R- 214

THE DISPOSAL OF DISCARDED RAILROAD WOOD CROSS TIES

- A STUDY OF ALTERNATIVES -

December, 1975

PREPARED BY

A. J. Dolby
Environmental Engineer
Illinois Central Gulf Railroad
Chicago, Illinois

PREPARED FOR

Association of American Railroads
Research and Test Department
Washington, D. C.

THE DISPOSAL OF DISCARDED RAILROAD WOOD CROSS TIES

- A STUDY OF ALTERNATIVES -

December, 1975

PREPARED BY

A. J. Dolby
Environmental Engineer
Illinois Central Gulf Railroad
Chicago, Illinois

PREPARED FOR

Association of American Railroads
Research and Test Department
Washington, D. C.

TABLE OF CONTENTS

LIST OF TABLES

APPENDIX 1

Tables 6 Through 18 - Basis For Tables 2,3, and 4

APPENDIX 2

York-Shipley Summary Report On Model FB50
Solid Waste Converter System

APPENDIX 3

Performance Evaluation Of York-Shipley Fluid Flame
Solid Waste Converter By Roy F. Weston, Inc.
(Comparison Of Test Results With EPA Requirements)

THE PROBLEM

Historically, approximately 25,000,000 wooden railroad cross ties must be replaced each year. In 1974 for instance, 23,000,000 cross ties were removed from track in the United States. In the past, these ties were usually burned near the point of removal; a number were left in a convenient place and made available to local farmers or homeowners. Two significant changes have occurred which have rendered these disposal methods ineffective. The first change was the adoption and widespread use of the tie saw as a tie removal tool. It was adopted to minimize the disturbance to the roadbed during tie removal and increase the production of tie gangs. It also made the ties, which were now removed in three pieces, practically useless to farmers and homeowners. The second change was the promulgation of pollution control regulations by various governmental bodies. As a result of these regulations, it is not permissible in most States to burn cross ties. Therefore, both methods previously used to dispose of cross ties removed from track have been rendered unavailable. This means that millions of waste cross ties are accumulating and the annual increments will increase as more attention is placed on upgrading the Nation's roadbeds.

THE SCOPE

This study has explored new disposal methods for discarded cross ties with the most emphasis being given to methods which have the potential for generating revenue. The most promising methods have been developed sufficiently to make it possible for the railroads to use the technology immediately.

OBJECTIVE

The objective of this study has been to develop several methods to reuse or dispose of discarded wooden cross ties.

METHODS

The following methods of reusing or disposing of discarded cross ties have been investigated:

1) Pulp Production
2) Particle Board Production
3) Shredding on the Right-Of-Way
4) Landfill
5) Fuel
6) Sale
7) Miscellaneous Methods

PULP PRODUCTION

The chemical composition of wood is as follows[1]:

TABLE 1

	Hardwood %	Softwood %
Cellulose	40-50	40-45
Lignin	20-25	25-35
Pectin	1-2	1-2
Starch	Trace	Trace
Hemicellulose	25-35	25-35
a. Glucuronorylan	Very Large	Small
b. Glucuronoarabinolylan	Trace	Small-Medium
c. Glucomannan	Small	Large
d. Galacloglucomannan	Very Small	Small-Medium
e. Arabinogalactan	Small	Very Small
f. Other galactons	Trace-Small	Trace-Small

Wood also contains .2 to 1.0 percent mineral matter which can be calcium, potassium, magnesium, manganese, chloride ion,[2] etc., and is usually reported as the ash content or the noncombustible portion of the wood.

---

[1] E.E. Dickey, Chemical Composition of Wood and the Hemicelluloses (Atlanta: Tappi Vol. 43, No. 9, 1960) p. 196

[2] James P. Casey, Pulp and Paper Chemistry and Chemical Technology (New York: Interscience Publishers, Inc., 1960) p. 89

As can be seen from Table 1, the major components of wood are lignin, cellulose, and hemicellulose. Cellulose is the major structural element. Lignin and hemicellulose are the binding substances which cement the fibers together. Hardwoods are composed of short fibers while softwoods have longer fibers.

Wood contains water both as free water in the cavities and hygroscopic water which has been absorbed by the wood. The point at which all free water has been removed and all hygroscopic water remains varies with species, but is usually 20 to 32 percent moisture.[1] An increase or decrease in the hygroscopic water present in the wood causes it to expand or contract respectively.

The pulping process breaks the wood down into individual fibers by removing the lignin. Several processes are available to accomplish this; however, the most common methods use sulfite in acidic conditions or sulfide in alkaline conditions. The amount of hemicellulose that can be removed depends on the product that will be manufactured using the pulp. Paper production requires a high level of hemicellulose. After the sulfite treatment, the fibers are usually bleached with a series of chemicals such as chlorine and sodium hydroxide to remove the remaining lignin and improve the color of the final product.

Pulp can be used to produce products such as paper, rayon, insulating board, hard board (such as the masonite process) etc. Obviously, the proper pulp for the production of a product depends on the characteristics which that end product must have. Where strength is required, the long

---

[1] E. E. Dickey, Chemical Composition of Wood and the Hemicelluloses (Atlanta: Tappi Vol. 43, No. 9, 1960) p. 196

fibered softwoods must be used, and when color is important, more attention must be given to the bleaching operation.

The condition of the wood fibers is extremely important in the pulping process. Normally, wood will give higher pulp yields with shorter elapsed times between cutting and pulping. If the wood is allowed to dry, the outer layers will dry and contract first resulting in cracking and fiber damage. The dry fibers will be stiff and brittle, and more mechanical damage to them will occur during the chipping operation.

The quality of the pulp can also be affected adversely if the wood begins to deteriorate through weathering or decay prior to pulping. Erosion of wood in air is extremely slow and results primarily in a rougher surface with a change in the color. On the other hand, the decay of wood, usually caused by the presence of fungi, can occur fairly rapidly. In the presence of metal, this process is greatly accelerated.

The majority of ties currently being removed from track are hardwood; therefore, the short fibers they could provide would only be useable to manufacture low-grade pulp products.

Cross ties are treated with creosote at a rate between 4 and 15 pounds per cubic foot depending on whether hardwood or softwood is being treated. The creosote used is a distillate derived entirely from bituminous coal tar. The American Railway Engineering Association specification for new creosote is as follows:

	Not Less Than	Not More Than
Water (percent by volume)	----	1.5
Matter insoluble in Benzene (percent by weight)	----	0.5

	Not Less Than	Not More Than
Specific gravity at 38°C compared with water at 15.5°C		
Whole Creosote	1.050	----
Fraction 235-315°C	1.027	----
Fraction 315-355°C	1.095	----
Distillation:		
The distillate, percent by weight on a water-free basis, shall be within the following limits:		
Up to 210°C	----	2.0
Up to 235°C	----	12.0
Up to 270°C	20.0	40.0
Up to 315°C	45.0	65.0
Up to 355°C	65.0	82.0

An analysis of one sample of creosote with a gas chromatograph yielded the following constituents:[1]

	bp°C	Specific Gravity
Naphthalene	218	1.0253
2-Methylnaphthalene	241.05	1.0058
1-Methylnaphthalene	244.64	1.0202
Diphenyl	255.9	0.8660
1,4-Dimethylnaphthalene	268	1.0166
2,3-Dimethylnaphthalene	268	1.003
Acenaphthene	279	1.0242 @99°C 1.225 @ 0°C

---

[1] R. H. Colley, Cooperative Creosote Project VIII (Proceedings of American Wood Products Association, 1974) pp. 1-19

	bp°C	Specific Gravity
Dibenzofuran	287	1.0886
Fluorene	293-5	1.203
Phenanthrene	340	0.9800
Anthracene	340	1.283
1-Methylphenanthrene	---	---
3-Methylphenanthrene	140-50	---
1-Methylanthracene	199-200	1.0471
2-Methylanthracene	---	1.81
9-Methylanthracene	196-7	1.065
Fluoranthene	N375	1.252
Pyrene	393	1.271
1,2-Benzofluorene	413	---
Chrysene	448	1.274
Carbazole	355	---

Creosote is usually blended either with petroleum oil or bituminous coal tar before it is applied to the cross-ties.

The tie samples analyzed during this study indicate that an average of 1.5 pounds per cubic foot of creosote remains in the ties[1] at the time they are removed from track. It can be reasonably assumed that the distillates in creosote with the lower boiling points and the lower boiling point distillates in the coal tar or petroleum oil blending agent have been removed from the tie by weathering during its service life. However,

---

[1] 195 lb/Tie ÷ 3.74 ft^3/Tie X 2.97% creosote

practically all the treatment is probably removed by weathering at the surface, while deeper into the portion of the tie originally penetrated by the treatment, a wider range of distillate boiling points can be found. Sufficient creosote residue definitely remains to interfere with the pulping process.

