Oil lb/hr	Waste Wood + 2% TDF + 11% Oil $lb \times 10^{-6}$/MMBtu
Particulate	46.2		63.8		11.0		15.4	
Metals								
Arsenic		NA		NA		3.3		6.28
Barium		257.4		350.5		11.3		29.1
Cadmium	0.009	42.8	0.007	31.3		2.9		5.8
Chromium	0.01	54.9	0.01	34.9		0.5		3.5
Copper		2,415.6		2,296.8		30.7		40.0
Iron		1,999.8		2,574.0		263.1		377.8
Lead	0.1	603.9	0.03	132.3		64.0		72.4
Nickel	0.1	689.0	0.01	59.0		3.5		3.6
Vanadium	0.2	902.9	0.001	8.9		3.0		7.5
Zinc	3.1	14,790.6	48.8	249,480.0	0.5	2,455.0	3.1	16,381.4
PNA's								
Anthracene	0.03	9.9	0.01	26.7		1.0		0.6
Phenanthrene	0.1	419.8	0.2	772.2		45.3		16.7
Fluoranthane		459.4		235.6		37.4		14.2
Pyrene		249.5		380.2		47.8		21.7
Benzo(b)Fluoranthene		0.6		1.2		2.3		0.0
Benzo(k)Fluoranthene		0.6		0.6		0.7		0.0
Benzo(a)Fluoranthene		1.6		2.2		0.0		0.0
Chrysene		3.2		2.4		0.0		0.0
TOTAL PNA's			0.3				0.02	

Table 5-3. Summary of Particulate Tests on Two Hog-fuel Boilers at Smurfit Newsprint, Newberg, OR[18,19,20,25]

#9 Boiler - Particulate[a]

Date	TDF, %	PM Emissions, lb/hr
3/13/87	0.0	315[a]
1/29/87	1.0	73
3/6/87	1.5	162.0
2/9/87	1.8	>140.6

[a] Controlled by venturi scrubber

#10 Boiler - Particulate[a]

Date	% TDF	PM Emissions	
		lb/hr	tons/yr[b]
5/28/87	0	26.8	117
5/28/87	1	45.6	200
5/28/87	1.5	57.2	251
11/14/87	1	30.5	134
8/14/90	1	26.0	114

[a] Controlled by venturi scrubber
[b] Assumes 8,760 h/yr

Table 5-4. Summary of Non-particulate Testing on the #10 Boiler at Smurfit Newsprint, Newberg, OR[18,19,20,25]

#10 Boiler - Other Pollutants[a]

Pollutant	Date	% TDF	lb/hr	ton/yr
Criteria				
VOC[b]	5/28/87	0	25.1	110
	5/28/87	1	8.0	35.1
	5/28/87	1.5	69.9	306
	11/14/89	1.0	1.2	5.3
	8/14/90	1.0	1.0	4.4
NO_x[c]	11/14/89	1.0%	82.8	36.3
	8/14/90	1.0%	33.4	146
SO_2[d]	11/14/89	1.0%	4.8	21
	8/14/90	1.0%	ND	ND
CO[e]	11/14/89	1.0%	94.9	417
	8/14/90	1.0%	146	639
Barium	11/14/89	1.0%	0.000	-
Cadmium	11/14/89	1.0%	0.017	-
Chromium	11/14/89	1.0%	0.006	-
Copper	11/14/89	1.0%	0.020	-
Iron	11/14/89	1.0%	0.260	-
Lead	11/14/89	1.0%	0.037	-
Zinc	11/14/89	1.0%	3.82	-
Titanium	11/14/89	1.0%	0.000	-

[a] Controlled by venturi scrubber
[b] VOC limit is 189 TPY
[c] NO_x limit is 2,850 TPY
[d] SO_2 limit is 250 TPY
[e] CO limit is 570 TPY

Table 5-5. Summary of Tests on 3 Hog-fuel Boilers at Package Corp. of America (formerly Nekoosa)[21]
November 7, 1989

Pollutant	0% TDF	1-2% TDF lb/hr	% Change
Particulate	19.0	20.7	+9
NO_x	114.36	107.06	-6
CO	111.09	147.23	+33
SO_2	180.67	268.00	+48
Chromium VI	0.0129	0.036	+179
<u>Metals</u>			
Arsenic	0.003	0.003	0
Cadmium	<0.0023	<.0023	DL[a]
Lead	0.019	0.018	-5
Nickel	<0.008	<0.008	DL[a]
Zinc	0.715	0.851	+19
Mercury	0.0005	0.0006	+20
Chloride	0.96	1.82	+90
Benzene	$<5.57 \times 10^{-2}$	6.65×10^{-2}	+20

NOTE: All three boilers are ducted to common duct and then to two ESP's.

[a] Below detection limit (DL).

Table 5-6. Emissions Burning TDF and Waste Wood
Dow Corning Corporation, Midland, MI[22,a]
March 9-29, 1989

Pollutant	0% TDF		5% TDF			10% TDF			15% TDF		
	lb/hr	lb/MMBtu	lb/hr	lb/MMBtu	% Change	lb/hr	lb/MMBtu	% Change	lb/hr	lb/MMBtu	% Change
Particulate	4.29	0.0122	7.53	0.0205	+68	11.22	0.0305[b]	+150	38.10	0.1130[b]	+826
Cadmium	0.00049	1.39×10^{-6}	-	-	N/T	-	-	N/T	0.0028	8.21×10^{-6}	+491
Total Chromium	0.00128	3.64×10^{-6}	-	-	N/T	-	-	N/T	0.0019	5.57×10^{-6}	+53
Zinc	0.0634	1.8×10^{-4}	-	-	N/T	-	-	N/T	11.32	0.03	+16,567
Beryllium[c]	ND	ND	-	-	N/T	-	-	N/T	ND	ND	ND
NO_x[d]	-	0.153	-	0.162	+6	-	0.133	-13	-	0.081	-47
SO_2[e]	-	0.026	-	0.028	+8	-	0.037	+42	-	0.059	+127

[a] Controlled by ESP.
[b] Emission limits of 0.035 lb/MMBtu at 12 percent CO_2.
[c] No limit for Beryllium was 7.3×10^{-5} lb/hr.
[d] NO_x emissions limit is 0.7 lb/MMBtu.
[e] SO_2 limit is 0.8 lb/MMBtu.
N/T = Not Tested.
ND = Not Detected.

Table 5-7. Summary of Tests on Hog-fuel Boiler at Champion International Corp., Sartell, MN[23] March 12-16, 1990[a]

	0%[b] lb/hr	4% TDF[c] lb/hr	% Change
Particulate	19.7	24.3	+23
SO_x	266	277	+4
Cadmium	0.0025	0.0018	-28
Chromium	0.048	0.0046	-90
Lead	0.050	0.036	-28
Mercury	0.00038	0.00008	+111
Zinc	0.23	3.43	+1,391

[a] Semivolatile organic samples at 4% TDF were lost in a lab accident; thus, baseline results are not included here.
[b] Baseline = 82% coal, 13% bark, 5% sludge, 0% TDF.
[c] TDF = 80% coal, 12% Bark, 4% sludge, 4% TDF.

supplemented with TDF for secondary tests (Smurfit, Packaging Corporation of America, and Dow Corning Corp.) The other three varied the primary and supplemental fuels dramatically. Port Townsend burned waste wood plus 5 percent oil for baseline, and waste wood plus 7 percent TDF for the rubber test.[19]

Crown Zellerbach burned waste wood and 12 percent oil for baseline, and waste wood with 11 percent oil and 2 percent TDF for the rubber test.[16] Champion International burned 82 percent coal, 13 percent bark and 5 percent sludge for baseline, and for the TDF test, burned 80 percent coal, 12 percent bark, 4 percent sludge, and 4 percent TDF.[23]

One additional source conducted a test on performance at a waste-wood boiler burning TDF that included results on steam generated and boiler efficiency using the heat-loss method for varied fuel mixes.[2] Although the test summary notes that emissions testing was done, the results were not obtained. Nevertheless, one of the conclusions of the test report was that TDF had no environmental disadvantages when compared with the supplemental coal used during the tests.[2]

5.3.1.1 Particulate Emissions. Particulate emissions increased in all six emission tests reported here. Percent TDF varied from 0 to 15 percent. A comparison of percent change in particulate emissions over baseline is given in Figure 5-2. An emission rate comparison is found in Figure 5-3.

One paper mill, Inland-Rome, in Rome, GA, ran four tests burning varying amounts of wood waste, TDF, biological sludge from the plants secondary effluent treatment system, and coal.[2] One TDF test was run at 7 percent TDF and 93 percent wood waste; particulate emissions were similar to baseline.[2] Another test was run with 12.8 percent TDF, 12.1

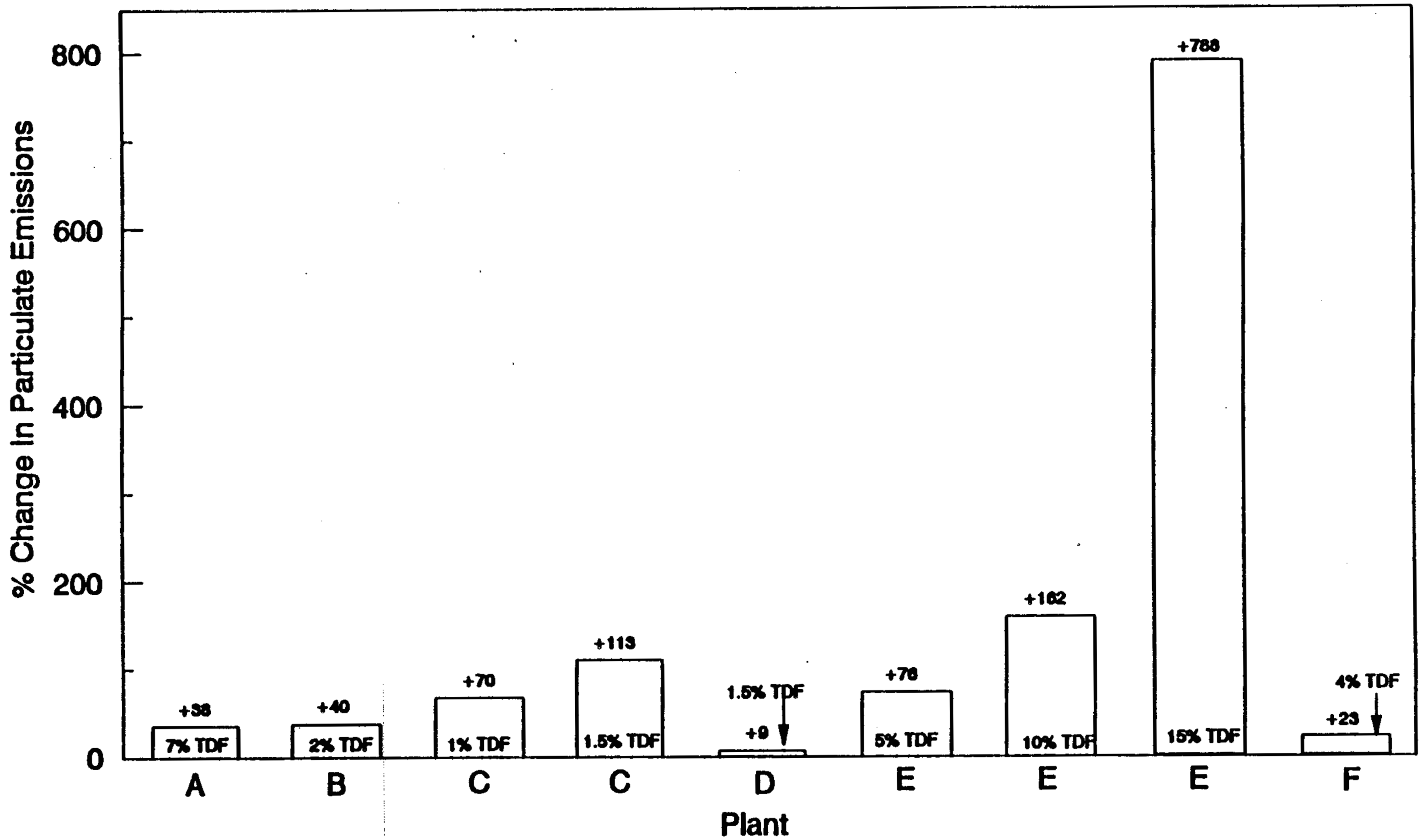
percent sludge, and 75.1 percent wood waste; particulate increased slightly over baseline in this test, but did not exceed permitted levels.[2] The test boiler at this facility shares the ESP and stack with three other power boilers (also burning wood waste and/or pulverized coal and TDF); therefore, the incremental increase due solely to the change in fuel mix at the test boiler could not be determined.[2]

5.3.1.2 Sulfur Dioxide Emissions. Sulfur dioxide emissions also increased somewhat in all tests. Figure 5-4 shows emission rate changes for SO_2.

5.3.1.3 Nitrogen Oxides Emissions. The nitrogen oxides (NO_x) in Dow-Corning's emissions decreased about 50 percent between their highest and lowest burning rates. Packaging Corp. of America's results show a 5 percent drop in NO_x. Smurfit and Champion did not test for nitrogen oxides. A summary of nitrogen oxides tests is given in Figure 5-5.

5.3.1.4 Carbon Monoxide Emissions. Emissions of carbon monoxide increased in the one data set comparing baseline to data with TDF. This comparison is graphed in Figure 5-6.

5.3.1.5 Heavy Metals and Polynuclear Aromatics (PNA). Zinc emissions are frequently mentioned as an element that could increase significantly when burning TDF, because of the zinc content of the rubber. Because zinc oxide has a small particle size, sources controlled by scrubbers have particular concern that the zinc oxide will escape the control device. ESP's, on the other hand, would be well suited to pick up a small metallic particulate. Zinc was measured at all six plants evaluated here. Data on zinc emissions show that in all five data sets where comparison to baseline levels was available, zinc emission rates did increase,often dramatically. Figure 5-7 graphs zinc



KEY
A-Port Townsend; Baseline included 5% oil; scrubber controlled
B-Crown Zellerbach; Baseline included 12% oil; TDF test included 11% oil; Scrubber controlled
C-Smurfit newsprint - scrubber controlled.
D-Packing Corp of America; ESP controlled.
E-Dow Corning; ESP controlled.
F-Champion; Baseline ='82% coal, 13% bark, 5% sludge; TDF included 80% coal, 12% bark, 4% sludge.

Figure 5-2. Percent change of particulate emissions over baseline (0% TDF) in wood waste boilers burning TDF.

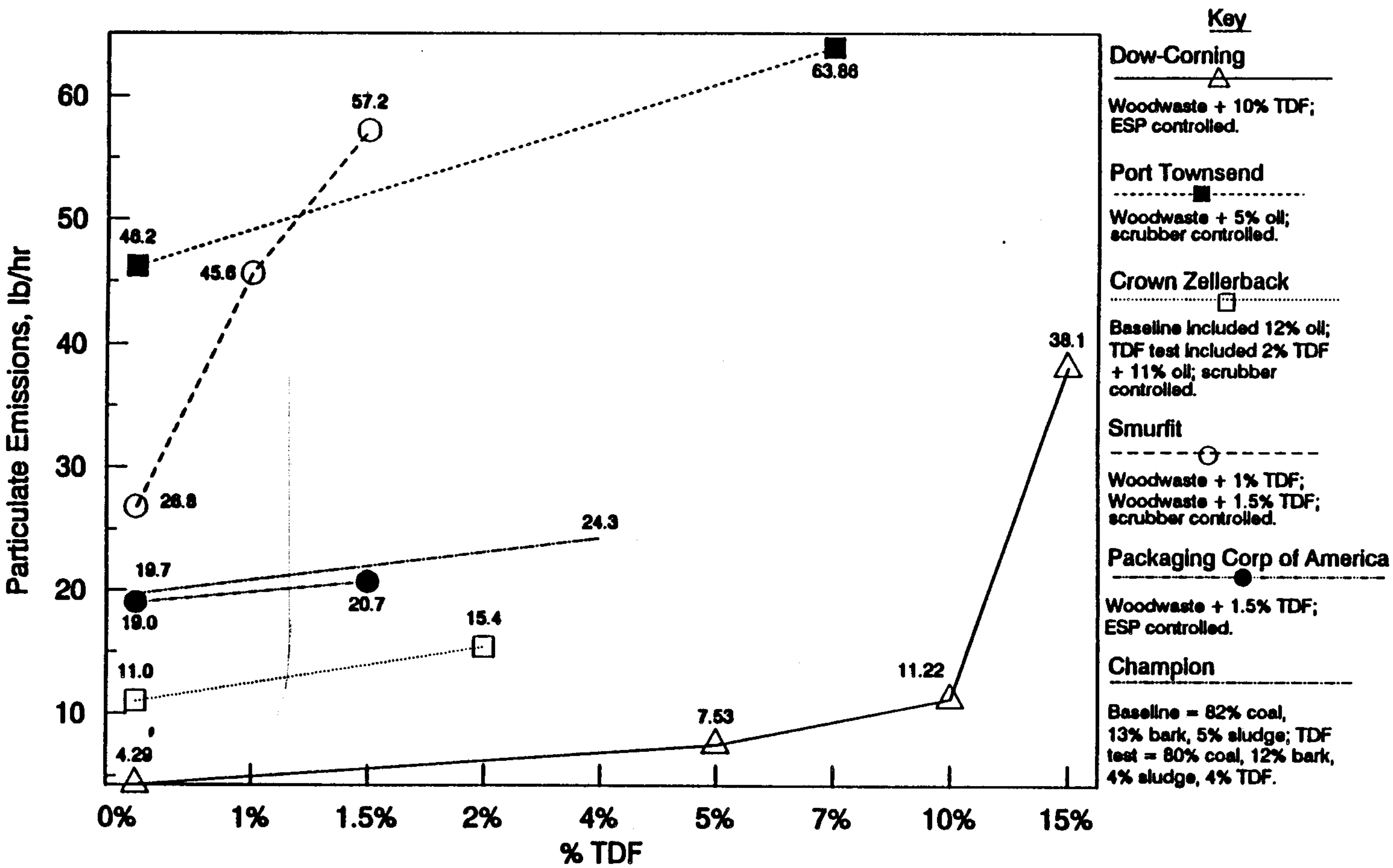


Figure 5-3. Particulate emission rates from hog-fuel boilers burning TDF supplementally.