Creosote is applied to wooden ties because it is toxic to the fungi which cause decay. However, as the tie gets old and the creosote content becomes lower, some decay usually occurs. This is especially true under the tie plates where the wood is in contact with metal. In addition to the fiber damage caused by decay, mechanical damage (mostly under the tie plates) is found to have occured during the life of the tie.

The ties must be reduced to chips 5/8 to 7/8 inches long by 1/4 to 2 inches wide and 1/4 inches thick before the pulping process can begin. Discarded ties often contain spikes and "S" bands and sometimes they still have tie plates attached to them. In addition, they usually have splits and voids in them which contain ballast, dirt, coal, etc. It would be extremely difficult to develop a chipper which could operate under these conditions, and if one were developed, the operating cost would likely be extremely high.

The moisture content of the ties sampled ranged from 2.1 and 45.7 percent. As a result of this, many of the fibers could be expected to be dry and brittle and experience mechanical damage during the chipping process.

As a result of all these difficulties, it is not currently feasible to pulp discarded cross ties, even if the pulp is subsequently intended for use in manufacturing low-grade products.

PARTICLE BOARD PRODUCTION

Particle board can be formed from wood splinters, shavings, or chips. These particles are bonded together by the use of a resin impregnated under elevated temperature and pressure. Ties must be chipped before they can be used as a raw material in the production of particle board. Shredding is not satisfactory since it results in excessive fiber damage and does not produce particles with sufficient uniformity. Therefore, this process, like pulping, suffers from the extreme difficulty experienced when attempting to chip cross ties.

Particle board manufactured from cross ties has limited marketability because it emits a slight odor of creosote. Yet, the creosote does not seem to interfere with the bonding process.[1] New cross ties have been produced on a very limited basis from particles of discarded cross ties at a cost somewhat greater than the cost of conventional wooden ties. However, none of these remanufactured ties has been in track long enough to completely evaluate its serviceability relative to that of a conventional tie. It should be noted that it is not currently feasible to recycle a particle board cross tie after it is removed from track.

Particle board produced from discarded wooden cross ties has not made a significant penetration into any market to date. Such conversion suffers from the cost of transporting the discarded wooden tie to the processing plant and chipping it, relative to the cost of forest product wastes which are often already chipped and located near the particle board.

---

[1] United States Forest Products Laboratory, Madison, Wisconsin reached this conclusion after testing the process and then producing a limited number of laminated particle board ties.

processing plant. Furthermore, the odor derived from creosote precludes its use in many of the existing markets for particle board such as the furniture and home building markets. However, it may still be a viable product with limited applications.

SHREDDING ON THE RIGHT-OF-WAY

Shredding is a process that uses a hammer and anvil or similar arrangement to break cross ties into small pieces. If the size of the final product is important screens are added. This process causes much more fiber damage and produces a less uniform product than chipping but the equipment used requires less maintenance.

However, maintenance is still a significant problem when shredding cross ties containing dirt, ballast, spikes, and an occasional tie plate. The maintenance can be reduced by eliminating the screen and allowing material varying greatly in product size to be discharged.

Track mounted shredding equipment can be purchased to shred the ties and distribute the pieces on the right-of-way. These machines typically discharge material varying in size from pieces 8" long by 1" square to dust particles. The production rate of these machines depends on local conditions such as the number of ties to be hogged per mile, the difficulty experienced in retrieving these ties from the right-of-way, and whether the ties are whole or have been sawed into three pieces. Sixty ties an hour is an extremely good production rate if no travel time to and from the job or traffic delays are experienced. The shredder is capable of achieving a much higher rate but the difficulty in removing ties from drainage ditches and the travel time between ties limit its production rate.

A sample economic analysis of the operation of a typical tie hog is as follows:

ASSUMPTIONS:

Estimated average production rate 60 ties/hr

Work 200 days/yr

Work 7 hrs/day; travel to and from job 1 hr/day

Ties have been sawed into 3 pieces and, therefore, only one laborer is required.

	COST PER TIE		
	LABOR	MATERIAL	
Operator Wages and Fringe Benefits 64 \$/day ÷ 420 ties/day	.152		
Laborer Wages and Fringe Benefits 55 \$/day ÷ 420 ties/day	.131		
Fuel Costs $\frac{[(15 \text{ gal/hr} \times 7 \text{ hrs}) + (10 \text{ gal/hr} \times 1 \text{ hr})]\ 0.30\ \$/\text{gal}}{420 \text{ ties/day}}$		.082	
Maintain Shredding Mechanism	.013	.170	
Engine Service (oil drains and filter changes)	.002	.002	
Miscellaneous Repairs and Service	.066	.051	
TOTAL	.364	.305	
Operating & Maintenance Total			.669
Depreciation $\frac{100{,}000\ \$/\text{shredder} \text{ (original cost installed)}}{(200 \text{ working days/yr})\ (420 \text{ ties/day})\ (10 \text{ yr/shredder})}$			.119
TOTAL COST PER TIE			\$.788

Note: No machine downtime included

No operator and laborer per diem

Based on the assumptions listed above, the cost of hogging ties on the right-of-way is 78.8 cents per tie.

Unfortunately, this expenditure does not eliminate the tie disposal problem. The ties are shredded and blown on the right-of-way. In many cases, the machine operator places the shredded ties in the drainage ditch and in other cases they are washed into the ditch by heavy rains. Once they get into the ditch, they can float during periods of high flow and clog drainage structures.

If the shredded ties are deposited in the weeds on the right-of-way, they can increase the danger of fire especially during seasons when the vegetation is dead and easily ignited. In spite of these disadvantages, shredding the ties eliminates the safety problem associated with discarded ties strewn along the right-of-way and improves the appearance of the railroad. Therefore, shredding the ties on the right-of-way is a relatively expensive process that only partially solves the tie disposal problem. It definitely has limited applications.

LANDFILL

Landfill is a viable method to dispose of discarded cross ties. Regional landfills or small landfills, near the point where the tie is removed from track, can be used. Unfortunately, this is a costly method of disposal and requires land suitable for that purpose.

An example of the costs that can be incurred when using this method is as follows:

ASSUMPTIONS:

The ties were sawed into three pieces when they were removed from the track.

Remove 1200 discarded ties from the right-of-way per day.

Land is available at no cost.

508	$/day work train with air dump cars.
68	foremen wages and fringes.
50	conveyor operating cost.
63	conveyor operator wages and fringes.
216	4 laborers wages and fringes.
905	$/day

905 $/day ÷ 1200 ties/day = .75 $/tie

Unload ties, distribute in landfill, and place cover.

Assume cover material is available from material removed when the landfill site was excavated.

$ 63	operator-dumps cars and runs dozer
50	operate dozer
113	$/day

113 $/day ÷ 1200 ties/day = .09 $/tie

Total cost per tie for landfill disposal method.

.75 $/tie + .09 $/tie = .84 $/tie

The actual cost for any particular situation depends on such things as the availability of land, distance ties must be transported, number of ties on the right-of-way per mile, whether the district is single, double or multiple track territory, amount of traffic on the track during the removal process, availability of fill dirt to use as cover material, etc.

It is not normally necessary to get a State permit to operate a landfill on your own property if the material you are depositing in the fill comes from your property. This may not be true if the ties come from your property in another State. You are required in all cases to operate the landfill in a manner that will not create a public nuisance.

If it is necessary to lease land for the landfill or obtain a State operating permit for any reason the following conditions are inherent in most permits:

1. Provide the State with a description of the site, population density, and land use in the surrounding area, results of soil borings, description of the groundwater, sources and types of waste to be received, and a description of the proposed operating method. This is done before the permit is issued.
2. Cover all material deposited with six inches of fill at the end of each day.
3. Make the landfill available for regular inspections by the State.
4. When the landfill is abandoned, cover it with two feet of fill and seed it.

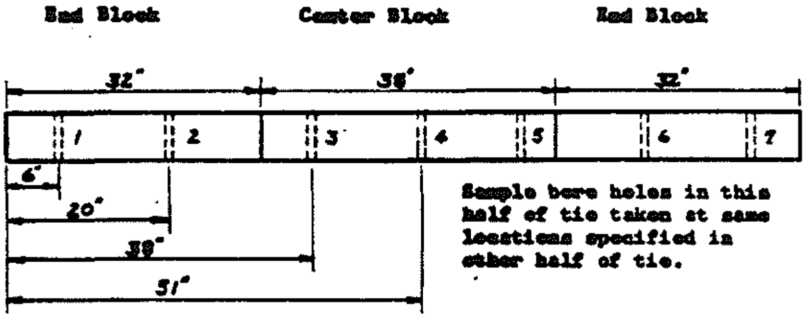
Even if no operating permit is required, it is advisable to be familiar with the regulations since they are intended to prevent the site from becoming a public nuisance.

FUEL

The cost and availability of fossil fuels have become problems in recent years. The price of oil has risen precipitously and natural gas, if it is available at all, is almost always supplied under an interruptible contract. During this same period of time the quantities of solid and liquid wastes have increased significantly due to the more stringent pollution control regulations. As a result, the costs of disposal of these wastes have increased markedly. Since many of these materials are high in heating value, they are now competitive with the conventional fossil fuels, especially if the disposal costs are considered.

Wood is an example of a waste material that makes an excellent fuel. Actually, before the use of oil and natural gas became commonplace, wood satisfied a large percentage of the nation's energy needs.

It is difficult to determine the characteristics of discarded cross ties as a fuel since they vary among ties and even within each tie. The following tie sampling method[1] has been used to gain a better understanding of the variation in characteristics within a given tie.



Sample bore holes in this half of tie taken at same locations specified in other half of tie.

NOTE: Holes drilled at 6 inches will sample the heavy weathering that normally occurs at the ends. The chips from holes drilled at 20 inches will provide a measure of wood condition under the tie plates.

---

[1] Developed by Tom Church, U. S. Department of Agriculture, Forest Service, Princeton, West Virginia.

Ties of various species of wood and from various parts of the country were sampled. The results of these tests are shown in Tables 6 through 18 in the appendix.

The highly variable results from the seven sampling points in each tie were averaged to obtain an overall value for each tie. These results are tabulated in Tables 2 and 3. The moisture content in the samples from Needles, California was much lower than the samples from other parts of the country due to the climatic conditions peculiar to that location. The extent of this difference can be seen in Table 4. Since the Needles ties do not exhibit the same characteristics as ties from other regions of the country, their analyses were not included when Column 1 of Table 4 was developed. The data in Column 1 are representative of ties in the United States with the exception of the desert areas.

Table 5 shows the characteristics of cross ties relative to oil, coal, and untreated wood. It is interesting that the heating value of cross ties is less than one third that for fuel oil per cubic foot; the number of pounds of sulfur per million BTU's is less than oil; and the ash content per million BTU's is 270 times the content of oil and approximately seven times the quantity expected in untreated wood. The increased ash content is due to ballast, dirt, coal, and other materials which are deposited in the cracks in the tie during its service life in track.

The volatiles reading of 57.06 which was taken from a composite sample of Norfolk and Western ties is well below the 78 which could be expected for hardwood. This is due partially to the fact that some volatiles are lost during the life of the tie,but this is offset to some extent by the creosote which remains in the tie and is measured as volatile matter. An

TABLE 2
COMPILATION OF TIE DATA

	1 ICG Miss.	2 ICG Miss.	3 ICG Miss.	4 AT&SF Needles Calif.	5 AT&SF Needles Calif.	6 AT&SF Needles Calif.	7 AT&SF Needles Calif.	8 AT&SF Needles Calif.	9 Average Miss.	10 Average Needles Calif.
% Moisture										
Wet Basis	34.7	30.4	24.4	7.1	5.4	7.7	---	8.2	29.8	7.1
Dry Basis	54.9	45.0	31.3	7.7	5.7	8.4	---	9.0	43.7	7.7
BTU Wet/lb.	5900	6348	7001	8004	9486	8442	8030	8902	6416	8573
Dry/lb.	8652	8953	8989	8496	9832	8678	---	9490	8865	9124
Species	Red Oak	Unknown	Unknown	Red Oak	Southern Pine	Gum	White Oak	Douglas Fir		

Each value in Columns 1 through 8 is the average of the values obtained from the seven sampling points used on each tie
Column 9 is the average of Columns 1 through 3.
Column 10 is the average of Columns 4 through 8.

Analyzed By:

United States Department of Agriculture, Forest Service, Thomas W. Church, Jr.

TABLE 3
COMPILATION OF TIE DATA

	1 ICG Miss.	2 ICG Chicago	3 ICG Chicago	4 AT&SF Needles Calif.	5 N&W Virginia	6 ICG Average	7 Average
% Moisture, Weight Wet Basis	10.73	33.22	35.74	4.59	29.44	26.56	27.28
% Ash, Weight	5.03	1.17	5.26	4.60	13.5	3.82	6.24
BTU							
Wet/lb.	7451	5496	6080	7810	6151	6342	6295
Dry/lb.	8231	8287	9133	8194	7860	8550	8378
% Sulfur, Weight	.07	.05	.05	.04	.09	.06	.07
% Creosote, Weight	3.9	1.78	---	3.14	3.24	2.8	2.97
% Volatiles, Weight	---	---	---	---	57.06	---	57.06
Species	Unknown	Unknown Random Samples	Unknown	Red Oak	Oak		

Columns 1,2,4 Analyzed by Commercial Testing and Engineering.
Columns 3,5 Analyzed by Suburban Laboratories.
Column 6 is average of values in Columns 1,2,3.
Column 2 is random samples. The Laboratory lost the designation.
Column 4 values are not considered representative. The Laboratory broke two of the seven samples from the tie.
Column 5 is average of the composite samples of the boiler test fuel.
Column 7 is average of Columns 1,2,3,5.

TABLE 4
COMPILATION OF TIE DATA

	1 Overall Average	2 Needles Calif. Average
% Moisture, Weight		
Wet Basis	28.54	7.1
BTU		
Wet/lb.	6356	8573
Dry/lb.	8622	9124
% Sulfur, Weight	.07	---
% Creosote, Weight	2.97	---
% Volatiles, Weight	57.06	---

Column 1 is average of all data except Needles, California data.

Column 2 is average of all Needles, California data except Column 4, Table 3.

TABLE 5
COMPARISON OF FUEL CHARACTERISTICS

	No. 1 Fuel Oil	No. 2 Fuel Oil	No. 5 Fuel Oil	Bit. West Va. Coal	Hardwood	Softwood	Crossties
Sulfur, Weight, Percent	0.01-0.5	0.05-1.0	0.5-3.0	1.54			0.07
Hydrogen, Weight, Percent	13.3-14.1	11.8-13.9	10.5-12.0	4.47	6	6	
Carbon, Weight, Percent	85.9-86.7	86.1-88.2	86.5-89.2	80.31	50	51	
Nitrogen, Weight, Percent	NIL-0.1	NIL-0.1		1.38			
Oxygen, Weight, Percent				2.85	44	43	
Ash, Weight, Percent			0-0.10	6.55	0.1-2.0	0.5-1.0	6.24
Heating Value BTU/lb.	19,670-19,860	19,170-19,750	18,100-19,020	12,410-15,670	8,500	9,000	8622 (Dry)
Water & Sediment, Volume, Percent		0-0.1	0.05-1.0				
Moisture, Weight, Percent				2.90	10-60	10-60	28.54
Lbs. Per Gallon	6.87-6.71	7.39-6.87	8.10-7.68				
Lbs. Per Ft.^{3}	51.38-50.19	55.27-51.38	60.58-57.44		40-70* Air Dry	25-40* Air Dry	37* (Dry)
Heating Value BTU/Ft.^{3}	1,003,667	1,037,802	1,095,226		467,500*	292,500*	319,014*
Sulfur Lb./Million BTU	0.131	0.272	0.943	1.097			0.080
Ash Lb./Million BTU			0.027	4.665	1.235	0.833	7.24
Volatiles, Weight, Percent				22.05	78	81	57.06

Fuel Oil and Coal Data By The Babcock and Wilcox Co., Steam, Its Generation And Use (New York: George McKibben & Son, 1955

Hardwood and Softwood Data By R.P. Murphy and J.F. Pottinger, Air Pollution From Wood Waste Incineration, (Australian Waste Disposal Conference 1971)

* Before shredding - $\frac{195 \text{ lb/Tie}}{3.74 \text{ ft}^3\text{/Tie}} \left(1 - .2854 \frac{\text{lb } H_2O}{\text{lb}}\right) = 37 \text{ lb/ft}^3$ Dry. - The volume will increase 2 to 3 times during shredding

average of 2.97 percent creosote remained in the ties tested[1] and the boiling point of all the components of creosote[2] is well below 550°C which is the temperature used to drive the volatiles off during the test procedure.

The remaining difference between the actual volatiles reading and the one that was expected is the high ash content. A large percentage of this ash is heavy noncombustibles such as stone and sand and since volatile matter is measured as percent by weight, this results in a lower volatiles reading. These noncombustibles can exert a similar influence on the moisture, BTU, sulfur, and creosote readings and the laboratory should be aware of it.