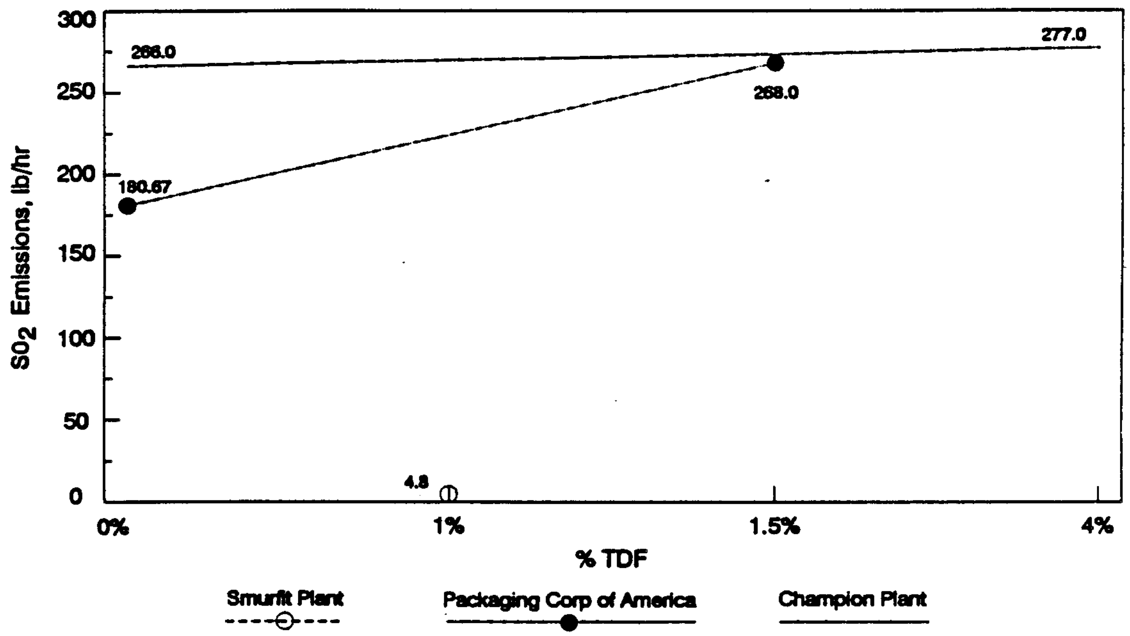


Figure 5-4. Change in emission rate of SO_2 over baseline (0% TDF) at varied TDF input rates for hog-fuel boilers.

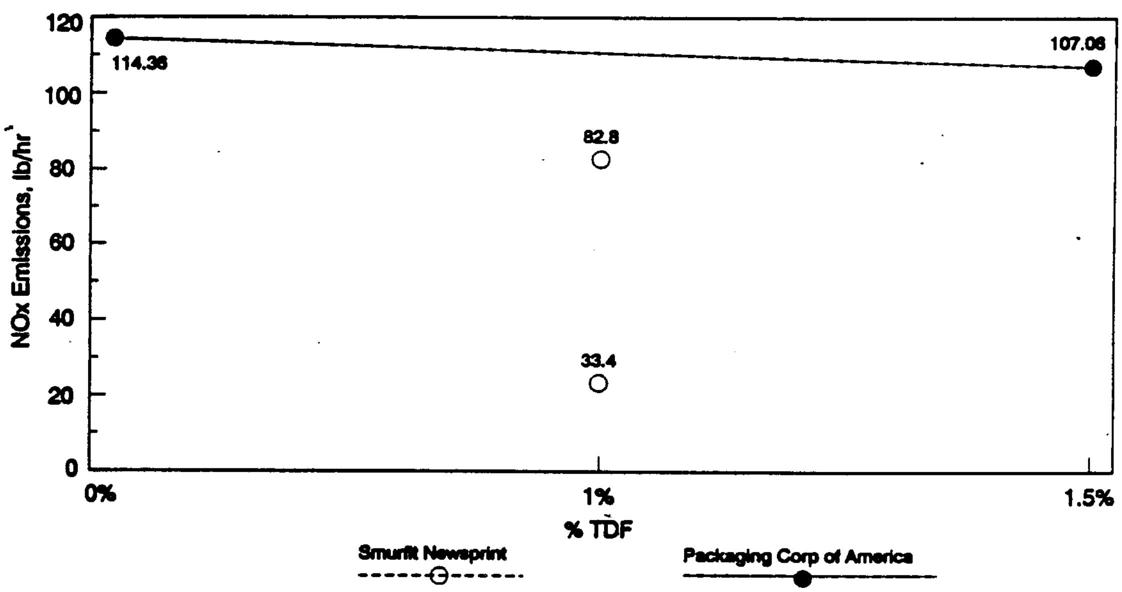


Figure 5-5. Change in emission rate for NO_x over baseline (0% TDF) at varied TDF input rates for hog-fuel boilers.

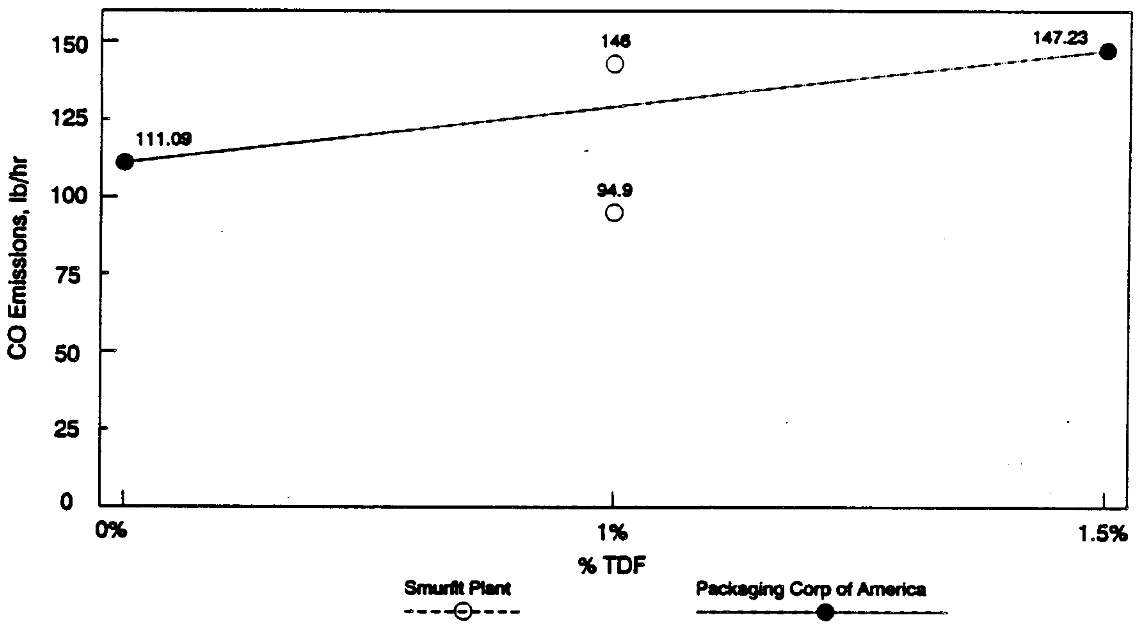


Figure 5-6. Change in emission rate of CO over baseline (0% TDF) at varied TDF input rates for hog-fuel boilers.

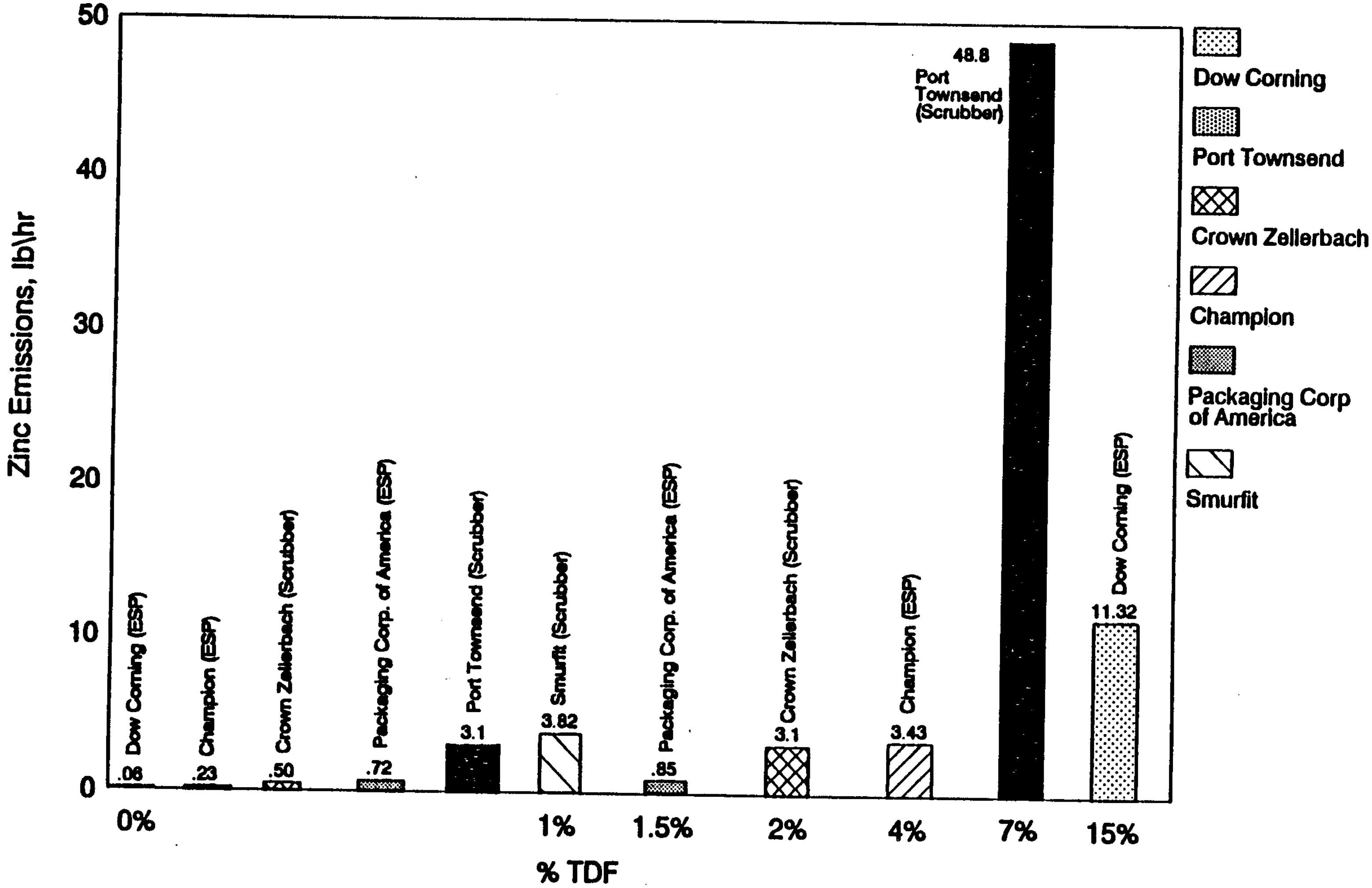


Figure 5-7. Change in zinc emission rates when burning TDF at six pulp and paper plants.

emission rates and denotes whether control at each facility is by scrubber or ESP.

Washington State tested two (Port Townsend and Crown Zellerbach) waste heat boilers controlled by venturi scrubbers for PNA's, both at baseline (no TDF) and while burning TDF.[24] Crown Zellerbach found emissions of zinc to be seven times higher when tires were burned, and emissions of arsenic, chromium, cadmium, and barium to increase 100 percent.[16] Port Townsend found zinc concentrations increased almost 17 times when burning tires, but other metals had decreases or smaller increases.[17] The high zinc increase at Port Townsend may be attributable to the higher tire input percentage, whereas the higher emissions of other metals at Crown Zellerbach may be because of the 11 percent Btu input provided by oil.[16,17] Figure 5-8 shows percent change in metals emissions other than zinc for both Washington paper facilities. Zinc emissions were shown in Figure 5-7.

Emissions of all PNA's from Crown Zellerbach decreased, while those from Port Townsend varied.[16,17] Figure 5-9 compares percent change of specific PNA's from the two companies.

5.3.2 Control Techniques

Of the seven plants where the control device was known, three controlled emissions with venturi scrubbers, three controlled emissions using ESP's, and one controlled emissions with one scrubber and one new ESP on two separate boilers. In total, 13 boilers were located at these seven plants. Four of the individual boilers were known to be controlled by venturi scrubbers, and nine were known to be controlled by ESP.

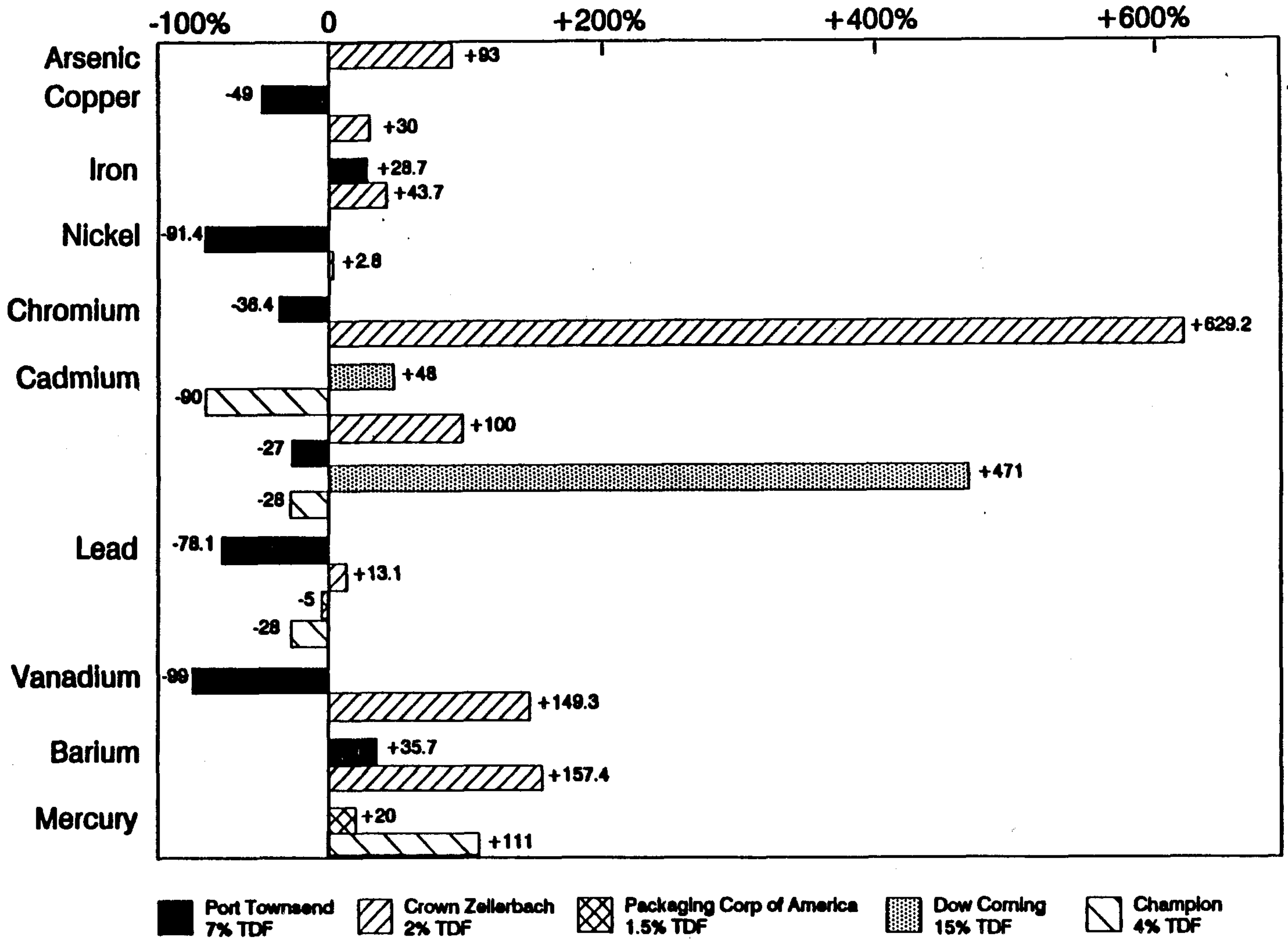


Figure 5-8. Percent change in metals emissions at five mills burning TDF.

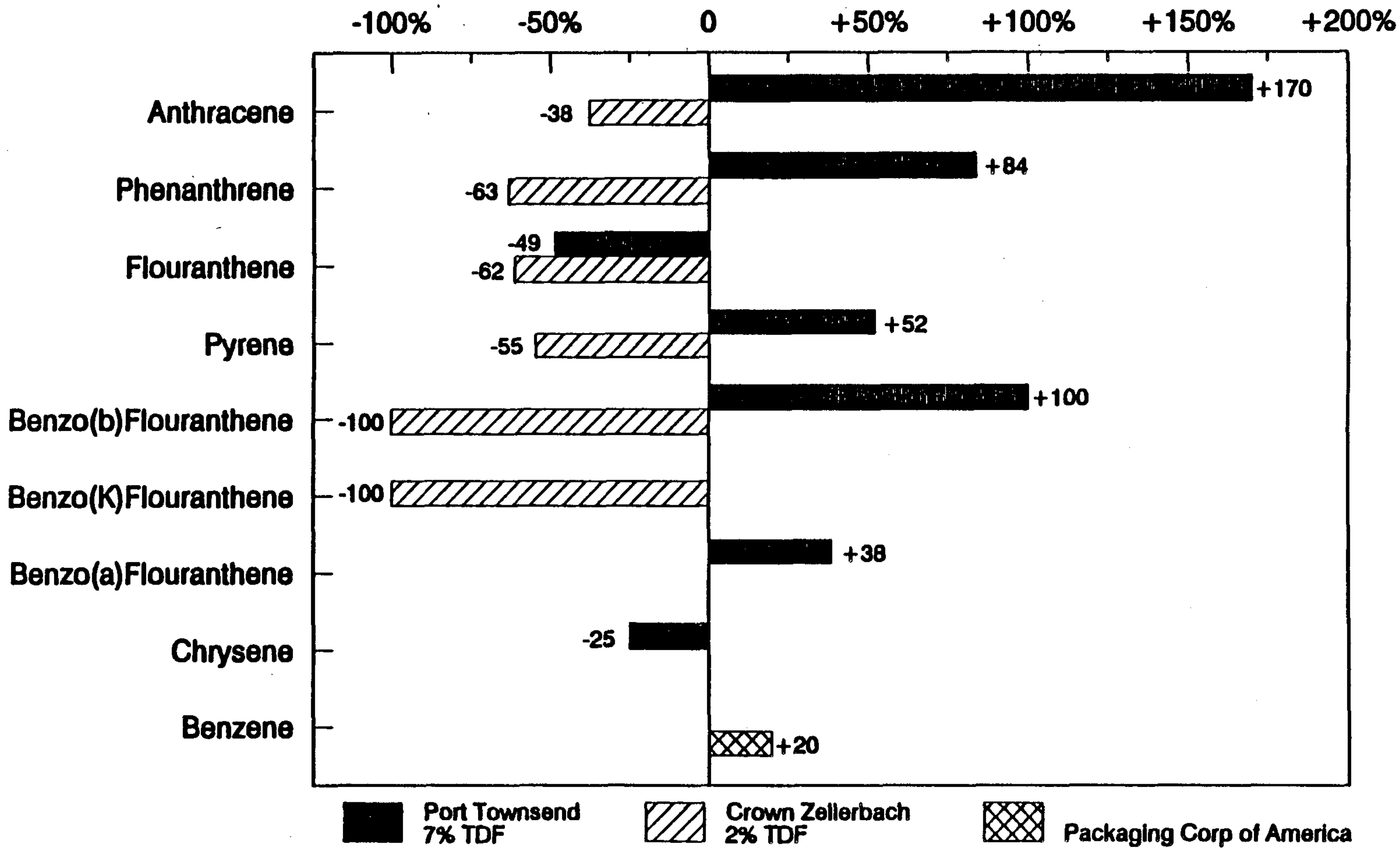


Figure 5-9. Percent change in emissions of PNA's at three paper mills burning TDF.

5.4 OTHER ENVIRONMENTAL AND ENERGY IMPACTS

A positive result of TDF use in waste wood boilers is that facilities are able to burn sludge and waste wood more successfully, decreasing the likelihood of solid waste disposal problems. Results from a series of waste wood boiler performance tests using ASME codes concluded that use of TDF supplementally in hog-fuel boilers enhances combustion of wood waste, and enables disposal of biological sludge in conjunction with wood waste without necessitating use of other fossil fuels such as coal.[2] No applicable environmental limits were exceeded during these tests.[2]

As noted earlier, use of TDF by Smurfit is currently limited to 1 percent of the boiler fuel (by weight) by their air permit. Smurfit hopes to increase the percent TDF burned to 5 percent when an ESP is brought on-line to control their larger boiler. Smurfit personnel believe that the use of the ESP may increase the zinc content of the ash, thereby affecting its quality. This increase in zinc is expected because the ESP will pick up the fine zinc oxide particles with much more efficiency than the scrubber. In addition, an increase in TDF burned will increase zinc levels.[15]

5.5 COST CONSIDERATIONS

Economically, the advantages of TDF can be very site-specific. Primary, or base load, fuel costs vary significantly, as does the delivered cost of TDF. TDF supplies a consistent and dry Btu input to boilers. This is an important advantage because the wood wastes typically fed to the hog-fuel boilers have a high and variable moisture content, which makes hog-fuel boiler operation a challenge. Availability of TDF is a problem at some mills. The costs of TDF to a pulp and paper mill is affected by whether there is a tipping (tire disposal) fee or State rebate incentives that provide revenue to offset TDF costs. For example, Smurfit paid between $39 and $43 per ton in 1990 and part of 1991, respectively, for their TDF. A rebate program lowered the respective costs to approximately $21 and $23 per ton of TDF, for an equivalent rebate of $18 and $20 per ton.[15]

5.6 CONCLUSIONS

Burning tires or TDF in a waste-wood boiler improves the performance of the boiler system. The high energy and low moisture content of TDF help stabilize boiler operations and overcome some of the operating problems caused by fuel with low heat content, variable heat content, and high moisture content.

Unfortunately, using TDF in hog-fuel boilers appears to deteriorate emissions quality. In every set of data, particulates in the emissions increased with a corresponding increase of TDF usage. The other criteria pollutants also increased in most cases, but not as consistently as particulates.

Cost considerations are site-specific and depend on the availability, cost, and transportation of alternative supplemental fuels.

5.7 REFERENCES

1. U.S. Environmental Protection Agency Compilation of air Pollution Emission Factors, Fourth Edition, AP-42. p. 1.6-1.

2. Jones, R.M., M. Kennedy, Jr., and N.O. Heberer "Supplemental Firing of Tire-derived Fuel (TDF) in a Combination Fuel Boiler." TAPPI Journal. May 1990 pp.107-113.

3. Ohio Air Quality Development Authority. Air Emissions Associated with the Combustion of Scrap Tires for Energy Recovery. Prepared by: Malcolm Pirnie, Inc. May 1991.

4. Telecon. Clark, C., Pacific Environmental Services, Inc. (PES), with Bosar, L., Fort Howard Corporation. February 27, 1991. TDF experience.

5. Telecon. Russell, D., PES, with Thorpe, L., Georgia-Pacific Paper Co., March 1, 1991. TDF experience.

6. Telecon. Clark, C., PES, with Fuller, B., Oregon Department of Air. February 28, 1991. TDF use in State.

7. Telecon. Clark, C., PES, with Jones, B., Inland-Rome Paper Co., March 6, 1991. TDF experience.

8. Telecon. Clark, C., PES, with Koziar, P., Wisconsin Waste Tire Program. February 20, 1990. TDF use in State.

9. Telecon. Clark, C., PES, with Miller, S., Smurfit Newsprint. February 27, 1991. TDF experience.

10. Telecon. Clark, C., Pacific Environmental Services, Inc. (PES), with Crispin, D.M., Oregon Department of Environmental Quality Hazardous and Solid Waste Division. February 27, 1991. TDF use in State.

11. Telecon. Clark, C., PES, with Wickwire, L., Willamette Industries. March 5,1991. TDF experience.

12. Memorandum from Clark, C., PES, to Michelitsch, D., EPA/ESD/CTC. Summary of Meeting with Scrap Tire Management Council. October 29, 1991.

13. U.S. Environmental Protection Agency. Nonfossil Fuel Fired Boilers -- Background Information. EPA-450/3-82-007. March 1982.

14. Schwartz, J.W., Jr. Engineering for Success in the TDF Market. Presented at Recycling Search Institute Scrap Tire Processing and Recycling Seminar. West Palm Beach, FL., April 27, 1989.

15. Memorandum from Clark, C., PES, to Michelitsch, D., EPA/ESD/CTC. October 28, 1991. Site Visit -- Smurfit Newsprint.

16. Washington State Department of Ecology. Polynuclear. Aromatic Hydrocarbons and Metals Emitted from the Burning of Tires at Crown Zellerbach, Port Angeles, Washington, June 10 and 11, 1986. Source Test 86-10a.

17. Washington State Department of Environmental Source Test Summary of Emissions to Atmosphere from Port Townsend Paper Co., Port Townsend, Washington. February 25 and March 5, 1986. Report No. 86-01.

18. Horizon Engineering. Particulate emissions test report on Smurfit Newsprint's #9 Hogged Fuel-Fired Boiler. Tire Chip Supplement Trials at Newberg, Oregon. January-March, 1987.

19. Horizon Engineering. Stack Emission Test Report. Smurfit Newsprint's No. 10 Hogged Fuel Fired Boiler. Tire Chip Supplement Trials. Newberg, Oregon. May-July 1987.

20. Horizon Engineering. Stack Emission Test Report. Smurfit Newsprint's No. 10 Hogged Fuel Fired Boiler. Fiber-Based-Fuel Trials and Annual Tests. Newberg, Oregon. November 14-17, 1989.

21. Clean Air Engineering. Report on Diagnostic Testing. Performed at Nekoosa Packaging Tomahawk Mill. Units 7,8, and 10. Tomahawk, Wisconsin. CAE Project No. 4842/2. November 7,1989.

22. EDI Engineering and Science. Report of Tire Chip Test Burn. Performed for Dow Corning, Midland Michigan, on the Wood Fired Boiler. March 9-29, 1989.

23. Pace Incorporated. Results of the March 12-16, 1990 TDF Trial burn Testing on the Unit 3 Stack at the Champion International Corporation Facility Located in Sartell, Minnesota.

24. Drabek, J., and J. Willenberg. Measurement of Polynuclear Aromatic Hydrocarbons and Metals from Burning Tire Chips for Supplementary Fuel. State of Washington Department of Ecology. Presented at 1987 TAPPI Environmental Conference. Portland,Oregon. April 26-29, 1987. 12 pp.

25. Horizon Engineering. Stack Emission Test Report. Smurfit Newsprint No. 10. Hog Fuel Fired Boiler. Annual Compliance Tests. Newberg, Oregon. August 14, 1991.

6. TIRES AND TDF AS SUPPLEMENTAL FUEL IN ELECTRIC UTILITY BOILERS

This section discusses electric utility plants that use whole tires or TDF supplementally to produce power in boilers. Facilities that combust 100 percent tires to produce power were discussed in Chapter 3, Dedicated Tires-to-Energy Facilities.

6.1 INDUSTRY DESCRIPTION

As described in Chapter 2, many boiler configurations have been tested and commercially operated burning whole tires or TDF on a supplemental basis. In the utility industry, coal-firing boilers are primarily of the pulverized coal configuration.

As of the Summer of 1991, at least nine boilers at seven plants were burning, or planning to burn, whole tires or TDF on either a test or commercial basis. Currently, one pulverized coal boiler at a utility plant is testing use of whole tires. Three cyclone-fired boilers at utilities are currently testing TDF use. One utility currently operates two underfed stoker boilers that use TDF on a commercial basis. One utility tested TDF unsuccessfully in a fluidized bed combustion (FBC) boiler that was a retrofitted spreader stoker design, and two utilities are currently constructing new FBC boilers to accommodate TDF use. Table 6-1 lists these plants and summarizes information about their TDF experience, boiler configuration, and air emissions testing.

6.2 PROCESS DESCRIPTION

Boilers at electric power plants use fuel to generate power for municipalities and industry. The heat generated by the

Table 6-1. Electric Utilities with TDF Experience as a Supplemental Fuel

COMPANY AND LOCATION	TDF USE	AIR EMISSIONS TEST DATA	BOILER(S) DESCRIPTION	COMMENTS/ REFERENCES
Illinois Power Baldwin Generating Station Baldwin, IL	Test basis; 3/91 most recent test. 1"x1"; 2% during test burn; 100 tpd TDF; add TDF at coal reclaim prior to hammer mills; also eventually want to test adding TDF after hammer mill and adding various sizes TDF.	Yes; 3/91 test burn on Unit No. 1; tested PM, SO_2, beryllium, cadmium, lead, total chromium, and zinc; 2% TDF during test.	2 twin cyclone fired boilers, universal pressure, balanced draft, turbine rated 560 MW; output capacity of 4,199,000 lb/hr steam at 2620 psig and 1005°F; burns Illinois coal; controlled by Western Precipitation ESP, design gas volume of 1,730,000 ft^3/min with 99% efficiency; 600 ft stack.	Have temporary test burn permit; References 1-5
Manitowoc Public Utility Manitowoc, WI	Current use; <10%; 2"x2" wire-free; mix with coal using a proportioning belt feeder; can't use in cold weather because tire pile freezes	No	Rebuilding two 90,000 lb/hr underfed stoker/spreader boilers for TDF when tire pile thaws; have 80,000 lb/hr coal-fired stoker/spreader, and 1 coal-fired 150,000 boiler; coal is <1% sulfur. Also have 1 new 200,000 lb/hr circulating fluidized bed, plan to burn some TDF here too. PBC has limestone sorbent for SO_2 reduction.	References 6 and 7
Northern States Power French Island, WI	Test in 1982; Unsuccessful; electrified filter bed for PM inadequate because metal in tires shorted out device; also heat level in boiler too high.	Yes	150,000 lb/hr steam capacity bubbling fluidized bed; retrofitted from spreader/stoker design; primary fuel is wood waste.	References 8 and 9
Ohio Edison Company Toronto, OH	2 tests 1990; Whole tires up to 20% Btu content; tires burned down to residual metal within 18-foot drop to boiler bed	Test in May 1990; tires dropped in at 5 different rates equating to 0, 5, 10, 15, and 20 percent tires as fuel. All particulate and SO_2 limits were met.	Pulverized coal-fed, front-fired, wet bottom, noncontinuous tap. Tires dropped into boiler.	Ohio EPA and USEPA have approved permits allowing tire input up to a 20% Btu level. References 2, 10, 11, 12, and 13

Table 6-1 (Continued)

COMPANY AND LOCATION	TDF USE	AIR EMISSIONS TEST DATA	BOILER(S) DESCRIPTION	COMMENTS/ REFERENCES
Otter Tail Power Co. Big Stone City, SD	Testing since 10/89; current use is 2"x2" wire free at 10%; no metering system, TDF is dumped into the coal handling system as it is received; one supply problem is wet TDF chips freeze to rail cars and are difficult to remove.	No	440 MW, 3,250,000 lb/yr cyclone-fired boiler; 3000°F; lignite is primary fuel;	Would burn higher percentage, but are limited by TDF supply. References 2 and 14
Traverse City Light & Power Traverse City, MI		Unknown		Reference 15
United Development Group Southern Electric Intl. Niagara Falls, NY	Under construction; designed for up to <20% TDF, wire-free. Commercial operation will begin on coal only. Test TDF after stable on coal	No	468,000 lb/hr, 52 MW, circulating fluidized bed. Bed augmented by limestone for SO_2 control. Pulse-jet FF planned, air-to-cloth ratio of 3.88.	Reference 16
United Power Association Elk River, MN	2 1979 tests: 1 test at 0%, 5%, and 10% TDF, wire-free, 2", polyester type tires, emissions testing done; 1 test with 2"-6"TDF, wire-in, rates from 5% to 65%, no air testing done.	Yes; first test only; tested for PM, SO_2, NO_x, Cl, and H_2SO_4.	3 boilers; TDF tested in 2 stoker-fired with traveling grate, 135,000 lb/hr, 12 MW; Also have 1 pulverized coal, 235,000 lb/hr, 25 MW, no TDF testing; all designed for coal, 2 also natural gas.	All 3 boilers vent to one FF. Plant waiting for economical and adequate supply of TDF before initiating commercial operation. Reference 17
Wisconsin Power & Light Rock River Gen. Station Beloit, WI	Test program since 8/89; have tested crumb at 10% with no problems; 1"x1" TDF tested up to 7% level wire-in	Yes; 7% TDF; measured PM, SO_2, SO_x, CO, organics, HCl, HF, trace metals, dioxin, and furan, PCB's, and POMs	2 boilers; both cyclone-fired 75 MW, 525,000 lb/hr; each has ESP.	References 2, 14, 18, 19, and 20

Note 1: Test data are available for NY State Gas and Electric, Bainbridge Plant, Binghamton, NY, and for Northern Indiana Power, South Bend, IN. Reference 13.

Note 2: Illinois has modified their regulations so that no permit modification is needed for permit holders wanting to burn tires or TDF up to the 20% level. The State must be notified of the fuel change, however. Reference 13.

burning of the tires rises into the radiation chamber. In this chamber, the heat causes water contained in pipes in the refractory brick wall to turn to steam. The high-pressures steam is forced through a turbine, causing it to spin. The turbine is linked to a generator that generates power. After passing through the turbine, the steam is condensed to water in a cooling system, and returned to the boiler to be reheated.

This section summarizes the experience of electric utility facilities that have tested TDF or tires, or that are using them in commercial operation. This section will describe the technical operation and modifications needed to accommodate TDF or tire use. The air emissions data and other environmental information will be described in sections 6.3 and 6.4 of this chapter respectively.

6.2.1 Materials Handling

Materials handling provides the first challenge to burning TDF in a utility boiler. TDF must be correctly sized so as to "fit" in fuel conveyors, and must be well-mixed, to ensure proper combustion.

Two plants have tried conveying TDF to the boiler through coal crushing equipment. At Illinois Power and Light, mixing of the coal and the TDF has to occur at the front of the conveying system, because the remainder of the system is closed.[5] Thus, TDF must be able to go through the hammer mills at this time.[5] In the future, the company would like to test having the TDF bypass the mill, because although the TDF caused no operational mill problems, the TDF size did not decrease appreciably.[1]

Wisconsin Power and Light (WP&L) experienced several problems conveying the TDF through the existing coal blending facility.[18] First, the crushers did not significantly reduce the size of the TDF. Second, the crusher has magnetic separators to remove large ferrous metal pieces that can damage the coal crushers. These magnets pulled the small crumb rubber from the conveyor. Therefore, to use TDF the magnet had to be turned off, which was unsafe and could cause damage to the crusher. Subsequently, Wisconsin Power and Light added an additional coal yard conveyor to safely blend TDF with coal downstream from the coal crushing equipment.[18]

Other companies have tried various methods of mixing fuel and TDF either on conveyors, or in storage. Otter Tail Power did not modify its existing lignite handling, feeding and burning equipment to burn TDF. Initially, TDF was fed into an auxiliary conveyor and mixed with lignite after the crusher house. The mixture then entered the boiler building on a single conveyor. In more recent tests, however, the TDF was pushed into a rotary car dumper and conveyed to live storage, where natural mixing with the lignite occurs.[21]

United Power used a coal/TDF blending system in which TDF was blended with coal at the reclaim hoppers. A variable speed conveyor belt was used to control the mixture during fuel reclaim.[17] This system worked well for the low (up to 10 percent) TDF fuel blends, but problems were experienced in the tests using up to 65 percent TDF. Specifically, the material plugged up the fuel conveying system at the reclaim hoppers and at the coal scales.[17] Further, the larger pieces of TDF segregated to the outside areas of the fuel storage bunkers, resulting in a non-uniform fuel blend that plugged the inlet to the stokers, and resulted in uneven fuel distribution on the furnace grates.

Wisconsin Power and Light has also experienced the problem of plugging of the coal feeders by oversized TDF; a plugged feeder must be manually dismantled and unplugged, causing several hours of unit derating. The company is working with suppliers to achieve more consistent and accurate TDF feed size.[18]

Two of the utility boilers reported here used 1-inch TDF, one at the 2 percent level and one at the 7 percent level. Three have used 2-inch TDF up to the 10 percent level. One has burned whole tires up to 20 percent of their Btu requirement.

Flyash and slag handling systems also require consideration, and sometimes modification. At Wisconsin Power and Light, the slag is sold to a buyer that can not tolerate wire content. Therefore, a magnetic separator is required to remove small pieces of steel wire that become incorporated into the slag during combustion.[18]

At United Power Association, ash was unaffected by TDF use at the 10 percent level.[17] However, when TDF provided as much as 65 percent, by weight, of the fuel mix, a dust control problem with the ash resulted as it was conveyed from the ash storage silo to the ash storage pit. The ash appeared to be significantly finer and more resistant to wetting, and use of wetting agents had to be increased.

6.2.2 Combustion

Generally, TDF contribution to combustion is a positive one. TDF provides an economic fuel with a constant Btu content and low moisture.

One boiler utilizing TDF on a continual test basis, Otter Tail Power, burns lignite as a primary fuel.[21] Because lignite has a relatively low Btu content (6200 Btu/lb), TDF offers improved flame stability to their operation.[12]

However, in initial tests burning 1-inch TDF at the 25 percent level, at Otter Tail, a significant amount of the rubber carried beyond the radiant section of the boiler.[21] The facility now does not exceed 10 percent levels of TDF input.