It is obvious from the data presented that discarded cross ties have a much greater volume per BTU and produce much more ash when burned than fossil fuels. However, the equipment which burns this fuel will still be required to meet air pollution control regulations promulgated by the local, State, and Federal Governments. These regulations usually control such emissions as, particulate matter, sulfur dioxide, nitrogen oxides, carbon monoxide, and visible emissions measured as opacity.

The high ash content will result in fly ash in the stack gas and ash or slag on the bed of the combustion facility. Therefore, fly ash control and slag or ash handling equipment will be required at all installations. No difficulty should be experienced in complying with the other emission control parameters.

---

[1] See Table 4

[2] See p. 2

Discarded cross ties are a viable fuel source for commercial or industrial power plants of any size. Economy of scale is very important to commercial power plants and even the smallest plant consumes large quantities of fuel. It has been demonstrated that coal burning power plants can burn garbage as an auxiliary fuel and there is no reason to believe that they cannot burn discarded cross ties also. This is a potential market for large numbers of ties.

The second market for cross tie fuel is industrial power plants whether they are owned by the railroad or someone else. As with commercial power plants, the return on investment is higher for larger facilities than smaller ones. New cross tie-fired boilers can be installed or existing units can be converted to receive the shredded ties. Existing oil fired boilers can be converted by removing the burner and installing a duct in its place which carries the hot stack gases from a separate incinerator to the boiler. A fluidized bed incinerator and conventional fire tube boiler combination was tested using cross tie fuel and proven to be feasible.[1] The fluidized bed incinerator operates at higher temperatures than conventional wood burning boilers and, therefore, gives added assurance that complete combustion will be achieved; however, complete combustion is possible at temperatures lower than those used in the fluidized bed system and there is no reason to believe that this is the only system on the market capable of burning cross ties. The capital and operating costs are higher for the fluidized bed method than they are for conventional wood burning boilers.

---

[1] See Appendix 2-3

A typical economic analysis of a tie burning boiler based on the fluidized bed system is as follows:

ASSUMPTIONS:

Cost of removing ties from the right-of-way[1]		.55 $/Tie
Cost to ship to point of use as fuel		1.00 $/Tie
Unloading Cost		
Crane Operating Cost	50 $/Day	
1 Crane Operator and 2 Laborers	171 $/Day	
221 $/Day ÷ 4000 Ties/Day		.06 $/Tie
Shipping and Unloading Total		1.61 $/Tie

Shredding Costs

ASSUMPTIONS:

Shredder Capacity 125 Ties/hr.

Shredder Motor 300 hp

Shredder is fed by a crane

Shredder Cost Installed $50,000

---

[1] See p. 35 TOTAL COST .278 + .271 $/Tie

	$/Tie		
	Labor	Material	Other
50 $/Day Crane Operating Cost			
50 $/Day ÷ 100 Ties/Day			.05
171 $/Day Crane Operator and 2 laborers			
171 $/Day ÷ 1000 Ties/Day	.171		
Maintain Shredder Shearing Mechanism	.003	.068	
Miscellaneous Repairs and Service	.039	.039	
300 hp @ .0312 $/KWH			
6.976 $/H ÷ 125 Ties/hr.			.056
Depreciation 50,000 $/shredder installed			
15 year life 137,532 Ties/yr			
50,000 ÷ (137532 Ties/yr) (15yr)			.024
	.213	.107	.130

TOTAL Shredding Cost .45 $/Tie

Cross Tie Fired Boiler Costs

ASSUMPTIONS:

Boiler 19,500,000 BTU/hr

Fuel 6356 BTU/lb. wet

195 lb./Tie

No Building Costs Are Incurred

19,500,000 BTU/hr ÷ (6356 BTU/lb. wet) (195 lb./Tie) = 15.7 Ties/hr

(15.7 Ties/hr) (24 hr/Day) = 376.8 Ties/Day or 137532 Ties/yr

Miscellaneous Maintenance and Repairs Including Bed Cleaning

3600 \$/yr ÷ 137532 Ties/yr = .026 \$/Tie

Operator 24 hr/Day 365 Days/yr @ 189 \$/Day

68985 \$/yr ÷ 137532 Ties/yr = .502 \$/Tie

Electricity

(123 KWH X .0312 \$/KWH) ÷ 15.7 Ties/hr .245 \$/Tie

Auxiliary Fuel For Startups

ASSUMPTIONS: 12 Startups Per Year

10 gallons #2 Diesel Fuel Per Startup @ .30 \$/gallon

(120 gallons/yr) (.30 \$/gallon) ÷ 137532 Ties/yr = .000 \$/Tie

Depreciation

ASSUMPTIONS: 400,000 \$/Boiler installed

15 year life

400,000 \$/Boiler ÷ (137532 Ties/yr) (15 yr/Boiler) = .194 \$/Tie

TOTAL Boiler Cost .967 \$/Tie

Fuel Storage Silo

ASSUMPTIONS: 9800 ft^3

Installed Cost \$25,000

Life 15 years @ 137532 Ties/yr

Depreciation

25,000 ÷ (137532 Ties/yr) (15yr) = .012 \$/Tie

TOTAL COST OF DISCARDED CROSS TIES AS A FUEL:

Shipping Costs + Shredding Costs + Boiler Bosts + Fuel Storage = TOTAL COST

1.61 \$/Tie + .45 \$/Tie + .967 \$/Tie + .012 \$/Tie = 3.04 \$/Tie

The most significant cost is the $1.00 that was included for shipping charges to move the gondola from the location where it was loaded to the boiler. This expense is dependent on the geographical location of the boiler relative to the source of the ties but could be reduced in most cases if the car does not go through interchange.

Oil Fired Boiler Costs

ASSUMPTIONS:

Boiler 19,500,000 BTU/hr

Fuel 138750 BTU/gallon @ .30 $/gallon

No Building Costs Are Incurred

[19,500,000 BTU/hr ÷ (138750 BTU/gallon)] (24 hr/Day) = 3373 gal/Day

or 1,231,145 gal/yr

Miscellaneous Maintenance and Repairs

1000 $/yr ÷ 1231145 gal/yr = .000 $/gallon

Operator 24 hrs/Day 365 Days/yr @ 189 $/Day

68985 $/yr ÷ 1231145 gal/yr = .056 $/gallon

Electricity

(50 KWH X .0312 $/KWH) ÷ 141 gal/hr = .011 $/gallon

Depreciation

ASSUMPTIONS:

Installed Cost $60,000

Life 15 years

60,000 ÷ (3373 gal/day) (365 day/yr) (15yr) = .003

TOTAL Boiler Cost .07 $/gallon

Fuel Storage Tank

ASSUMPTIONS:

50,000 gallon

Installed cost with dike, pumps

unloading facilities, etc. $60,000

Life 15 years

60,000 $/tank ÷ (3373 gal/Day) (365 day/yr) (15yr) = .003 $/gallon

TOTAL Cost of #2 Diesel Oil As A Fuel

Oil Cost	+	Boiler Costs	+	Fuel Storage	=	TOTAL COST
.30 $/gallon	+	.07 $/gallon	+	.003 $/gallon	=	.37 $/gallon

.37 $/gal ÷ 138750 BTU/gal = 2.66 $/million BTU

(6356 BTU/lb wet) (195 lb/Tie) = 1,239,420 BTU/Tie

1.24 Million BTU/Tie X 2.66 $/million BTU = 3.30 $/Tie

The value of a discarded cross tie as a fuel oil replacement is 3.30 dollars and the cost of using it as a fuel is 3.04 dollars.

(3.30 - 3.04) $/Tie X 137532 Tie/yr = 35,758 $/yr

A saving in fuel costs for a 19,500,000 BTU/hr oil fired boiler of 35758 dollars per year will be achieved if it is replaced with a wood burning boiler.

A York-Shipley fluidized bed incinerator and fire tube boiler combination was tested on September 23, 1975 at the York-Shipley Plant in York, Pennsylvania. The equipment tested and the results of the stack gas analyses are described in the York-Shipley "Summary Report"[1], and the Weston "Performance Evaluation"[2]. The Performance Evaluation was to determine compliance with Regulations of the U.S. Environmental Protection Agency.

The stack gas from the fluidized bed incinerator was piped into a standard York-Shipley fire tube boiler. An auxiliary fuel is required each time the unit is started up but is not required during normal operation. The test unit required the following during the test:

550 ft^3 of 1000 BTU Gas during the 1 hour, 3 minute startup period.

48.8 KWH of electricity during the test.

751 lb/hr of shredded cross ties.