Wisconsin Power and Light also found that if larger TDF were burned, the oversize pieces were swept out the bottom of the boiler with the slag. Some carry over is acceptable, because some combustion does occur in the furnace behind the cyclone. Even if partially burned TDF does exit the boiler, WP&L personnel state that it is quickly extinguished in the slag tank and removed by screening. Nevertheless, WP&L limits TDF size to 1-inch, wire-in. No operational or equipment changes to the boiler were necessary for WP&L to utilize TDF as a supplemental fuel.[18]

Ohio Edison made modifications to its boiler so that whole tires could be added to the boiler at varying feed rates. The rate of addition of whole tires was chosen to result in TDF percentage in the fuel corresponding to baseline (0 percent),5, 10, 15, and 20 percent.[12]

United Power Association reported very even boiler operation including longer, hotter flames during their initial tests of up to 10 percent TDF. A higher smoke generation rate was reported when burning TDF, but the fabric filter operated successfully (although more frequent cleaning was required due to increased pressure drop over the system). United Power conducted another test, burning up to 65 percent TDF, by weight, although no emissions tests were run. The boiler had no operational problems combusting the TDF up to 50 percent TDF. In fact, this high TDF fuel blend showed a significant combustion advantage in starting up the boilers, because the rubber ignited at a lower temperature than the subbituminous coal. However, at TDF levels from 50 to 65 percent, the grates did not always maintain an adequate layer of ash to prevent overheating damage, and the fuel tended to seal the grate combustion holes, causing incomplete combustion.[17]

6.3 EMISSIONS, CONTROL TECHNIQUES AND THEIR EFFECTIVENESS

Air emissions testing data from five facilities were evaluated for this report. The results are summarized here, by pollutant. The most extensive testing was performed by WP&L, who tested criteria pollutants, heavy metals, dioxins and furans, and other organic compounds. Table 6-2 summarizes test data for all criteria pollutants at WP&L.[18] Ohio Edison tested particulate, SO_2, NO_x , and lead; emissions results from this whole tire test are provided in Table 6-3.[12] Illinois Power tested PM, metals, and SO_2; their emissions data are summarized in Table 6-4.[4] In 1979, United Power Association performed two TDF tests at their Minnesota facility, and conducted air emissions tests during the first test burn for particulate, NO_x, SO_2, sulfuric acid, and chloride.[17] These emission results are summarized in Table 6-5.[17] Northern States Power tested TDF in their wood-fired utility boiler in 1982, without much success.[9] Their emissions data are summarized in Table 6-6.[9] Comparisons of the data from these plants are provided in the pollutant specific discussions that follow; the Northern States Power data are not included with graphical summaries of the other four facilities, because its boiler is wood fired, while the other four co-fire the TDF with coal.

6.3.1 Particulate Emissions

Three of the five data sets show that particulate emissions decreased overall with increased TDF loading. A fourth company, Illinois Power, did not provide baseline data by which to compare emissions. Figure 6-1 compares the

Table 6-2. Air Emission Test Data for Wisconsin Power And Light[18]

Pollutant	100% Coal	7% TDF	Change (%)
Particulate Matter, lb/MBTU	0.52	0.14	-73
Sulfur Dioxide, lb/MBtu	1.14	0.87	-24
Nitrogen Oxides, lb/MBtu	0.79	0.91	+16
Carbon Monoxide, lb/hr	1.52	7.26	+377
Hydrocarbons (as CH_4), lb/hr	5.16	10.27	+99
HCl, lb/hr	25.77	19.89	-23
HF, lb/hr	1.86	1.34	-28

Table 6-3. Emission Results at Ohio Edison[12] (lb/MMBtu)

		Tire Feed Rate	Particulate	SO_2	NO_x	Lead
Day 1	Run 1		0.0764	4.71	0.761	0.0000938
0% Tires	Run 2	None	0.0370	5.15	0.598	0.0000931
	Run 3		0.0760	6.03	0.445	0.000102
	Average		0.0631	5.30	0.601	0.0000963
Day 2	Run 1	1 tire per	0.0472	5.44	0.391	0.0000973
5% Tires	Run 2	34 seconds	0.0959	5.83	0.547	0.0000997
	Run 3		0.0719	5.93	0.593	0.000101
	Average		0.0717	5.73	0.510	0.0000993
Day 3	Run 1	1 tire per	0.0414	5.62	0.324	0.0000977
10% Tires	Run 2	17 seconds	0.0892	5.76	0.478	0.0000966
	Run 3		0.0385	5.74	0.504	0.0000947
	Average		0.0564	5.71	0.436	0.0000963
Day 4	Run 1	1 tire per	0.0781	4.85	0.342	0.0000931
15% Tires	Run 2	11.3 seconds	0.0776	5.80	0.455	0.0000986
	Run 3		0.0889	5.75	0.531	0.0000982
	Average		0.0815	5.47	0.443	0.0000966
Day 5	Run 1	1 tire per	0.0377	5.03	0.313	0.0000881
20% tires	Run 2	8.5 seconds	0.0380	5.38	0.407	0.0000934
	Run 3		0.0603	5.60	0.440	0.0000921
	Average		0.0453	5.34	0.387	0.0000912

[a] On day 4 (15% TDF), tire feed supply problems resulted in several interruptions of tire supply to the boiler.

Table 6-4. Summary of Emission Rates Burning 2% TDF at Illinois Power, Baldwin Generation Station[4] March 21, 1991

Pollutant	lb/hr	PPM	lb/MMBtu
PM (ESP inlet)	17,926.93		3.438
PM (ESP outlet)	922.7		0.1722
SO_2		2,396	5.28
Beryllium	0.00966		
Cadmium	0.02387		
Total Chromium	0.56249		
Lead	0.08095		
Zinc (filter catch only)	0.00484		

Table 6-5. Summary of Emission Rates from Testing at United Power Association, Elk River, MN[17] May, 1979

Pollutant	0% TDF		5% TDF		10% TDF	
	lb/hr	lb/MMBtu	lb/hr	lb/MMBtu	lb/hr	lb/MMBtu
Particulate	5.49	0.021	3.55	0.015	2.61	0.009
SO_2	380	1.41	454	1.80	430	1.53
NO_x	202	0.78	144	0.58	90	0.30
H_2SO_4	4.0	0.015	3.6	0.014	3.3	0.012
Chloride (as Cl-) inlet to fabric filter	8.1	0.029	7.2	0.029	7.7	0.027

Table 6-6. Summary of Emissions from a Wood-fired Utility Boiler Cofiring TDF Northern States Power Co.[9] French Island, WI

November, 1982

Pollutant	100% Wood-Waste		9% Rubber Buffings		7% TDF	
	ppm (dry)	lb/MMBtu	ppm (dry)	lb/MMBtu	ppm (dry)	lb/MMBtu
Particulate	-	0.083	-	0.25[a]	-	0.31[a]
SO_2	7	0.020	-	-	50	0.074
NO_x	90	0.19	-	-	48	0.125
CO	2300	-	2700	-	2200	-
Aldehydes	66.6	-	14	-	12	-
Benzene	18	-	-	-	25	-
Phenols	61	-	-	-	14	-
Polyaromatic hydrocarbons	130	-	-	-	170	-

[a] Exceeds Wisconsin limit of 0.15 lb/MMBtu

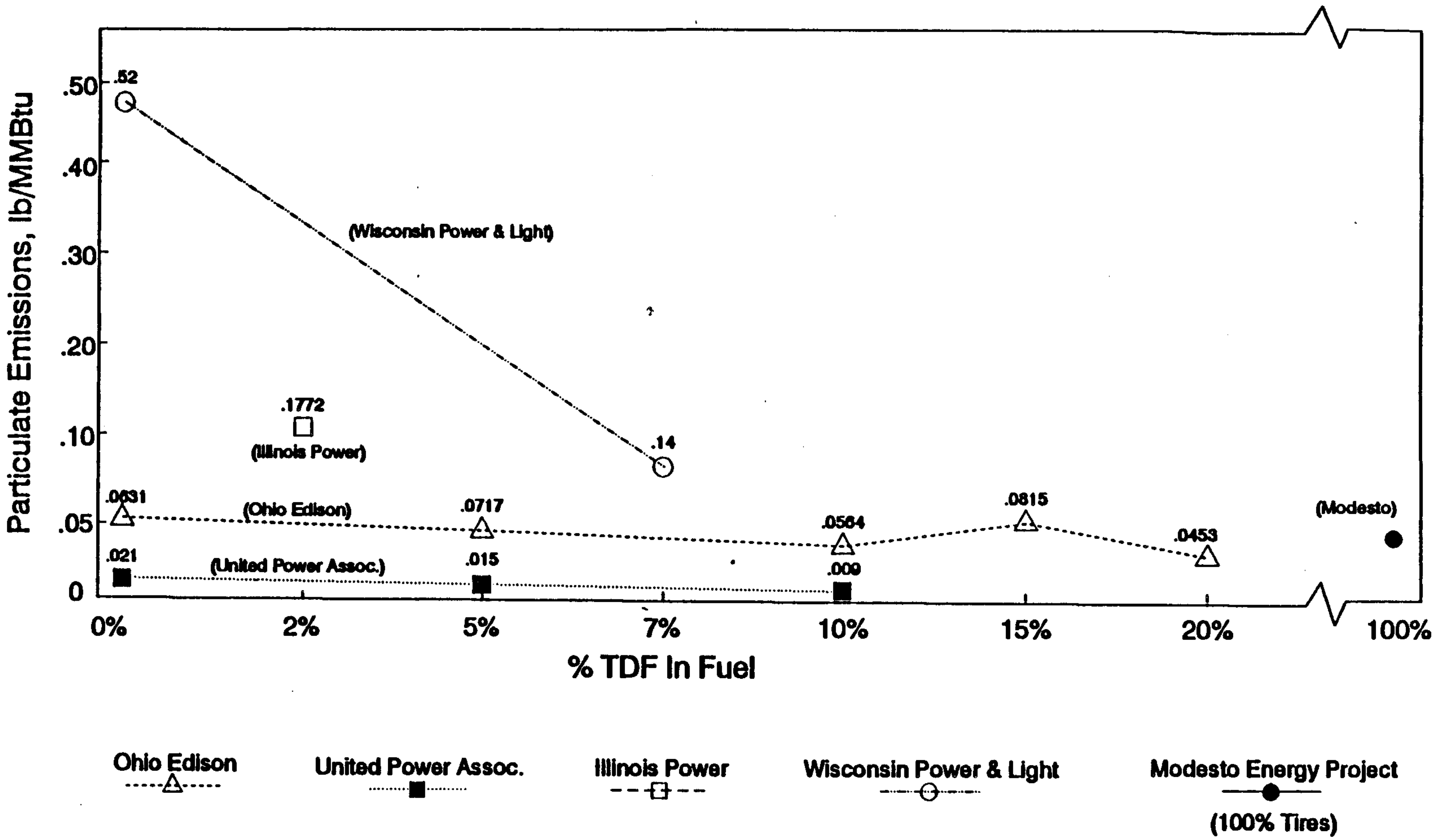


Figure 6-1. Particulate emissions while burning TDF or whole tires at coal-fired electric utilities.

Note: On day 4 (15% TDF) Ohio Edison experienced tire feed supply problems that resulted in several interruptions of tire supply to the boiler.

particulate emission rates for these four companies by TDF level. The fifth company, Northern States Power, had significant operational problems with their particulate control device during their test.[9] Their particulate data are not included in Figure 6-1 for this reason, and also because the boilers primary fuel is wood waste, not coal.[9]

Wisconsin Power and Light reported that, when burning certain high-sulfur coals, opacity from their ESP's increased by about 1.5 percent for each 1 percent incremental increase in the TDF blend rate.[18]

Ohio Edison reported that the higher emission rates at lower tire feed rates may be related to the non-uniform Btu supply associated with slower whole tire feed rates. To achieve a 5 percent TDF rate, on a Btu basis, whole tires were added one per 34 seconds. Tires were added every 8.5 seconds to result in a 20 percent TDF input. As Btu supply from tires approached a uniform and fairly constant feed rate during their tests, operating conditions appeared to stabilize and emission rates to decline. On day 4 of the test (15 percent), for example, tire feed problems caused interrupted tire supply, and the report states that data from that day support the view that uniform tire feed results in lowered emissions.[12]

6.3.2 SO_2 Emissions

As shown in Figure 6-2, SO_2 emission results showed variable emission rates over different TDF levels at different facilities. Variations in the sulfur level of the primary coal fuel could account for some of these inconsistent results.

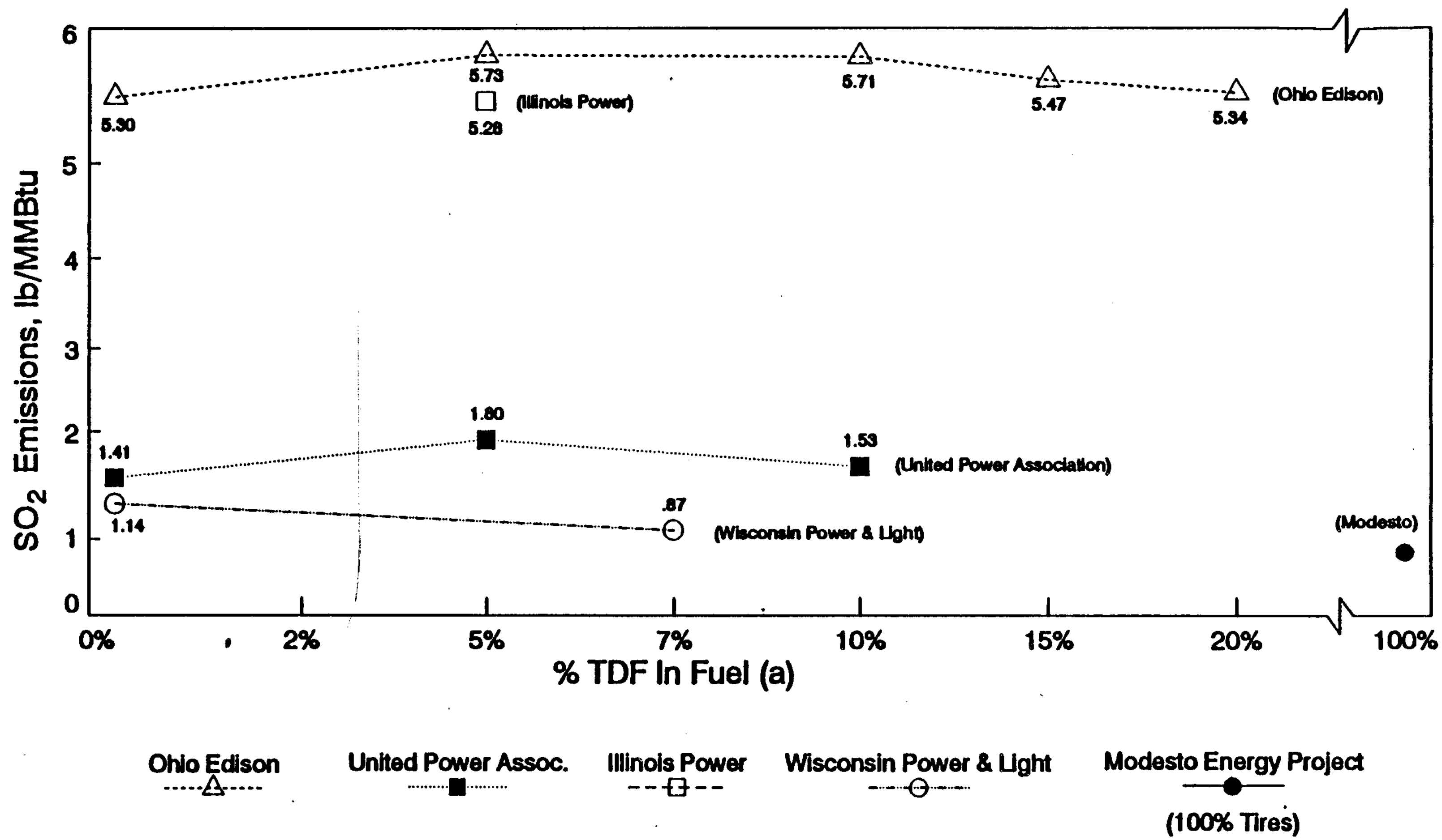


Figure 6-2. SO_2 emissions while burning TDF or tires at coal-fired electric utilities.

Note: On day 4 (15% TDF) Ohio Edison experienced tire feed supply problems that resulted in several interruptions of tire supply to the boiler.

6.3.3 NO_x Emissions

Two tests showed decreased NO_x emissions, and one, WP&L showed increased NO_x emissions. Figure 6-3 graphs these emission data. The levels emitted at WP&L were still only 60 percent of the facilities' emission limit.[18] WP&L personnel theorize that the emissions increase is due to higher flame temperatures in the cyclone caused by the TDF and a subsequent increase in thermal nitrogen oxide formation.[18] Cyclone boilers tend to have high NO_x emissions because of high flame temperature, relative to other boiler configurations, even when burning coal.

6.3.4 CO Emissions

Data from WP&L were the only information to compare CO emission rates over varied TDF levels. WP&L found that CO increased, indicating that additional excess air may be required when utilizing TDF, but levels were still less than 50 percent of the permitted level.[18]

6.3.5 Trace Metal Emissions

WP&L provides the only data showing trace metal concentrations in flue gas. Changes in trace metal emissions during testing at WP&L were reported to be small and statistically insignificant.[18] Figure 6-4 shows trace metal emission rate comparisons for WP&L. Figure 6-5 shows change in rate for trace metals at WP&L.

6.3.6 Other Air Emissions Information

Ohio Edison reported emissions of lead during their test; lead remained relatively constant throughout the tests from 0 percent to 20 percent TDF.[12] WP&L reported that HCl and

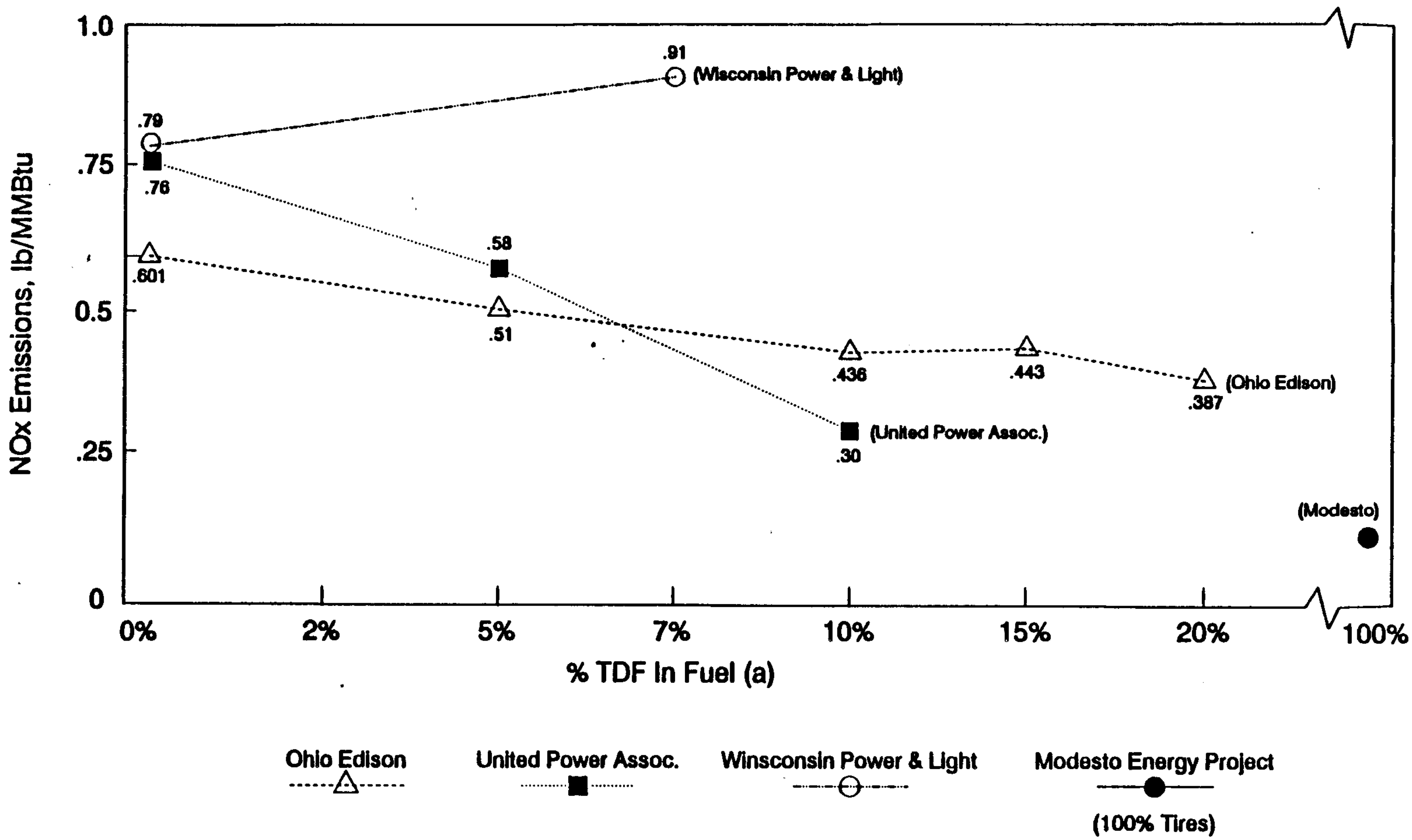


Figure 6-3. NO_x emissions while burning TDF or tires at coal-fired electric utilities.

Note: On day 4 (15% TDF) Ohio Edison experienced tire feed supply problems that resulted in several interruptions of tire supply to the boiler.

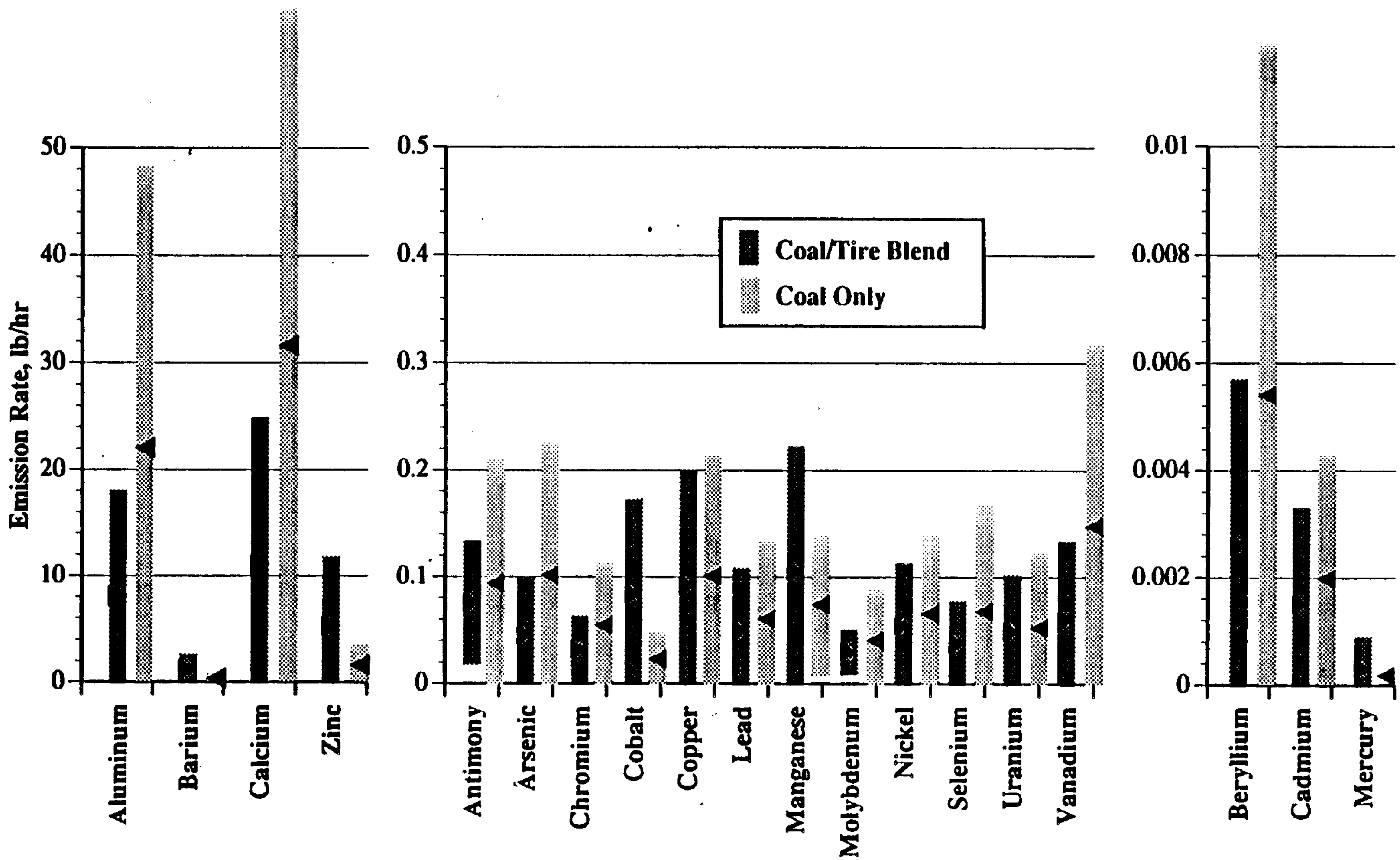


Figure 6-4. Trace metal emission rates when burning waste tires compared to coal.[18]

Note: Tick mark indicates average emission rate; bar shows +/-2 standard deviation range in data. Bars are truncated at zero.

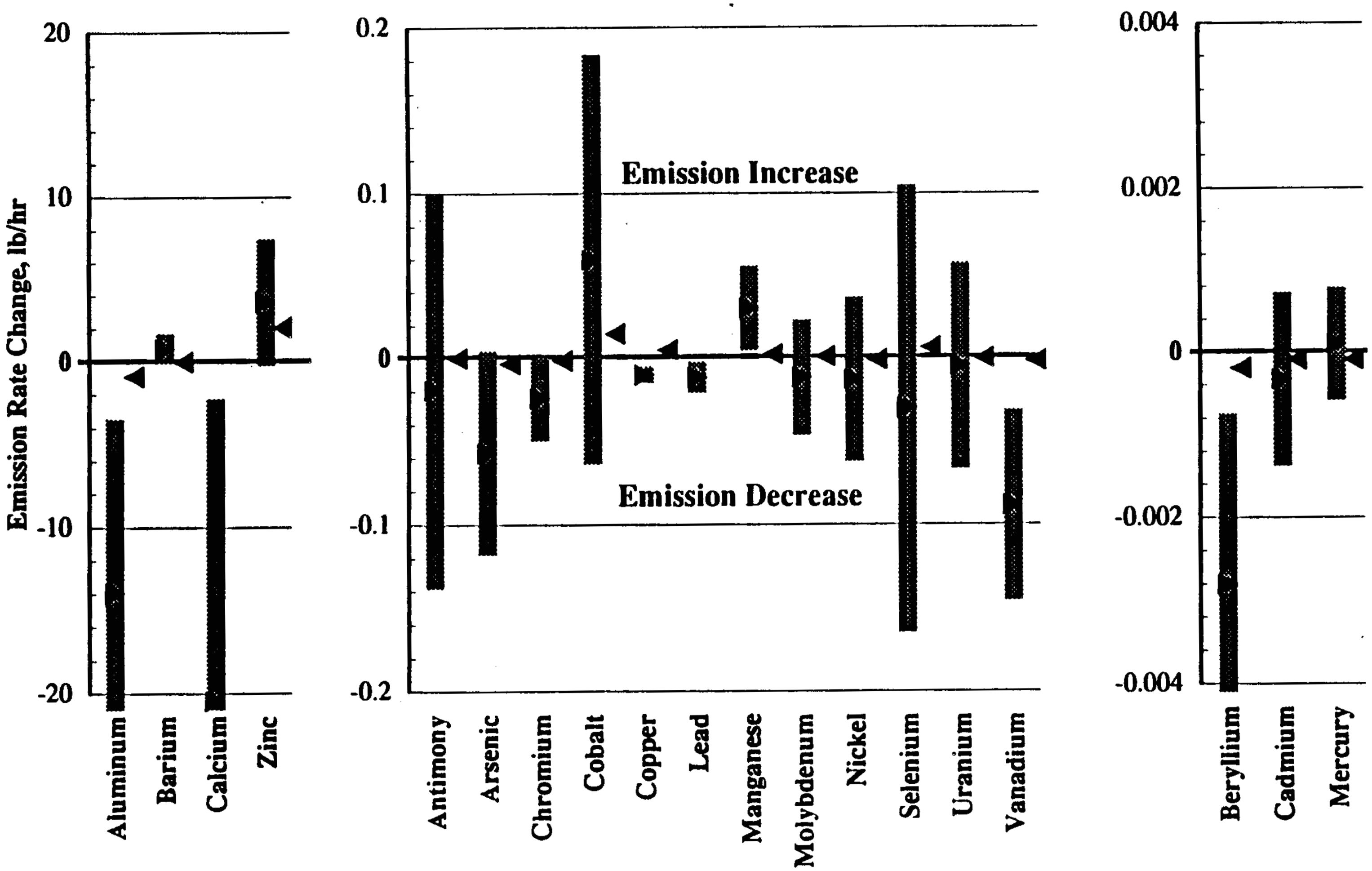


Figure 6-5. Trace metal emission rate changes when burning waste tires compared to coal.[18]

Note: Positive change indicates an emission increase when burning tires blended with coal as compared to coal only. Tick mark (▸) indicates average measured change; bar shows +/-2 standard deviation range in data. Tick mark (◂) indicates estimated emission change based on fuel analyses.

HF emissions were reduced.[18] Reasons for this reduction were unknown.[18] WP&L reported that dioxin and furan emission rates were small, and the change over baseline in all cases was statistically insignificant.[9] Figure 6-6 graphs emission rates of several dioxin and furan compounds at WP&L and Figure 6-7 graphs the change in emission rate for dioxin and furan compounds. Polycyclic organic matter and PCB's were measured at WP&L, but were not detected during any test runs.[18]

6.3.7 Control Equipment Issues

Weekend shutdown maintenance at WP&L has shown some unusual deposits on the ESP plates and wires, but the deposits are soft and easily removed.[18]

United Power Association experienced good fabric filter operation when burning up to 10 percent TDF. However, when the facility tested TDF levels up to 65 percent, operation of the fabric filter was of primary concern. The ash from the rubber was significantly more difficult to cleanoff the bags than the coal ash. The resultant ash build up on the bags caused an increased pressure drop across the system from 3" to 6". Personnel operated the cleaning cycle continuously, and operated both reverse air fans for the duration of the test, which improved the situation.[17]

The Northern States Power facility experienced significant operational problems with their electrolyzed pebble bed scrubber during tests burning from 7 to 9 percent TDF (mixed with woodwaste) in a retrofitted fluidized combustion bed boiler. The electrostatic voltage dropped to near zero on several occasions; on others, the collection efficiency declined continually. Several reasons for this are suggested. First, the ash during the test was more cohesive

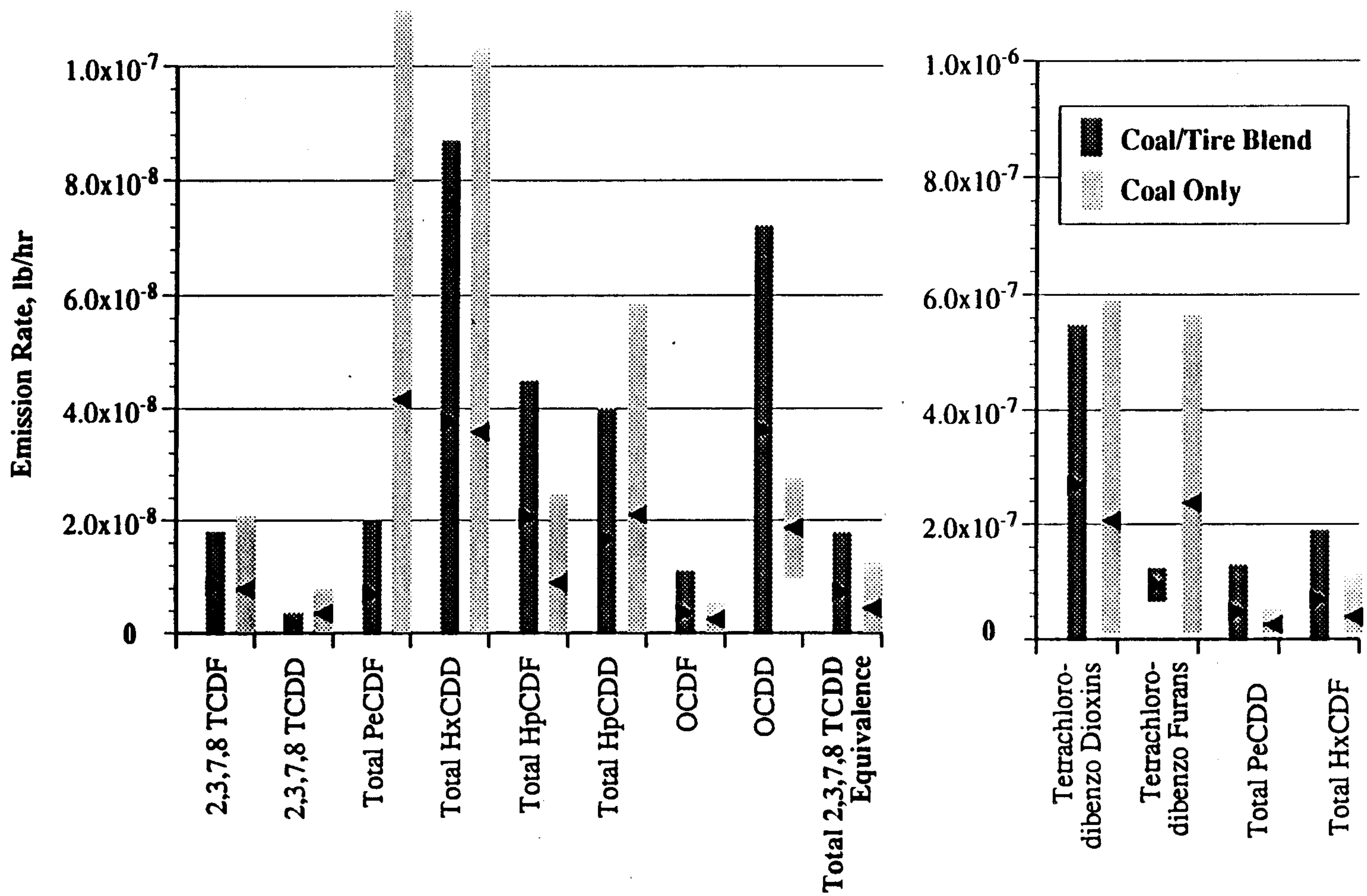


Figure 6-6. Dioxin and furan emission rates when burning waste tires compared to coal.[18]

Note: Tick mark indicates average emission rate; bar shows +/-2 standard deviation range in data. Bars are truncated at zero.

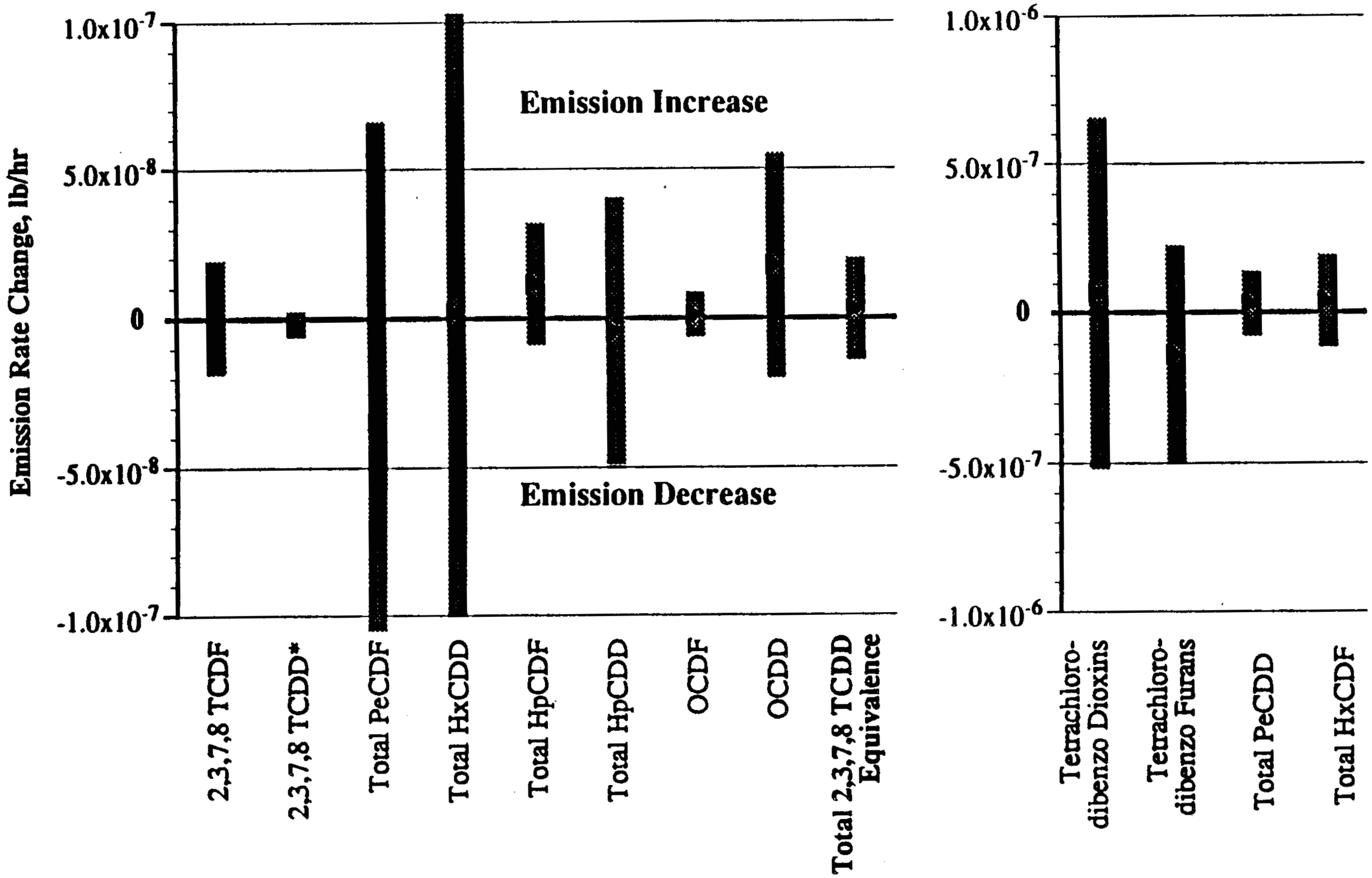


Figure 6-7. Dioxin and furan emission rate changes when burning waste tires compared to coal.[18]

Note: Positive change indicates an emission increase when burning tires blended with coal as compared to coal only. Tick mark (▸) indicates average change; bar show +/-2 standard deviation range in data.

than the ash generated from waste wood alone. This ash hindered the flow of the scrubber media and increased microbridging in the annulus, allowing more unscrubbed particulate matter to penetrate the scrubber. Further, the ash burden to the scrubber was 50 percent higher than normal, overloading the scrubber. Last, the high carbon content of the ash, together with the high ash loading, caused the electrostatic grid current to rise to a point that the scrubber control circuit dropped the grid voltage.[9]

6.4 OTHER ENVIRONMENTAL AND ENERGY IMPACTS

Slag leachate tests performed at WP&L showed no changes as a result of burning TDF.[18] Table 6-7 shows a summary of results of metals analysis on the slag at WP&L.