The test demonstrated that the York-Shipley equipment provides an acceptable method to use discarded cross ties as a fuel for the production of steam for heating or air conditioning systems. However, the following two problems were encountered that will require correction on permanent installations:

1) The particulate emissions exceeded the EPA standards. This occurred because the Breslove Fly Ash Collector was not designed to remove the large quantity of fly ash with the particle size distribution produced by this fuel. The ash content of the fuel used in this test was much higher than is normally found in cross ties.[3] This was partially due

---

[1] See Appendix 2

[2] See Appendix 3

[3] See p. 20, TABLE 3, Column 5

to the fact that after the ties were shredded, a high percentage of the shreds were too large to burn in this system. The small pieces and the noncombustibles were screened out and used as the fuel, thereby increasing the percentage of noncombustibles present in the fuel used. A properly designed fly ash collector will correct this problem.

2) The fluidized bed developed cold spots near the end of the all-day test. This was caused by the noncombustibles that accumulated in the bed during the day. The bed is composed of olivine, an orthosilicate of magnesium with varying quantities of ferrous iron[1], and the bed temperature averages approximately 1900°F. Since the bed is suspended in a column of air it is critical that the specific gravity and size of the bed material be closely controlled. The high temperature maintained in the bed can lead to slagging under certain conditions. A properly designed bed cleaner and possibly a change in the bed material could correct this problem.

---

[1] William E. Ford, Dana's Manual of Mineralogy (New York: John Wiley and Sons, Inc., 1929) p. 212

SALE

The most straight-forward method to dispose of discarded cross ties is to sell them. Unfortunately, the market for them is extremely limited after they have been sawed into three pieces during removal from track. Practically the only value they have is as fuel.[1]

When cross ties are removed from track whole, they are a valuable commodity. In all large population centers, discarded ties are worth from $3 to $7 each for landscaping purposes. This is an extremely large market which can handle all the ties of suitable quality that the industry can provide for many years if it is properly developed. It is necessary, however, to sort the ties which are removed from track since many of them are not of suitable quality to be used for landscaping. A hypothetical economic analysis to convert from sawed tie removal to whole tie removal and and sell the ties is as follows:

Assume the existing tie gang has the following configuration.

1 Foreman
1 Assistant Foreman
1 Mechanic
1 Spike puller operator
1 Saw operator
1 Laborer tie removal

---

[1] See p. 29

1	Tie crane operator - tie removal
3	Laborers plates and anchors
1	Scarifier operator
1	Operator tie crane - tie placement
1	Operator tie inserter
1	Laborer tie inserter
2	Laborers - fill cribs
1	Tamper operator
1	Operator rail lifters
1	Laborer plate placement
2	Spiker operators
2	Anchor machine operators
2	Laborers anchor placement
25	Total

When the ties are removed whole, the saw operator, tie crane operator-tie removal, and the laborer-tie removal, are replaced by a whole tie remover operator and two laborers. The 25 man tie gang is retained but a saving in wages and fringe benefits of 10.72 $/day is realized.

ASSUMPTIONS:

Tie gang removal rate is 600 ties/day before and after the change

Whole tie remover costs $45,000

Secondhand value of the tie shear is $2,000

The tie handler eliminated from the gang is used to remove the ties from the right of way

Wage and fringe benefit saving per tie:

$10.72 $/day ÷ 600 ties/day = .018 $/tie

ASSUMPTIONS:

The ties will be removed from the right-of-way by placing them on a push car with the tie handler which was removed from the gang, banding them, and then dumping the bundles back onto the right-of-way to be picked up later by a rail mounted crane and a work train.[1] An alternate method is to allow a contractor to come onto the right-of-way and pick them up.

The ties are currently being left on the right-of-way with no disposal costs.

Assemble and Band Whole Ties

63	$/day tie handler operator-wages and fringe benefits
54	laborer-push car
50	equipment operating cost
167	$/day

167 $/day ÷ 600 ties/day = .278 $/ties

Remove Banded Ties From Right-Of-Way

68	$/day foreman
794	work train with gondolas
50	rail mounted crane operating cost
171	1 operator and 2 laborers for the crane
1,083	$/day

---

[1] Tom Church, U.S. Department of Agriculture, Princeton, West Virginia, has proposed an alternate method where an especially designed tie crane runs on rails mounted on top of gondolas.

ASSUMPTIONS:

Place 400 ties/gondola

Remove 4,000 ties/day from right-of-way

1,083 \$/day ÷ 4,000 ties/day = .271 \$/tie

Total cost + difference in tie removal cost + band cost + loading gondola cost

Total cost = -.018 + .278 + .271

Total cost = .53 \$/tie

ASSUMPTIONS:

Value is 1 \$/tie - purchaser will take all ties regardless of condition and will pay the railroad the shipping charges or will remove them from the gondolas and haul them by truck. Two days per diem on the gondolas was included in the work train cost and no credit was given for revenue generated by shipping the ties to the purchaser.

Revenue generated:

1.00 \$/tie - .53 \$/tie = .47 \$/tie

.47 \$/tie X 600 ties/day/gang = 282 \$/day/gang

ASSUMPTIONS:

The gang works 200 days/yr

282 \$/day/gang X 200 days/yr/gang = 56,400 \$/yr

Capital investment - new equipment:

\$45,000 whole tie remover

-2,000 tie saw scrap value

\$43,000

Return on investment:

$$\frac{56{,}400 \text{ revenue}}{43{,}000 \text{ investment}} \text{ X } 100 = 131\% \text{ ROI}$$

The above calculations indicate that it can be extremely profitable to remove ties from track whole and sell them. They would have been much more favorable if a cost had been assigned to cover the disadvantages of leaving the sawed ties on the right-of-way.[1]

Based on economics alone, it appears that the best market currently available to dispose of ties is to remove them from track whole and sell them.

---

[1] See p. 34

MISCELLANEOUS METHODS

Incineration of the discarded cross ties on the right-of-way has been used by some railroads on a very limited basis. The most common method that has been used is to burn the ties in a pit under a curtain of forced air. This method is not acceptable to the Air Pollution Control Agencies in most regions. Generally, the use of the air curtain system is limited to burning trees and brush when cleaning a right-of-way and is not permissible for burning treated wood such as cross ties. In addition, it is difficult to construct the proper pit at a reasonable cost under the adverse soil conditions that are encountered in many locations.

Cross tie products, such as charcoal, cribbing, and pallets, usually result in a product that is inferior to the items currently being sold, without a significant cost reduction.[1] Therefore, these products are extremely difficult to market.

---

[1] Tom Church, U.S. Department of Agriculture, Forest Products Laboratory, Princeton, West Virginia has studied several possibilities in this area.

CONCLUSIONS AND RECOMMENDATIONS

The traditional methods of disposing of cross ties removed from track are no longer available and ignoring the problem and leaving the ties on the right-of-way is a totally unsatisfactory alternative, even on a short-term basis. It is necessary, therefore, for each railroad to develop a comprehensive plan, based on its yearly tie renewal program, to dispose of all discarded ties.

The tie disposal plan should include the combination of techniques which best satisfies the local conditions and overall needs of the railroad. An aggressive marketing program is imperative to expand the usage of discarded cross ties and make potential buyers aware of their availability.

All the resources necessary to develop and administer a tie disposal plan are available. The successful programs will convert a liability into a significant source of revenue.

APPENDIX 1

TABLES 6 THROUGH 18 - BASIS FOR TABLES 2,3, AND 4

TABLE 6
ICG TIE
MISSISSIPPI

	1	2	3	4	5	6	7	Avg.
% Moisture								
Wet Basis	34.0	33.1	29.9	39.6	45.7	38.0	22.9	34.7
Dry Basis	51.6	49.4	42.8	65.6	84.3	61.2	29.7	54.9
BTU (Wet)/lb.	5867	6094	Missing	5692	5815	5549	6384	5900
BTU (Dry)/lb.	7791	8972	8801	8598	8831	8919	8655	8652

Analyzed By:

United States Department Of Agriculture Forest Service
(Thomas W. Church, Jr.)
November 10, 1975

TABLE 7
ICG TIE
MISSISSIPPI

	1	2	3	4	5	6	7	Avg.
% Moisture								
Wet Basis	27.3	18.6	24.5	36.5	37.4	31.5	37.4	30.4
Dry Basis	37.2	22.8	32.4	57.5	59.8	45.9	59.7	45.0
BTU (Wet)/lb.	6303	6131	6842	5920	6139	7371	5734	6348
BTU (Dry)/lb.	9033	9017	9009	8808	8795	8984	9024	8953

Analyzed By:

United States Department of Agriculture Forest Service
(Thomas W. Church, Jr.)
November 10, 1975