6.5 COST CONSIDERATIONS

One company, WP&L, purchases TDF at a cost of $20 to $30 per ton delivered. On an energy basis, this is $0.67 to $1.00 per MMBtu.[22] The State of Wisconsin has an incentive program that reimburses WP&L for disposing of scrap tires originating in Wisconsin. The reimbursement rate is $0.20 per tire, or about $20 per ton, based on an average tire weight of 20 pounds per tire. With this incentive, the cost of TDF to WP&L is between zero and $0.33/MMBtu. The cost of coal, delivered, to WP&L ranges from $1.80 and $2.00/MMBtu.[22]

6.6 CONCLUSIONS

Based on the experience and the emissions data from power plants burning tire or TDF, the use of tires and TDF as supplemental fuel is viable. In many cases, the quality of the emissions actually improves with increased use of tires or TDF as supplemental fuel.

Table 6-7. Comparison of the Heavy Metal Content of Slag at Baseline and 5% TDF at Wisconsin Power And Light[18]

Trace Metal	100% Coal, mg/l	5% TDF, mg/l	Change, %
Arsenic	0.004	<0.002	>-50
Barium	<0.01[a]	0.01	DL[a]
Boron	<0.1	<0.1	DL[a]
Cadmium	<0.01	<0.0002	DL[a]
Calcium	4.78	2.89	-40
Chromium	<0.02	0.0004	DL[a]
Copper	<0.02	<0.02	DL[a]
Iron	<0.02	0.06	>200
Lead	0.004	<0.003	>25
Mercury	<0.002	0.0002	DL[a]
Nickel	<0.02	<0.02	DL[a]
Selenium	<0.002	<0.002	DL[a]
Silver	<0.01	<0.01	DL[a]
Sulfate	<5	<5	DL[a]
Zinc	<0.01	0.02	>100
Total Dissolved Solids	28	40	+43

[a] Below detection limit (DL).

Because electric utilities use so much primary fuel, they obtain the best prices for the fuel and transportation. As a result, the differential savings, per million Btu's, are less than other industries. On the other hand, the benefits of using tires or TDF on creating stable operating conditions in the boiler may be more important than the differential cost savings for the overall profitability.

6.7 REFERENCES

1. Telecon. C. Clark, Pacific Environmental Services, Inc., (PES), with Stopek, D., Illinois Power Co. March 7, 1991. TDF use at Illinois Power

2. Telecon. C. Clark, PES, with McGowin, C., Electric Power Research Institute. February 15, 1991. TDF experience at utility oilers.

3. Telecon. D. Russell, PES, with Purseglove, P., Illinois EPA. February 14, 1991. TDF experience of Illinois facilities.

4. Burns & McDonnell. Tire-Derived-Fuel Emissions Test Report for Illinois Power Co. at their Baldwin Station Unit 1. March 1991.

5. Stopek, D.J., A.K. Millis, J.A. Stumbaugh, and D.J. Diewald. Testing of Tire-Derived Fuel at a 560 MW Cyclone Boiler. Presented at the EPRI Conference: Waste Tires as a Utility Fuel. San Jose, CA. January 28, 1991.

6. Telecon. D. Russell, PES, with Gulash, T., Manitowoc Public Utility. February 25, 1991. Experience with TDF at Manitowoc.

7. Phalen, J., A.S. Libal, and T. Taylor. Manitowoc Coal/Tire Chip-Cofired Circulating Fluidized Bed Combustion Project. Presented at EPRI Conference: Waste Fuels in Utility Boilers. San Jose, CA. January 28, 1991.

8. Howe, W.C. Fluidized Bed Combustion Experience with Waste Tires and Other Alternate Fuels. Presented at EPRI Conference: Waste Tires as A Utility Fuel. San Jose, CA. January 28, 1991.

9. Northern States Power Co. Alternative Fuel Firing in Atmosphere Fluidized-Bed Combustion Boiler. EPRI CS-4023. Final Report. June 1985.

10. Telecon. C. Clark, PES, with Justice, A., Illinois Department of Energy and Natural Resources. February 14, 1991. Tire recovery program at Illinois.

11. Telecon. D. Russell, PES, with Horvaf, M., Ohio Edison. February 26, 1991. Experience with tires-for-fuel.

12. Horvath, M. Whole Tire and Coal CoFiring Test in a Pulverized Coal-Fired Boiler. Presented at EPRI Conference: Waste Fuels in Utility Boilers. San Jose, CA. January 28, 1991.

13. Memorandum from Clark, C., PES, to Michelitsch, D., EPA/ESD/CTC. Summary of Meeting with Scrap Tire Management Council. October 29, 1991.

14. Telecon. D. Russell, PES, with Rolfes, M., Otter Tail Power. February 25, 1991. TDF experience.

15. Ohio Air Quality Development Authority. Air Emissions Associated with the Combustion of Scrap Tires for Energy Recovery. Prepared by: Malcolm Pirnie, Inc. May 1991.

16. Gaglia, N., R. Lundquist, R. Benfield, and J. Fair. Design of a 470,000 lb/hr Coal/Tire-Fired Circulating Fluidized Bed Boiler for United Development Group. Presented at EPRI Conference: Waste Fuels in Utility Boilers. San Jose, CA. January 28, 1991.

17. O'Brien, M.V., and W.C. Hanson, United Power Association, Elk River, MN. Shredded Tires for Electric Generation. Presented at APCA. Atlanta, GA. June 19-24, 1983.

18. Wisconsin Power and Light Company. The Operational and Environmental Feasibility of Utilizing Waste Tires as a Supplemental Fuel in a Coal-Fired Utility Boiler. Preliminary Report. State of Wisconsin, 1990. Waste Tire Management and Recovery Program.

19. Telecon. C. Clark, PES, with Eirschele, G., Wisconsin Power and Light. February 20, 1991. TDF experience.

20. Hutchinson, W., G. Eirschele, and R. Newell. Experience with Tire-Derived Fuel in a Cyclone-Fired Utility Boiler. Presented at EPRI Conference: Waste Fuels in Utility Boilers. San Jose, CA. January 28, 1991.

21. Schreurs, S.T. Tire-Derived Fuel and Lignite Co-Firing Test in a Cyclone-Fired Utility Boiler. Presented at EPRI Conference: Waste Fuels in Utility Boilers. San Jose, CA. January 28, 1991.

22. Memorandum from Russell, D., PES, to Michelitsch, D., EPA/ESD/CTC. November 8, 1991. Site Visit -- Wisconsin Power and Light Company.

7. USE OF TDF AS A SUPPLEMENTAL FUEL AT OTHER INDUSTRIAL FACILITIES

Several coal-fired boilers at industrial manufacturing facilities have reported using TDF as a supplemental fuel on a commercial or test basis. Further, TDF has been considered as a secondary fuel at several boilers firing biomass or refuse-derived fuel (RDF). This chapter summarizes information obtained on some of these facilities.

Note that data from a boiler burning TDF at a silicon manufacturing facility, Dow Corning in Midland, Michigan, are reported in Chapter 5 with waste wood boilers, because the primary fuel for this boiler is wood chips. Further, data on TDF use at Boise Cascade, an "other" manufacturing facility, are included in Chapter 4 with cement manufacturing, because the rotary kiln used to manufacture lime is similar to the rotary cement kilns.

7.1 DESCRIPTION OF INDUSTRIES

As of the Summer of 1991, at least eight industrial facilities have used TDF commercially or have tested TDF. These facilities are listed in Table 7-1. Only one, Firestone Tire Manufacturing in Decatur, IL, is known to be using TDF currently on an on-going basis.[2] Two, Hannah Nickel in Oregon, and Firestone Tire Manufacturing in Des Moines, Iowa, are no longer burning tires. Hannah Nickel closed, and, although it has reopened under new ownership, the facility has no plans to burn tires.[3] The boiler at Firestone in Iowa was shut down, because it could not meet particulate limits burning the very large agricultural tires manufactured at the plant.[2]

At Les Schwab Tires in Oregon, the small package steam generator uses 25 tires per hour. It has been in operation

Table 7-1. Other Industrial Boilers with TDF Experience

COMPANY AND LOCATION	TDF USE	AIR EMISSIONS TEST DATA	BOILER(S) DESCRIPTION	COMMENTS/REFERENCES
Archer Daniels Midland Decatur, IL	Current; long-term test basis; installing their own shredder on-site	Test burning may occur in April 1991; IL EPA granted Company a long term permit; doing testing and tire-burning on their own;		Grain processing plant. Reference 1
Caterpiller Tractor IL		Test planned for summer 1991	Spreader stoker boiler making process steam	Reference 1
Firestone Tire Des Moines, IA	Past; could burn 100 tpd; 20,000 lb/hr; 500,000 tires/hr; burned large agric. tires & other waste.	Exceeded opacity limit; needed fabric filter, but decided not econ. feasible.	1983 pulsating floor furnace.	Shut down 1987 for exceeding opacity limit. Reference 2
Firestone Tire Decatur, IL	Current; can burn 100 tpd; 22,000 lb/hr; 500,000 tires/yr; passenger tires; burns 25% by weight passenger tires + other rubber scraps; rest is wood, paper, misc.; 80% of Btu comes from tires.	Measures particulates, CO and CO_2 only; opacity	1984 pulsating floor furnace; hydraulic ram pushes waste from charging hopper into primary comb. chamber with stepped hearth; water cooled walls in chamber; pulses of air shake the fuel charge and move it down hearth; typical run is 7 to 17 days.	Permit limits number of operating hours; can burn 100% tires. References 2 and 3
Hannah Nickel OR	Past	Unknown	At one time, burned tires for 2-3 years in nickel calciners.	Primary nickel plant producing nickel metal; abandoned tire burning and closed plant; new owner has opened plant, but has no plans to burn tires. Reference 4
Les Schwab Tires Prineville, OR	Current; 25 whole tires per hour; both passenger and light truck tires	Unknown	Small steam generator	Retreader. Reference 2
Monsanto Company Sauget, IL	Test basis; 20% TDF, wire-in, 2" x 2"	Yes; test 12\90 boiler #8; tested PM, SO_2, NO_x, CO, Fl, HCl, total organics, metals, dioxin; TDF blended with coal.	Spreader stoker Traveling grate boiler; ESP controlled	Chemicals plant. References 5 and 6

Table 7-1. (Concluded)

COMPANY AND LOCATION	TDF USE	AIR EMISSIONS TEST DATA	BOILER(S) DESCRIPTION	COMMENTS/REFERENCES
Saginaw Division, GMC Saginaw, Michigan	Test basis; 5% TDF	Yes; tested boiler #6 in 11/83 for PM, SO_2, NO_3, at 0 and 10% TDF; tested #2 in 3/88 for PM, SO_2, SO_3, NO_x, at 0 and 5% TDF; tested #2 in 1/89 for PM at 0, 10, 15, and 20% TDF.	#2 spreader stoker traveling grate, 50,000 lb/hr; controlled by multiclone.	Steering and gear facility. References 7, 8, and 9
Biomass and Refuse-Derived Fuel Facilities				
Akron Recycle Energy System Akron, OH		Unknown		Refuse-derived-fuel power plant. Reference 10
RDF plant(s), Name unknown SC		Unknown		Problems in State in past burning TDF in REF boilers; none occurring now. Reference 11
Refuse-derived-fuel power plant Name unknown Columbus, OH		Yes; performed 24 hr test to get permitted; CEMS measurements only; on 3rd shift exceedances occurred, and no permit approved. Company wants to try again.		Refuse-derived-fuel power plant. Reference 10
Biomass burner Name unknown ME	Has capability to burn tires	Unknown		Currently being permitted by Maine DEP. Reference 12

since 1987 with moderate success. Whole tires are automatically fed into the unit, which burns tires at 2000°F and produces 100 psig process steam.[2]

Four facilities are currently testing tires, as shown in Table 7-1. Three are testing on an occasional basis, but Archer Daniels Midland (ADM), a grain processing plant in Decatur, Illinois, has been granted a long-term test permit by the Ohio EPA.[1] Little information was gathered regarding boiler configuration or pollution control devices in use at these facilities.

Four plants are reported to have considered burning TDF supplementally in boilers with a primary fuel of biomass or refuse-derived fuel. These plants are listed in Table 7-1. Two RDF fired power plants are attempting to obtain permits to burn tires.[10] One biomass burner in Maine is reportedly in the permit process, and has been designed with the capability of burning tires.[12] Personnel at the State Air Pollution Agency in South Carolina indicated that several municipalities had tried, unsuccessfully, in the past to burn TDF in their RDF incinerators.[11] No information was obtained on boiler configuration or air pollution control equipment.

7.2 PROCESS DESCRIPTION

Descriptive information of equipment or process flow was obtained for only one facility. The Firestone Tire Manufacturing facility in Decatur, Illinois, operates a pulsating floor boiler. A hydraulic ram stokes the chamber, which has a stepped grate. Pulses of air shake the fuel charge, and move it down the hearth.[2] The boiler burns tires and other waste on a batch basis; a typical run lasts from 7 to 17 days.[2]

7.3 EMISSIONS, CONTROL TECHNIQUES AND THEIR EFFECTIVENESS

Emission test data were evaluated for two facilities: Monsanto Company in Sauget, Illinois, and Saginaw Steering and Gear, in Saginaw, Michigan. Figure 7-1 summarizes percent change in particulate, SO_2, and NO_x emissions at these two facilities.

Test results for Monsanto are summarized in Table 7-2. Testing in 1990 measured criteria pollutants, HCl and HF while burning 100 percent coal, and while burning coal and 20 percent TDF. Emissions of all pollutants decreased, except CO and SO_2. The increase in CO does not appear significant given the negligible emission rate of CO in both tests.[5]

Three sets of tests have occurred at Saginaw Steering and Gear. The first, in 1983, measured particulate, SO_2 and NO_x, in Boiler #6.[7] All three pollutants increased at 10 percent TDF compared to baseline.[7] In 1988, boiler #2 was tested for particulate, SO_2, SO_3, at baseline and 5 percent TDF. Particulate, SO_3, and NO_x increased, while SO_2 decreased.[9] In 1989, particulate emissions from boiler #2 were tested given this time at four TDF levels: 0, 10, 15, and 20 percent.[8] Particulate emissions rose throughout the series.[8] Table 7-3 summarizes all these data.

7.4 OTHER ENVIRONMENTAL AND ENERGY IMPACTS

No information on other environmental and energy issues was obtained for these sources.

7.5 COST CONSIDERATIONS

No information on cost considerations was obtained for these sources.

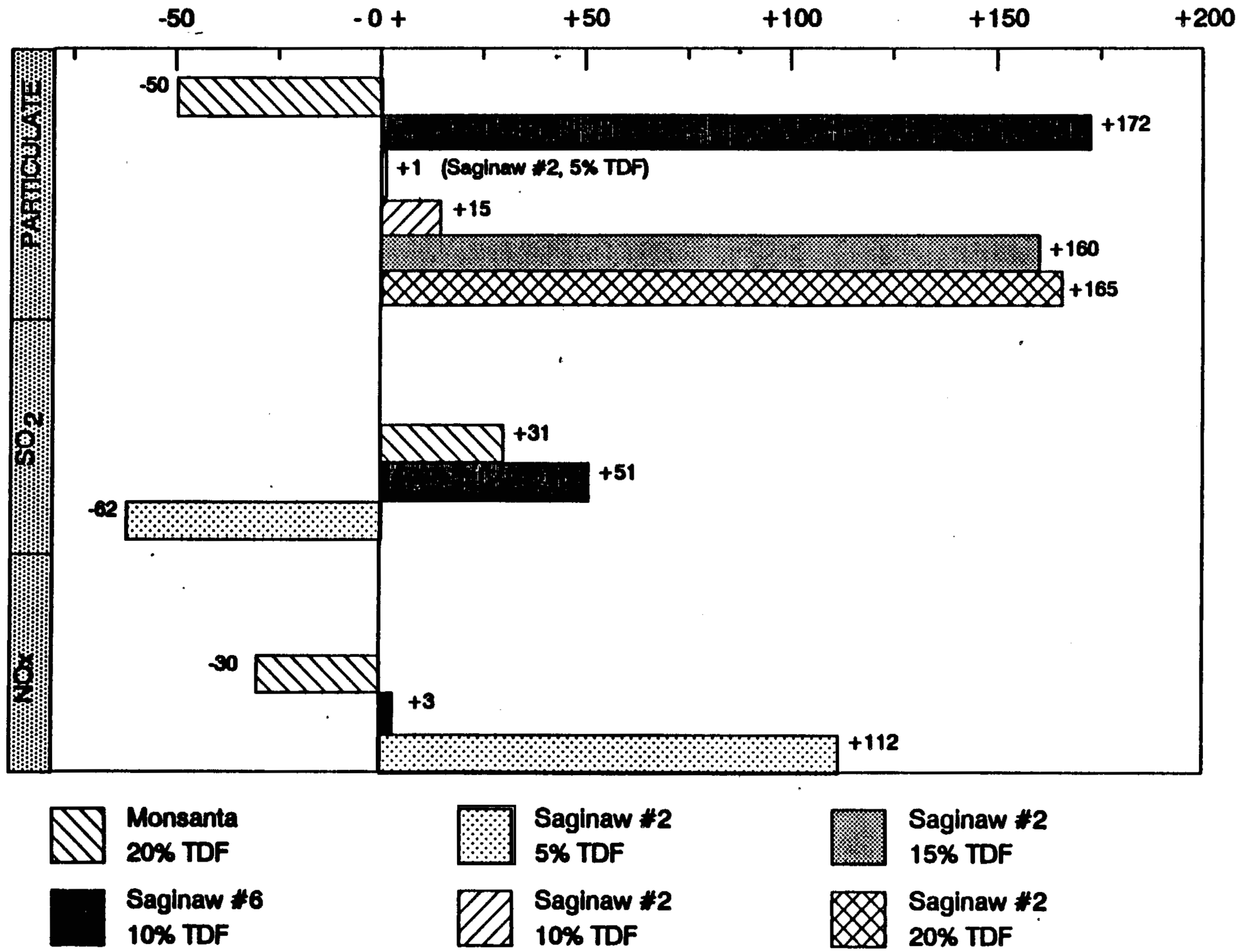


Figure 7-1. Summary of percent change in SO_2, NO_x, and particulate emissions at Monsanto Chemicals and Saginaw Gear[5,7,8,9]

Table 7-2. Summary of Emissions at Monsanto Sauget, IL[5]

December 18-19, 1990

	100% Coal lb/hr	80% Coal, 20% TDF lb/hr	% Change
Particulate	3.60	1.79	-50
CO	0.38	0.53	+40
VOC	1.04	0.73	-30
SO_2	83.0	109.0	+31
NO_x	34.7	24.3	-30
HCl	13.5	9.59	-29
HF	0.93	0.84	-10
Metals Dioxin	Test Data Not Available Yet		

Table 7-3. Summary of Air Emissions Test Data While Burning TDF at Saginaw Steering and Gear[7,8,9,a] Saginaw, MI

Date	Boiler No.	Pollutant	Baseline 100% Coal lb/hr	5% TDF lb/hr	10% TDF lb/hr	15% TDF lb/hr	20% TDF lb/hr
November 2-3, 1983	6	Particulate	28.34		76.99		
		SO_2	106.75		161.34		
		NO_x	81.98		84.42		
March 22-24, 1988	2	Particulate	6.93 (0.2656 lb/MMBtu)	7.02 (0.2628 lb/MMBtu)			
		SO_3	34.7	40.2			
		SO_2	6.11	2.35			
		NO_x	4.06	8.59			
January 23-26, 1989	2	Particulate	4.42		5.09	11.40	11.72

[a] TDF burned supplementally with coal.

7.6 CONCLUSIONS

The results of burning TDF as supplemental fuel at other industrial facilities are inconsistent and incomplete. Because of this, no conclusions can be made as to the effects of burning TDF in other industrial facilities.

7.7 REFERENCES

1. Telecon. Clark, C., Pacific Environmental Services, Inc. (PES), with Justice, A., Illinois Department of Energy and Natural Resources. February 19, 1991. Illinois TDF testing plans.

2. U.S. Environmental Protection Agency. Markets for Scrap Tires. EPA/530-SW-90-074B. September 1991.

3. Ohio Air Quality Development Authority. Air Emissions Associated with the Combustion of Scrap Tires for Energy Recovery. Prepared by: Malcolm Pirnie, Inc. May 1991.

4. Telecon. Clark, C., PES, with Fuller, B., Oregon Department of Air. February 28, 1991. Oregon TDF experience.

5. The Almega Corporation. Boiler Emissions and Efficiency Testing TDF/Coal Mixed Fuel Project. Prepared for Monsanto Company, Sauget, IL. December 18 and 19, 1990.

6. Telecon. Russell, D., PES, with Purseglove, P., Illinois EPA. February 14,1991. TDF experience in Illinois.

7. A.H. Environment, Inc. Report to Saginaw Steering and Gear, GMC. Boiler #6. November 2, 3, 1983.

8. Affiliated Environmental Services, Inc. Report to Saginaw Div/GMC on Stack Particulate Samples Collected on Boiler #2 At General Motors Steering Gear, Saginaw, MI. February 10, 1990.

9. Swanson Environmental, Inc. Air Emission Study Plant #2 Powerhouse, Boilers #1 and #2. Prepared for Saginaw Division, GMC, Saginaw, Michigan. March 22-24, 1988.

10. Telecon. Clark, C., PES, with Hilkins, T., Ohio EPA, Air Division. February 28, 1991. TDF Use in Ohio.

11. Telecon. D. Russell, PES, with L. Bunn, South Carolina Department of Health and Environmental Control. February 14, 1991. TDF experience in SC.

12. Telecon. D. Russell, PES, with L. Hamjian, U.S. Environmental Protection Agency. Region I. February 15, 1991. Facilities burning TDF in Region I.

8. SCRAP TIRE PYROLYSIS

Pyrolysis is the process of thermal degradation of a substance into smaller, less complex molecules. Many processes exist to thermally depolymerize tires to salable products. Almost any organic substance can be decomposed this way, including rice hulls, polyester fabric, nut shells, coal and heavy crude oil. Pyrolysis is also known as destructive distillation, thermal depolymerization, thermal cracking, coking, and carbonization.

Pyrolysis produces three principal products - pyrolytic gas, oil, and char. Char is a fine particulate composed of carbon black, ash, and other inorganic materials, such as zinc oxide, carbonates, and silicates. Other by-products of pyrolysis may include steel (from steel-belted radial tires), rayon, cotton, or nylon fibers from tire cords, depending on the type of tire used.

Each product and by-product is marketable. The gas has a heat value from 170 to 2,375 Btu/ft^3 (natural gas averages 1000 Btu/ft^3). The light oils can be sold for gasoline additives to enhance octane, and the heavy oils can be used as a replacement for number six fuel oil. The char can substitute for some carbon black applications, although quality and consistency is a significant impediment.

Conrad Industries operates a pyrolysis unit in Centralia, Washington. The unit is manufactured by Kleenair Products Company of Portland, Oregon, and licensed to Conrad. The plant began operation in March 1986, and currently has 10 employees. The unit is operated one shift per day, 5 days per week, 52 weeks per year. Conrad has five additional units planned around the United States, using four different feedstocks.[1]

The pyrolysis unit in Centralia converts 100 tires per hour (about one ton, assuming each tire weighs 20 pounds) to 600 pounds of carbon black, 90 gallons of oil, and 30 therms (8000 ft^3) of vapor gas. In addition to tire rubber, Conrad's unit has been used to pyrolyze substances as diverse as rice hulls, nut shells, biomass (including wood, paper, and compost), and plastics (including polyester, polyethylene, and propylene).[1]

This chapter discusses a "generic" pyrolysis process in detail and describes some of the significant variations. An analysis of the environmental impact and financial viability is also be presented.

8.1 PROCESS DESCRIPTION

The actual pyrolysis process is the result of heating long-chain polymers in the absence of oxygen. The heat causes the molecules to vibrate. The higher the temperature, the more rapid the vibration. At temperatures above 237°C (460°F), the vibration causes the weaker bonds in the molecules to snap, creating new, shorter molecules. These new molecules have lower molecular weights than the parent molecules. Long exposure to high temperature will eventually cause all of the organic molecules to break down, leaving the char residue. The quality and quantity of these three pyrolytic products, oil, gas, and char, depend upon the reactor temperature and reactor design.[2] Table 8-1 shows the effect of reactor temperature on the product mix. Conrad Industries generates gas, oil, and char in approximately equal proportions.[1]

Nearly all of the processes used for tire pyrolysis have the same basic unit operation, with variations in the reactor design. First, this chapter describes the basic process

Table 8-1. Approximate Product Distribution as a Function of Pyrolysis Reactor Temperature for Reductive Process Category[3]

Reactor Temp, °C (°F)	Gas, %	Oil, %	Char, %
500 (932)	6	42	52
600 (1112)	10	50	40
700 (1292)	15	47	38
800 (1472)	31	40	29

using a "black box," or generic reactor as shown in Figure 8-1. Specific types of reactors are described later in the chapter.

8.1.1 Materials Handling

The only raw material required for most tire pyrolysis processes is scrap tires. Some processors purchase and use whole tires, while others chip whole tires into two inch pieces, or purchase the tires already chipped. Conrad uses a local tire chipper to shred whole tires to a 2-inch size, wire-in, for their use. The tire chipper, who works on Conrad property, receives a tipping fee for collecting the tires, and provides the TDF to Conrad free of charge. Conrad has had no problem with reliability of their TDF source.[1]

If whole tires are used, they are usually added manually to the reactor. If the processor is using chipped tires, the chips are stored in a chip silo (see Figure 8-1, Item 1), and are fed from the silo into the reactor using a vibratory feeder or a screw conveyor to achieve a controllable and known feed rate. The feed passes through an air lock system consisting of two valves or a rotary star valve. From the air lock, the feed enters the pyrolysis reactor (Item 2).

8.1.2 Generic Reactor Description

In the reactor, the chips are heated to pyrolysis temperature, and the tire chips begin to break down. Reactors are operated from 237 to 1000°C (460 to 1830°F), with the maximum oil yield occurring at 450°C (840°F).[1] Conrad's reactor, which is a cylindrical-shaped furnace chamber with two reaction tubes or retorts, is operated between 900 and 1,000°F.[1]

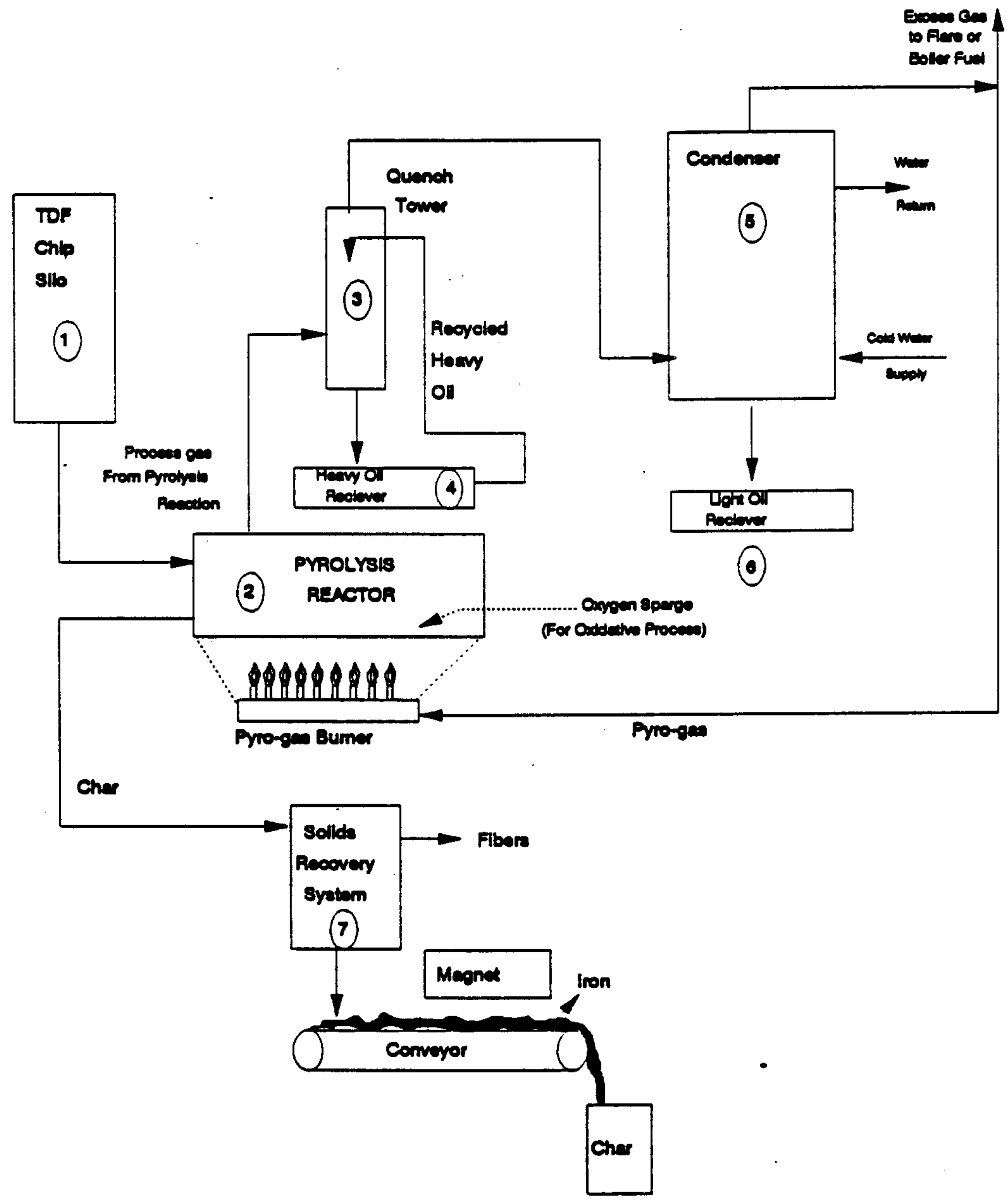


Figure 8-1. Generic Pyrolysis Process

Because of high reactor temperatures, the hydrocarbon volatiles vaporize immediately, and are vented from the reactor to a quench tower (Item 3), where they are sprayed with cooled, recycled, heavy oil, and the larger molecules (molecules containing eight carbon atoms (C8) or more) are condensed. The condensate leaves from the bottom of the quench tower and is collected in the heavy oil receiver (Item 4). Compounds that are not condensed (i.e., light oil, C3-C7) in the quench tower enter a non-contact condenser that uses cold water. The light oils, C3 to C7, are condensed and collected in the light oil receiver (Item 6).

Although pyrolytic oil contains significant quantities of benzene and toluene that have high value in the pure form, removal of these compounds from the pyrolytic oil requires expensive fractional distillation equipment. Pyrolysis operators have been reluctant to make the capital investment in distillation equipment because the risk is too high and the return on investment is too low. As a result, the pyrolytic oil must be sold as a replacement for Number Six (low priced grade) fuel oil. The oils generated at Conrad's Centralia facility contain a maximum of 1.5 percent sulfur, and have a potential market as blender oils for commercial fuel.[1]

The gas remaining after oil recovery, called pyrolytic gas, or pyro-gas, is typically composed of paraffins and olefins with carbon numbers from one to five. Depending on the process, the heat value of the gas can range from 170 to 2,375 Btu per cubic foot, and averages 835 Btu per cubic foot.[4] (Natural gas averages around 1000 Btu per cubic foot.) Most processes use the pyrolytic gas as fuel to heat the reactor. Any surplus gas can be flared or used to replace natural gas as boiler fuel. Emissions from burning pyro-gas would be similar to those from burning natural gas or low sulfur coal.

Part of the gas generated at Conrad's Centralia facility is used as fuel for the plant pyrolysis unit. The remaining gas currently is burnt in a outside flare. Currently, about 3.5 MMBtu's are burnt in the flare as excess; Conrad staff hope to have a commercial market for the excess gas in the future.[1]

Char is the solid product from the pyrolysis reactor. Char represents about 37 percent, by weight, of the total products from the process.[4] Pyrolysis char has limited marketability due to unfavorable characteristics. First, the char contains as much as 10 to 15 percent ash, which adversely affects its reinforcing properties in new tire manufacturing. Also, the char's particle size is too large to permit it to qualify as high quality carbon black.[4] Third, the char from the reactor is contaminated with steel wire, and rayon, cotton, and nylon fibers. Fibers can be removed mechanically, however, and the steel wire can be removed using a magnet. The carbon black from Conrad's Centralia facility averages less than 0.75 percent sulfur, and can be sold for uses such as copier toner, plastics products, rubber goods (hosing, mats), and paint.[1]

Most pyrolysis projects make some attempt to reduce the ash content and to upgrade the product char to a material comparable with commercial carbon black. Steam activation, pulverizing, screening, acid leaching, benzene extraction, filtering, and other processes have been used to upgrade char, but with questionable results. Pulverizing, screening, and conveying will create fugitive particulate emissions. Steam activation, extraction, leaching and filtering generate VOC fugitive emissions. Even upgraded char, however, cannot compete with virgin carbon black, or even with carbon black made from substoichometric combustion of hazardous organic wastes.

8.2 SPECIFIC REACTOR TYPES

Although there are hundreds of tire pyrolysis processes, they all can be categorized as either oxidative or reductive. Table 8-2 contains a list of manufacturers of oxidative and reductive processes with capacities, operating temperatures, and product mixes.

The oxidative process is not precisely "pyrolysis" because it injects oxygen or air into the reactor.[5] The strict definition of pyrolysis is the thermal degradation of material in the absence of oxygen. The oxidative process is included here, because the elements of the process and the unit operations are identical to pure pyrolysis. In the oxidative process, thermal degradation still occurs, but the oxygen reacts with degradation products causing partial combustion. This partial combustion is called "sub-stoichiometric combustion", because there is insufficient oxygen for complete combustion. Heat from the combustion causes additional thermal degradation of the remaining scrap tires. Gases produced by the partial combustion include carbon monoxide, carbon dioxide, hydrogen, and sulfur dioxide, which are not produced in the reductive process.

Steam injection is a variation of oxidative combustion because the predominant reactions involve cracking hydrocarbons to form carbon monoxide, carbon dioxide, and hydrogen. Because the gas products are not consumed as in the substoichiometric process, the steam injection process produces more combustible gas products than the oxidative process. In addition to the heat required to heat the reactor and contents, the steam injection process requires an external source of heat to produce the steam.

Table 8-2. Manufacturers of Pyrolysis Units and Operating Conditions

Process Name	Capacity tpd	Reaction Temp, °C	Yields as a percent of Tires			
			Oil, %	Char, %	Gas, %	Iron, %
OXIDATIVE:						
Quinlyn	120	600	62	16	11	0
Nippon Zeon	26.5	449-500	56	31	3	10
Sumotomo	5	704	54.7	31.7	9.5	4.1
Tosco	15	510	52	29	11	4
REDUCTIVE:						
Kobe	26.5	500	41	33	7	5
MVU	8.6	677	22	47	17	10
Herko/Kiener	238	600	47	30	17	6
ERRG	3	871	38	30	28	4
Carb Oil & Gas	60	600	45	33	13	9
Nippon O & F	27	500	49	36	10	5
Inten Company	100	496	52	35	7	4
Kutrieb	6	427	35	38	20	5
Carb-Oil	112	1010	43	34	18	6
Yokohama	8.2	500	53	33	n/a	n/a
Onahama	30	400	21	20	51	7
Tyrolysis	165	534	45	39	0	16
Bergbau	1.3	923	5	35	20	10
DRP	25	722	27	39	12	0

The reductive process is the more traditional process for tire pyrolysis. This process excludes all sources of oxygen and relies on the reactor heat alone to decompose the tires. Some processors pressurize the reactor with an inert gas such as nitrogen to prevent air from leaking into the reactor, while some inject hydrogen to react with the sulfur present in the rubber in the tires to form hydrogen sulfide. Hydrogen sulfide can be recovered and sold as a by-product.