TABLE 8
ICG TIE
MISSISSIPPI

	1	2	3	4	5	6	7	Avg.
% Moisture								
Wet Basis	18.4	27.5	26.0	27.4	28.2	22.9	20.9	24.4
Dry Basis	22.5	37.6	35.3	37.7	30.2	29.7	26.4	31.3
BTU (Wet)/lb.	7761	6402	6572	6570	7094	6985	7625	7001
BTU (Dry)/lb.	9400	9007	8996	8413	8804	9104	9203	8989

Analyzed By:

United States Department Of Agriculture Forest Service
(Thomas W. Church, Jr.)
November 10, 1975

TABLE 9
SANTA FE TIE
NEEDLES, CALIFORNIA
RED OAK

	1	2	3	4	5	6	7	Avg.
% Moisture								
Wet Basis	8.1	7.2	6.0	6.5	7.2	8.7	6.4	7.1
Dry Basis	8.8	7.8	6.4	7.0	7.8	9.6	6.8	7.7
BTU (Wet)/lb.	7863	8051	7945	8268	7867	7933	8104	8004
BTU (Dry)/lb.	8359	8303	8441	8694	8619	8474	8583	8496

Analyzed By:

United States Department Of Agriculture Forest Service
(Thomas W. Church, Jr.)
November 10, 1975

TABLE 10
SANTA FE TIE
NEEDLES, CALIFORNIA
SOUTHERN PINE

	1	2	3	4	5	6	7	Avg.
% Moisture								
Wet Basis	4.8	6.3	5.2	5.1	5.8	5.3	5.2	5.4
Dry Basis	5.0	6.7	5.5	5.3	6.1	5.6	5.5	5.7
BTU (Wet)/lb.	10135	9352	9343	9323	8940	9966	9343	9486
BTU (Dry)/lb.	10490	9522	9645	9669	9401	10458	9643	9832

Analyzed By:

United States Department Of Agriculture Forest Service
(Thomas W. Church, Jr.)
November 10, 1975

TABLE 11
SANTA FE TIE
NEEDLES, CALIFORNIA
GUM

	1	2	3	4	5	6	7	Avg.
% Moisture								
Wet Basis	6.2	7.7	6.9	6.2	6.5	14.2	6.1	7.7
Dry Basis	6.6	8.3	7.4	6.6	7.0	16.5	6.5	8.4
BTU (Wet)/lb.	8722	8192	8132	8246	8302	8501	9003	8442
BTU (Dry)/lb.	8883	8468	8349	8597	8570	8765	9117	8678

Analyzed By:

United States Department Of Agriculture Forest Service
(Thomas W. Church, Jr.)
November 10, 1975

TABLE 12
SANTA FE TIE
NEEDLES, CALIFORNIA
WHITE OAK

	1	2	3	4	5	6	7	Avg.
% Moisture								
Wet Basis	Missing	Missing	Missing	Missing	Missing	Missing	Missing	----
Dry Basis	Missing	Missing	Missing	Missing	Missing	Missing	Missing	----
BTU (Wet)/lb.	7902	7804	8005	8086	7814	8241	8362	8030
BTU (Dry)/lb.	Missing	Missing	Missing	Missing	Missing	Missing	Missing	----

Analyzed By:

United States Department Of Agriculture Forest Service
(Thomas W. Church, Jr.)
November 10, 1975

TABLE 13
SANTA FE TIE
NEEDLES, CALIFORNIA
DOUGLAS FIR

	1	2	3	4	5	6	7	Avg.
% Moisture								
Wet Basis	7.1	9.6	8.6	10.0	4.8	7.4	10.0	8.2
Dry Basis	7.6	10.6	9.4	11.2	5.1	8.0	11.1	9.0
BTU (Wet)/lb.	9809	8718	8781	8226	8359	9414	9007	8902
BTU (Dry)/lb.	10450	9561	9310	8664	8558	10150	9735	9490

Analyzed By:

United States Department Of Agriculture Forest Service
(Thomas W. Church, Jr.)
November 10, 1975

TABLE 14
ICG TIE
JACKSON, MISSISSIPPI

<u>SAMPLE</u>

		1	2	3	4	5	6	7	Avg.
% Moisture	- As Received	9.16	----	7.26	9.69	11.50	11.66	15.14	10.73
	- Dry Basis	----	----	----	----	----	----	----	----
% Ash	- As Received	4.56	----	2.42	3.04	12.76	1.96	5.42	5.03
	- Dry Basis	5.02	----	2.61	3.37	14.42	2.22	6.39	5.67
BTU	- As Received	7920	7017	7660	7063	7290	7882	7324	7451
	- Dry Basis	8719	7029	8260	7821	8237	8922	8631	8231
% Sulfur	- As Received	0.03	----	0.04	0.05	0.19	0.06	0.05	0.07
	- Dry Basis	0.03	----	0.04	0.06	0.22	0.07	0.06	0.08
Creosote Type Preservative % Weight	- As Received	3.3	1.8	5.5	2.9	Insuff. Sample	5.2	4.8	3.9

Analyzed By:

Commercial Testing & Engineering Co.
May 14, 1975

TABLE 15
ICG TIES
CHICAGO, ILLINOIS

RANDOM SAMPLES

							Avg.
% Moisture	- As Received	43.92	41.40	18.62	27.91	34.27	33.22
	- Dry Basis	----	----	----	----	----	----
% Ash	- As Received	2.37	0.59	0.80	1.54	0.56	1.17
	- Dry Basis	4.23	1.01	0.98	2.14	0.85	1.84
BTU	- As Received	5062	5068	6436	5608	5308	5496
	- Dry Basis	9026	8648	7908	7779	8076	8287
% Sulfur	- As Received	0.05	0.03	0.07	0.07	0.03	0.05
	- Dry Basis	0.09	0.05	0.09	0.10	0.05	0.07
Creosote Type Preservative % Weight	- As Received	4.1	0.4	0.8	0.9	2.7	1.78

Analyzed By:

Commercial Testing & Engineering Co.
March 25, & 26, 1975

TABLE 16
ICG TIE
CHICAGO, ILLINOIS

	1	2	3	4	5	6	7	Avg.
% Moisture (Wet)	40.53	37.13	37.83	38.77	39.52	25.65	30.78	35.74
% Ash	1.17	8.44	7.91	2.00	1.00	4.29	12.00	5.26
BTU (Wet)/lb.	5389	6275	4838	6136	5249	7753	6922	6080
BTU (Dry)/lb.	8887	10015	9598	8679	8985	9645	8119	9133
% Sulfur	0.0609	0.0518	0.0919	0.0290	0.0713	0.0124	0.0654	0.0547

Analyzed By:

Suburban Laboratories, Inc.
Hillside, Illinois
October 2, 1975

TABLE 17
SANTA FE TIE
NEEDLES, CALIFORNIA
RED OAK

SAMPLE

		1	2	3	4	5	6	7	Avg.
% Moisture	- As Received	Broken	5.50	6.73	5.30	Broken	3.29	2.13	4.59
	- Dry Basis		----	----	----		----	----	----
% Ash	- As Received		1.62	1.99	3.40		15.13	0.84	4.60
	- Dry Basis		1.71	2.13	3.59		15.64	0.86	4.79
BTU	- As Received		8060	8281	8157		6361	8192	7810
	- Dry Basis		8529	8878	8614		6577	8370	8194
% Sulfur	- As Received		0.04	0.02	0.03		0.06	0.05	0.04
	- Dry Basis		0.04	0.02	0.03		0.06	0.05	0.04
Creosote Type Preservative % Weight	- As Received		1.9	3.9	4.2		3.0	2.7	3.14

Analyzed By:

Commercial Testing & Engineering Co.
May 14, 1975

TABLE 18
N and W OAK TIES
CENTRAL VIRGINIA
BOILER TEST FUEL

% Moisture (Wet)	27.59	24.04	33.03	33.09	29.44
% Ash	6.01	16.94	12.98	18.07	13.5
BTU (Wet)/lb	6510	6529	6185	5379	6151
BTU (Dry)/lb	7759	7764	7853	8064	7860
% Sulfur	.12	.0438	.0742	.1022	.0851
% Creosote (By Weight)	3.98	2.93	3.01	3.03	3.24
% Volatiles (By Weight)	66.40	59.02	53.99	48.84	57.06

Sample #1 - Grab Sample - Converter at 1000°F

Sample #2 - Grab Sample - Converter at 1550°F

Sample #3 - Composite Sample - 10:40 AM - 12:15 PM - 15 minute grabs

Sample #4 - Composite Sample - 12:15 AM - 3:00 PM - 30 minute grabs

Analyzed By:

Suburban Laboratories, Inc., Hillside, Illinois
October 9, 1975

SUMMARY REPORT

FB 50 SOLID WASTE CONVERTER SYSTEM

SEPTEMBER 1975

BY: YORK-SHIPLEY, INC.

W. Doerflein
R. Miller
Roy F. Weston, Inc.
K. Petry

YORK-SHIPLEY, INC.

YORK, PA.

OBJECTIVE

The objective of the test was to investigate the operating parameters and determine the overall performance of the solid waste converter when burning hogged railroad ties. The concentration and mass rate of particulate matter, sulfur dioxide, nitrogen oxides and total hydrocarbons in the emissions were measured in accordance with EPA methods.

EQUIPMENT

A YORK-SHIPLEY, INC. Model FB 50 converter was used for the test.

The heat recovery boiler was a low pressure steam (15 P.S.I.G.) three (3) pass dry back scotch type with 875 sq. ft. of fireside heating surface.

The system was equipped with the standard auxiliary equipment concisting of conveyor, gas/oil ignition burner, gas/oil auxiliary burner, induced draft fan, and Breslove fly ash separator.

INSTRUMENTATION

The major items of instrumentation are listed below:

Fuel Input --	Fairbanks Morse & Co. Balance Beam Scale
Evaporation Rate --	2" IPS Bufflo Meter Co. Calibrated Water Meter
Air Pressure --	Magnetic Indicating Pressur Gauges
Temperature --	Honeywell Electronik Model 112-24 Point
Steam Press --	U.S. Gauge Model 611 Steam Press. Gauge

FUEL The test was conducted using hogged railroad ties with the following characteristics:

Moisture = 33.03%
Heating Value (Dry) = 7853.0 Btu/Lb.
Heating Value (Wet) = 6185.0 Btu/Lb.
Heating Value (Net) = 4662.0 Btu/Lb.
Ash = 12.98%
Sulfur = .0742
Creosote = 3.01% By Wt.

DATA

COMBUSTION

CO_2 - %	12.4
Plenum Press - in W.C.	29.8
Vapor Press. - in W.C.	0.3
Gas Temp. - °F	1920
Fuel Burner - Lbs/Hr.	751
Gross Input (HHV) BTUH	4,645,000
Net Input (LHV) BTUH	3,561,545

BOILER

CO_2 - %	8.3
Steam Press. - R.S.I.	4.8
Waste Heat Temp. - °F	1450
Stack Temp. - °F	300
Feed Water Temp. - °F	65
Output - BTU/Hr.	2,699,800
Evap. Rate - LB/Hr. @ 212°F	2780.4
Approx. Boiler H.P.	80

YORK-SHIPLEY, INC.
York, Pennsylvania

PERFORMANCE EVALUATION

YORK-SHIPLEY FLUID FLAME SOLID WASTE CONVERTER

W.O. 1259-01

Roy F. Weston, Inc.
Environmental Consultants - Designers
Weston Way
West Chester, Pennsylvania 19380
(215) 692-3030

ROY F. WESTON, INC
WESTON WAY
WEST CHESTER PA 19380
PHONE. (215) 692-3030
TELEX. 83-5348

WESTON
ENVIRONMENTAL CONSULTANTS-DESIGNERS

26 September 1975

York-Shipley, Inc.
P.O. Box 349
York, Pennsylvania 17405

Attention: Mr. Fred Snyder
Vice President, Engineering

Gentlemen:

Roy F. Weston was retained by York-Shipley to conduct a source emission test program for evaluation of the performance of the Fluid Flame Solid Waste Converter installed at the York, Pennsylvania manufacturing facilities.

The objective of the test program was to establish if the stack emissions are in compliance with criteria dictated by the U. S. Environmental Protection Agency Standards of Performance for New Stationary Sources[1].

In order to provide adequate data for evaluation of the solid waste unit as either an incinerator or a steam generator, emission tests included measurement of the concentration and mass rate of particulates, sulfur dioxide, and nitrogen oxides, with intermittent visible emissions observations for opacity levels. The evaluation also included the measurement of total hydrocarbons in the emissions.

All tests were conducted on 23 September 1975, while utilizing hogged railroad ties for fuel.

The test methods employed for particulate sampling were in accordance with the U. S. Environmental Protection Agency Methods One, Two, Three, and Five. Sulfur dioxide was measured by EPA Method Six. Nitrogen oxides were determined by EPA Method Seven procedures. Total hydrocarbons were measured by on-site gas chromatographic techniques.

---

[1] Federal Register, Vol. 36, No. 247, Dec. 23, 1971 as amended.

York-Shipley personnel were responsible for the operation of the unit and recorded pertinent operation data during the test period.

This report presents the results of the test. Descriptions of the sampling trains, test procedures, sample recovery, analytical methods, and representative calculations have been included.

A comparison of the test results with EPA Emission Standards is provided in Table 1.

The summary of test results is presented in Tables 2 and 3. Table 4 provides the summary of test data.

It has been a pleasure to work with you on this project, and if Weston can be of service for additional test activities, or for other areas of environmental engineering, please contact us.

Very truly yours,

James W. Davison

James W. Davison
Supervisor
Air Pollution
Measurement Services

JWD:kw

YORK-SHIPLEY, INC.
York, Pennsylvania
Test Results Comparison with EPA Emission Standards

TABLE 1

	Test Result	EPA Emission Standard
Particulate		
Grain/SCF, Dry[1]	0.318	0.080
Pounds/Million BTU Input	1.010	0.100
Sulfur Dioxide		
Pounds/Million BTU Input	0.121	0.800
Nitrogen Oxides		
Pounds/Million BTU Input	0.177	0.700
Total Hydrocarbons		
Parts per Million[2]	<1	NA
Opacity		
Percent Opacity	5	20
Carbon Monoxide		
Percent CO[3]	<0.1	NA

---

[1] Grain per Dry Standard Cubic Foot Corrected to 12% CO_2.

[2] Bed Temperature - 2000°F.

[3] Orsat Analysis - Sensitivity of Analysis - 0.1%

NA - Not Applicable -

No Emission Standard has been established for carbon monoxide.
Ambient Air Standards consider Hydrocarbon and Carbon Monoxide.

INTRODUCTION

York-Shipley, Inc. is currently evaluating the performance of the York-Shipley Fluid Flame Solid Waste Converter for the incineration of various solid waste fuels. This unit is equipped with a heat recovery boiler and was recently modified by the installation of a Breslove Regenerative Fly Ash Collector.

Solid fuel is fed into the York-Shipley Fluid Flame Incinerator over a bed of sand fluidized by pre-heated air. Combustion of the waste fuel occurs on the sand and in the gas vapor at temperatures ranging from 1500 to 2000°F. The incinerator bed is initially raised to operating temperature utilizing an oil or gas-fired burner. This unit is shut down when the solid fuel combustion becomes self-sustaining.

Incinerator flue gases are routed through the multiple pass heat recovery boiler, and discharged to the atmosphere after passage through an in-line Breslove Regenerative Fly Ash Collector. The emission tests covered in this report were conducted under steady state bed conditions.

DESCRIPTION OF SAMPLING TRAINS

Particulate Matter

The sampling train designed to perform the particulate sampling is the train required by the Environmental Protection Agency Method 5 (See Figure 1). A stainless steel nozzle attached to a heated (250°F) pyrex probe was connected directly to a pyrex filter holder containing a Reeve Angel 900 AF glass fiber filter. The filter holder was maintained at 250°F and was connected to the first of four impingers. Impingers 1 and 2 each contained 100 ml of distilled water. The third impinger was dry and the fourth contained 200 grams of dry pre-weighed silica gel. The first, third, and fourth impingers were a modified Greenburg-Smith type; the second was the standard Greenburg-Smith design. All impingers were maintained in a crushed ice bath. A Research Appliance Meter Control Case provided a leakless vacuum pump, a dry gas meter, a calibrated orifice, and inclined manometers.

Sulfur Dioxide

The sampling train utilized for sulfur dioxide emissions measurements conforms to the requirements of EPA Method 6. A heated pyrex probe (250° F) was connected directly to the first of four midget impingers. Impinger 1 contained 15 ml of 80% isopropanol. Impingers 2 and 3 each contained 15 ml of 3% hydrogen peroxide solution, and the fourth impinger was dry. The first impinger was a fritted glass bubbler. The last three were standard type midget impingers. Glass wool was placed at the exit of Impinger One to prevent particulate matter and liquid carry over entering the peroxide solutions. The last impinger was connected by vacuum tubing to a dry test meter equipped with a sample rate control valve. A vacuum pump completed the train. Figure 2 illustrates the EPA Method 6 sampling train.