As mentioned earlier, a number of different types of reactors have been tried in tire pyrolysis. Almost any vessel that can be sealed can be used as a pyrolysis reactor. Reactor design has a significant effect on the quality of char produced, due to a uniform temperature gradient, and the abrasion of the particles with one another. Some of the reactor types that have been used are:

- sealed box
- rotary kiln
- screw kiln
- traveling grate kiln
- fluidized bed

Below, different reactor designs are discussed in order of increasing technical complexity, and thus, increasing cost. Char quality also improves through the list, but none produce a quality char comparable to carbon black in most applications, even after upgrade.

8.2.1 Sealed Box

The sealed box is the simplest but most labor intensive process. In this process, whole tires are stacked manually in a steel cylinder equipped with airtight heads on each end. Heat is added either externally or directly inside the reactor until the reactor reaches the desired pyrolysis temperature. The reactor is then held at that temperature for several hours. Next the reactor is cooled, opened, and manually cleaned to remove char, wire, and fabric. It is then reloaded, and the process is repeated. This process requires a minimum of three reactors to provide a constant source of gas to fire a boiler.

8.2.2 Rotary Kiln

The rotary kiln is simple in concept, but difficult to operate in practice. The rotary kiln is a refractory lined, steel cylinder mounted horizontally on trunions and riding rings. It is pitched slightly toward the discharge end to facilitate material flow through the kiln. The kiln is fed from the high end and can be fed either whole tires or TDF chips. It can be fired internally or heated externally. One of the biggest operating problems is sealing the inside of the kiln against leaks. Kilns are usually operated with a slight negative pressure (induced draft). Almost all kilns leak to some degree, and these leaks cause outside air to enter the reactor, which results in ignition of the product gases. Rotary seals are provided at the inlet and discharge ends of the kiln, but sealing an eight to ten foot rotating cylinder is extremely difficult.

8.2.3 Screw Kiln

The screw kiln is a stationary steel cylinder equipped with a rotating screw device that moves the material through the cylinder. Screw kiln cylinders are often much smaller in diameter than rotary kilns. The normal feed is chipped tires with the wire removed. (Exposed wire causes feed and handling problems.) The primary advantage of using its screw kiln reactor is that its screw shaft is much smaller, and therefore easier to seal, than the large cylinder of the rotating kiln. The main disadvantage of the use of the screw kiln is the mechanical problems associated with a screw moving inside an extremely hot, erosive environment.

8.2.4 Traveling Grate Kiln

The traveling grate kiln is a fixed vessel equipped with a chain-link type grate that moves continuously from the feed end to the discharge end. The kiln can be heated directly or indirectly. Tires or TDF are fed through an air lock onto the feed end of the grate. As the grate moves, the tires are degraded. The char is discharged at the end of the bed into a collection hopper, and the grate is recycled back to the feed end of the kiln. Mechanical problems exist with the traveling grate kiln because equipment must operate in a high temperature, erosive environment.

8.2.5 Fluidized Bed

The fluidized bed reactor is a vertical steel vessel to which TDF is fed through a side port. A fluidized bed of TDF is maintained with hot air. The abrasive action of the fluidized particles erode the char from the TDF, reducing the tire material to small pieces. As the TDF decomposes, ash and char are swept out of the reactor with the fluidizing air. The biggest disadvantages of a fluidized bed system are the need to remove entrained solids from the vapors, and the need to maintain the hot, fluidizing gas. The two main advantages are the good solids mixing and uniform solids temperature profile in the fluidized bed. These two advantages produce the finest grade char of any of the pyrolysis processes.

8.2.6 Other Reactors

Other reactors and processes include the hot oil bath, molten salt bath, microwave, and plasma. These processes have been researched on laboratory and some cases pilot plant scale. None have proven commercially successful.

8.3 ENVIRONMENTAL IMPACTS

Pyrolysis units are expected to have minimal air pollution impacts because most of the pyro-gas generated in the pyrolysis process is burned as fuel in the process. During burning, the organic compounds are destroyed. Assuming complete combustion, the decomposition products are water, carbon dioxide, carbon monoxide, sulfur dioxide and nitrogen oxides.

Conrad's Centralia plant has no pollution control equipment except for the outside flare for the excess gas. No continuous emissions monitoring systems are used. No local regulations apply to the facility, although an annual inspection is conducted on site by regulatory agencies. Plant personnel conduct weekly leak checks for gases from pipes, valves, and flanges. Few air emissions result from operation of this equipment. Air pollution control equipment is not even necessary to meet state standards.[1]

An emissions test of the pyro-gas was conducted at Conrad on December 18, 1986, while pyrolyzing TDF. Measurements included particulate, metals, volatile and semi-volatile organic compounds, sulfur dioxide (SO_2), nitrogen oxides (NO_x), carbon dioxide (CO_2), oxygen (O_2), and carbon monoxide (CO).[1] The test results are presented in Table 8-3. Note that these emission estimates do not reflect atmospheric emissions.

8.3.1 Particulate Emissions

As seen in Table 8-3, particulate emissions in the pyro-gas were estimated to be emitted at a rate of 0.0001 lbs per MMBtu.[1]

Table 8-3. Emission Estimates from Pyrolysis Facility, Conrad Industries[1,a]

	Concentration ($\mu g/m^3$)	Emission Rate[b] (lbs per MMBtu)
Particulate	2,500	1×10^{-4}
Plasma Metals		
Aluminum	1.51	6.7×10^{-8}
Chromium	0.82	3.7×10^{-8}
Iron	9.89	43.9×10^{-8}
Magnesium	0.45	2.0×10^{-8}
Manganese	0.09	0.4×10^{-8}
Mercury	0.05	0.2×10^{-8}
Nickel	2.95	13.1×10^{-8}
Potassium	1.84	8.2×10^{-8}
Sodium	18.62	82.7×10^{-8}
Zinc	0.65	2.9×10^{-8}
Semi-Volatile Organic Compounds		
Bis-(2-ethyhexyl)phthalate	10.2	45.3×10^{-8}
Butyl Benzylphthalate	1.7	7.5×10^{-8}
Di-n-butylphthalate	0.9	4.0×10^{-8}
Naphthalene	2.87	12.7×10^{-8}
Phenol	1.4	6.2×10^{-8}
Volatile Organic Compounds		
Benzene	20.2	c
Ethylbenzene	24.1	c
Toluene	30.8	c
Xylenes	16.2	c
Sulfur Dioxide	310,500	7.7×10^{-2}
Nitrogen Oxides	210,000	9.7×10^{-3}

a These emission estimates reflect the composition of the pyro-gas, which is either burned in the process as fuel or (for the excess pyro-gas) vented to the facility's flare. These estimates do not reflect atmospheric emissions.

b These emission rates were calculated by taking the average concentrations reported for the compound and multiplying it by the average flow rate for the test runs. An energy input value of 31 MMBtu was used to calculate lbs/MMBtu.

c Flow rates were not reported. Thus, pounds of emissions per hour could not be calculated.

Quantitative estimates of fugitive emissions were not available. Fugitive emissions of particulate occur during the handling and processing of char. Char contains carbon black, sulfur, zinc oxide, clay fillers, calcium and magnesium carbonates and silicates, all of which produce PM_{10} emissions. Operations such as screening, grinding, and processing cause PM_{10} emissions and could be controlled with dust collectors and a baghouse.

8.3.2 VOC Emissions

The major source of VOC emissions is from fugitive sources. VOC fugitive emissions occur from leaks due to worn or loose packing around pump shafts and valve stems, from loose pipe connections (flanges), compressors, storage tanks, and open drains. The composition of the fugitive emissions is a combination of "pure" pyro-gas and non-condensed light oils. Table 8-4 presents the composition of "pure" pyro-gas.[2] The primary constituents of pyro-gas are hydrogen, methane, ethane, propane, and propylene. These five constituents account for over 98 percent of the pyro-gas composition.

In practice, pyro-gas will always contain some non-condensed light oils. Table 8-5 gives the composition of the light oil condensed from pyro-gas at 0°C (32°F).[4] Listed among the components are toluene, benzene, hexane, styrene, and xylene. Emissions of benzene, ethylbenzene, toluene, and xylene were measured in the stack test at Conrad Industries. Flow rates for the tests measuring these compounds were not reported; thus, emission rates (lbs/MMBtu) could not be estimated.

No references to fugitive emissions from the pyrolysis process could be found in the literature. To estimate the order-of-magnitude emissions from this process, a model plant was assumed. Based on a Department of Energy study, the most economical plant size is 100 tons per day (2000 tires per day).[4] This size would make the plant roughly equal to one hundredth the size of the model refinery listed in AP-42.[6] Table 8-6 gives one hundredth of the fugitive emissions from the refinery, the number units in the process, and the daily emissions from each source. Based on these assumptions, a typical pyrolysis plant would emit about 50 kilograms of VOC's per day (about 100 pounds per day), or 18.7 megagrams per year (21 tons per year total).

Fugitive VOC emissions can be significantly reduced by specifying components (e.g., pumps, valves, and compressors) specifically designed to minimize fugitive emissions. Fugitive VOC emissions can also be reduced by training operators and mechanics in ways to reduce fugitive emissions, good supervision, and good maintenance practices.

8.3.3 Other Emissions

Semi-volatiles, SO_2, and NO_x were also measured in the pyro-gas. The majority of the semi-volatile compounds detected were phthalates. The methods used to detect the semi-volatiles (gas chromatography/mass spectrometry analysis using dry sorbent resins) could have been the source of the phthalates, because these methods can give rise to phthalate contamination.[1]

8.4 OTHER ENVIRONMENTAL AND ENERGY IMPACTS

If markets for char cannot be developed, the char becomes a major solid waste problem. Analysis of char from the pyrolysis of scrap tires does not indicate a problem with hazardous materials.[4] However if it must be disposed of in a landfill, the char should be collected in plastic bags and shipped and disposed of in steel drums to prevent additional fugitive emissions during transportation and disposal.

Table 8-4. Chromatographic Analysis of Pyrolytic Gas from Shredded Automobile Tires with Bead Wire In[2]

Constituent	Volume Percent
Hydrogen	47.83
Methane	29.62
Ethane	18.52
Propane	5.70
Propylene	8.82
Isobutylene	0.73
Isobutane	0.34
Butane	0.23
Butene-1	0.14
trans-Butene-2	0.07
iso-butene-2	trace
Pentane	ND[a]
1,3-Butadiene	ND[a]

[a] ND = not detected

Table 8-5. Chromatographic analysis of light oil condensed from pyrolytic gas at 0°C using shredded tires with bead wire4

Constituent	Volume Percent
Toluene	11.05
Benzene	8.83
1-Hexene	5.85
Hexane	4.07
8-Methyl-8-Butene	3.55
trans & cis-8-Hexene	3.42
Styrene	3.03
Ethyl Benzene	3.33
Xylene	4.18
3,3-Dimethyl-1-Butene	1.11
8-Methyl Butane	1.04
2,8-Dimethyl Butane	1.04
8-Methyl-1,3-Butadiene	1.85
Cyclopentane	1.48
Other	46.17

NOTE: These light oils comprise only about 2 percent of the total pyrolytic gas volume.

Table 8-6. Estimated fugitive VOC emissions from a "generic" pyrolysis plant[6,a]

Fugitive Emissions Source	No. of Sources in Process	VOC Emissions kg/day	lb/day
Pipe Flanges	47	2.72	6
Valves	12	30.84	68
Pump Seals	4	5.90	13
Compressors	1	5.00	11
Pressure Relief Valves	1	2.27	5
Open Drains	7	4.54	10
TOTAL		51.27	113

[a] Based on one hundredth the size of the refinery (value x 0.01).

In addition, depending on the feedstock, some non-flammable by-products result, such as fiberglass, or scrap steel. Conrad hopes to generate a market for the fiberglass as a filler material, although it is landfilled currently. The scrap steel can be sold to a scrap dealer.[1]

If non-contact, water cooled condensers are used, water pollution problems should be minimal. Except for cooling, the only other source of water contamination is water used in washing the plant floors and equipment. Oil spills may occur, and should be isolated, contained and cleaned up without contaminating the waste water.

Most processors like to maintain at least a 30 day stock pile of raw materials as protection against market fluctuations, transportation problems or work stoppages. The pile must be maintained properly. If the pile is not "live storage" (first in, first out), the pile could pose a potential health hazard due to rodent and insect infestations. The potential of a tire pile fire is always a possibility, and fire fighting equipment and access to the pile is important.

8.5 COST CONSIDERATIONS

During the past ten years, no less than 34 major pyrolysis projects have been proposed, designed, patented, licensed, or built (see Table 8-2). Only one or two are operational today, arguably, none on a commercial basis. Technically, tire pyrolysis is feasible; but financially, it is very questionable. This section reviews some of the highlights of the financial analysis of the process and products.

The economics of the pyrolysis business are extremely complex. First, an investment of over $10 million is required to construct a 100 ton per day plant.[4] Second, the business has many important variables, none of which are fixed or easily predictable. For example, the yield of the pyrolytic oil can vary from 82 to 171 gallons per ton of tires fed into the process. The selling price of pyrolytic oil can vary from 36 to 95 cents per gallon, depending on the composition and quality. Other products of the pyrolysis process have similar potential variations. Because of this, economic analyses require many assumptions.

In 1983, the U.S. Department of Energy evaluated the economic viability of tire pyrolysis and published its findings in a report entitled Scrap Tires: A Resource and Technology Evaluation of Tire Pyrolysis and Other Selected Alternative Technologies.[2] Their "Economic Results" stated in part:

> "Economic Results. An analysis of each project using the preceding economic parameters and computer program was performed. The results showed negative cash flows for each project. Using the accelerated capital recovery system (ACRS) still showed negative cash flows for each project. The reason for these negative cash flows is that tire pyrolysis is only economic with unique situational variables. There are a number of questions about product quality, product price, and feed stock cost which tend to lend a vagueness to the economic analysis..."

The DOE report evaluated the sensitivity of the model results to changes in selected variables such as capital investment, labor, utilities, and product prices. In this analysis, all but one of the variables were held constant and the selected variable was evaluated from minus 20 percent of the assumed value to plus 20 percent, in 10 percent increments. The two variables with the largest impact on profitability were the tire tipping fees (fees paid for the disposal of scrap tires -- an income for tire acquisition cost), and selling price of the products. Table 8-7 summarizes the tipping fees and product selling prices

Table 8-7. Tire Acquisition Prices and Selling Prices of Products Required to Produce a 20 Percent Return-on-equity for Five Tire Pyrolysis Units[2] (dollars)

Material	ERRG	Foster-Wheeler	Garb Oil	Kobe	Kutrieb
Tipping fee[a]	0.75	0.04	0.16	1.03	0.11
Oil[b]	8.13	0.60	0.77	8.15	0.77
Char[c]	0.10	0.06	0.07	0.33	0.06
Steel[d]	121	13	35	68	39

[a] Tipping fee, credit received for tire disposal,$/tire
[b] Selling price of pyrolytic oil, $/gallon
[c] Selling price of char, $/pound
[d] Selling price of scrap steel, $/ton

required to produce a 20 percent Return-on-Equity (ROE) for five pyrolysis processes modeled in the report. The analysis assumes all of the pyro-gas generated is consumed as fuel in the process.

Higher tire tipping fee could enhance tire pyrolysis economics. The business can be made financially successful if the tipping fees to the process operator range from $1.00 to $8.00. Currently, several states charge a tire disposal fee of a dollar or more at the time of purchase. Most of the fees, however, pay to administer the program, pay the tire collector, the distributor, the tire processor, and the end user of the scrap tires. The end user frequently collects only 15 to 20 cents per tire. As a comparison for Table 8-7, in the 2nd quarter of 1991, crude oil sold for about $20 per barrel ($0.47 a gallon), high quality carbon black sold for $0.28 per pound, and scrap steel sold for approximately $25 per ton.

8.6 CONCLUSIONS

Air pollution implications of pyrolysis are minimal with correct design and operation. VOC's in the gas can leak from pump seals, pipe flanges, valve stems, drains, and compressors. Particulate matter is generated from handling and processing the char. Emissions data from pyrolysis units are minimal, because many plants operate for short periods of time, and often only at pilot scale level.

Tire pyrolysis operations are currently small scale. Large scale operations would not be economically feasible at present. Economically, pyrolysis is a marginal venture. Unless area tire disposal costs are high, on-site energy savings can be realized, tax advantages are present, and higher value products (such as benzene and toluene) can be made.

8.7 REFERENCES

1. Memorandum from Clark, C., Pacific Environmental Services, Inc., (PES) to Michelitsch, D., EPA/ESD/CTC. September 28, 1991. Site Visit -- Conrad Industries.

2. Dodds, J., W.F. Domenico, D.R. Evans, W. Fish, P.L. Lassahnn, and W.J. Toth. SCRAP TIRES: A Resource and Technology Evaluation of Tire Pyrolysis and Other Selected Alternate Technologies. U.S Department of Energy. November, 1983.

3. Schulman, B.L., P.A. White. Pyrolysis of Scrap Tires Using the Tosco II Process. American Chemical Society 0-8418-0434 9/78/47-076-274. September, 1978.

4. Wolfson, D.E., J.G. Beckman, J.G. Walters, and D.J. Bennett. Destructive Distillation of Scrap Tires U.S. Department of Interior, Bureau of Mines. Report No. 7302. April 1973.

5. Foster Wheeler Power Products, Ltd. Corporate Report; Tyrolysis--Tyre Pyrolysis Plant.

6. U.S. Environmental Protection Agency. Compilation of Air Pollutant Emission Factors, Fourth Edition, AP-42, p. 9.1-13.

APPENDIX A

STATE CONTACTS FOR WASTE

TIRE PROGRAMS

(Reprinted from U.S. Environmental Protection Agency, Markets for Scrap Tires, EPA-530-SW-90-074B, September 1991)

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16. ABSTRACT

This document was developed in response to increasing inquiries into the environmental impacts of burning waste tires in process equipment. The document provides information on the use of whole, scrap tires and tire-derived-fuel (TDF) as combustion fuel and on the pyrolysis of scrap tires. The use of whole tires and TDF as a primary fuel is discussed for dedicated tire-to-energy facilities. The use of whole tires and TDF as a supplemental fuel is discussed for cement manufacturing plants, electric utilities, pulp and paper mills, and other industrial processes. The focus of the document is on the impact of burning whole tires and TDF on air emissions. Test data are presented and, in most instances, compared with emissions under baseline conditions (no tires or TDF in the fuel). The control devices used in these industries are discussed and, where possible, their effectiveness in controlling emissions from the burning of whole tires or TDF is described. In addition, this report provides information on the processes themselves that use whole tires or TDF, the modifications to the processes that allowed the use of whole tires or TDF, and the operational experiences of several facilities using whole tires or TDF. The economic feasibility of using whole tires and TDF for the surveyed industries is discussed. Finally, contacts for State waste tire programs are presented.

17. KEY WORDS AND DOCUMENT ANALYSIS

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