Nitrogen Oxides

The nitrogen oxides sampling train used for the tests satisfies EPA Method 7 requirements. A heated pyrex probe (containing glass wool as a filter) was attached to a two liter evacuated flask fitted with a three-way valve. The flask was connected to a 36 inch U-tube mercury manometer. A one way purging bulb and a vacuum pump completed the sampling train. (Refer to Figure 3).

Total Hydrocarbons

The stack gases were passed through a Teflon probe directly to two one-liter flasks in parallel. An activated carbon tube was positioned prior to one of the flasks. A vacuum pump completed the train. Heating tapes were wrapped around the sample flasks to maintain the hydrocarbons in a vapor state.

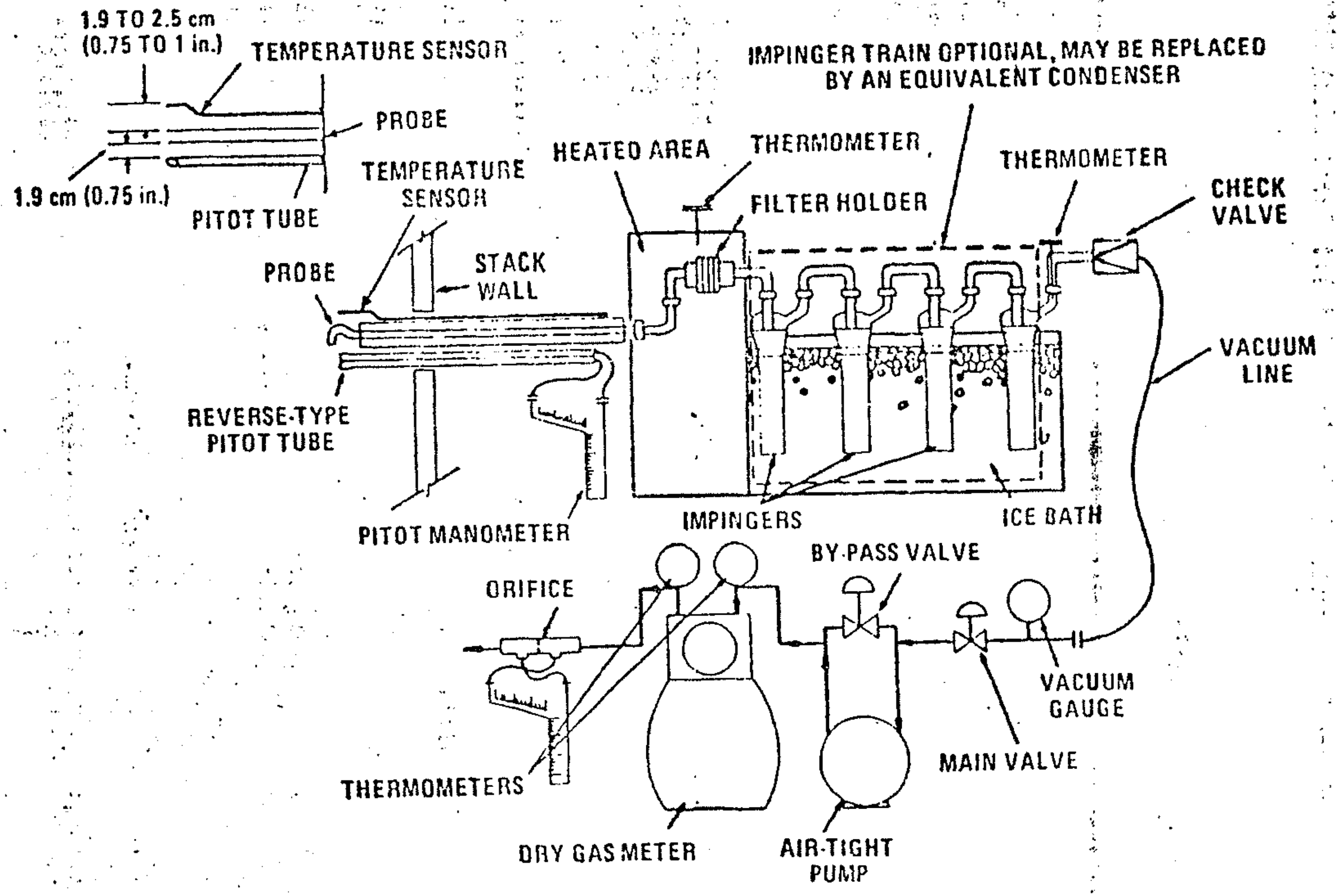


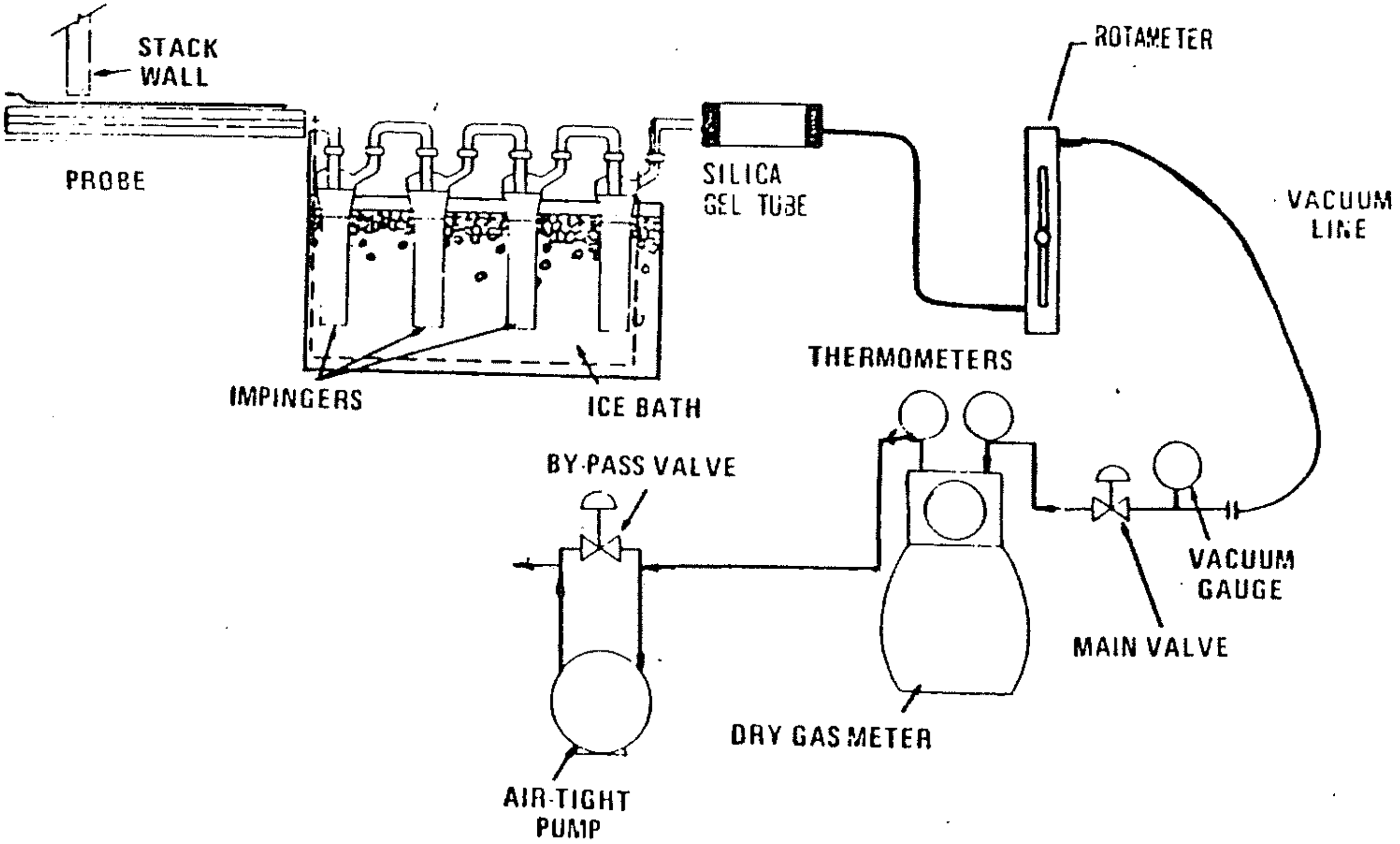
FIGURE 1

Particulate-sampling train.

EPA METHOD 5

ROY F. WESTON, INC.
WESTON WAY
WEST CHESTER, PA. 19380
PHONE: (215) 692-3030
TELEX: 83-5349

YORK-SHIPLEY, INC.
York, Pennsylvania



Sulfur Dioxide Train

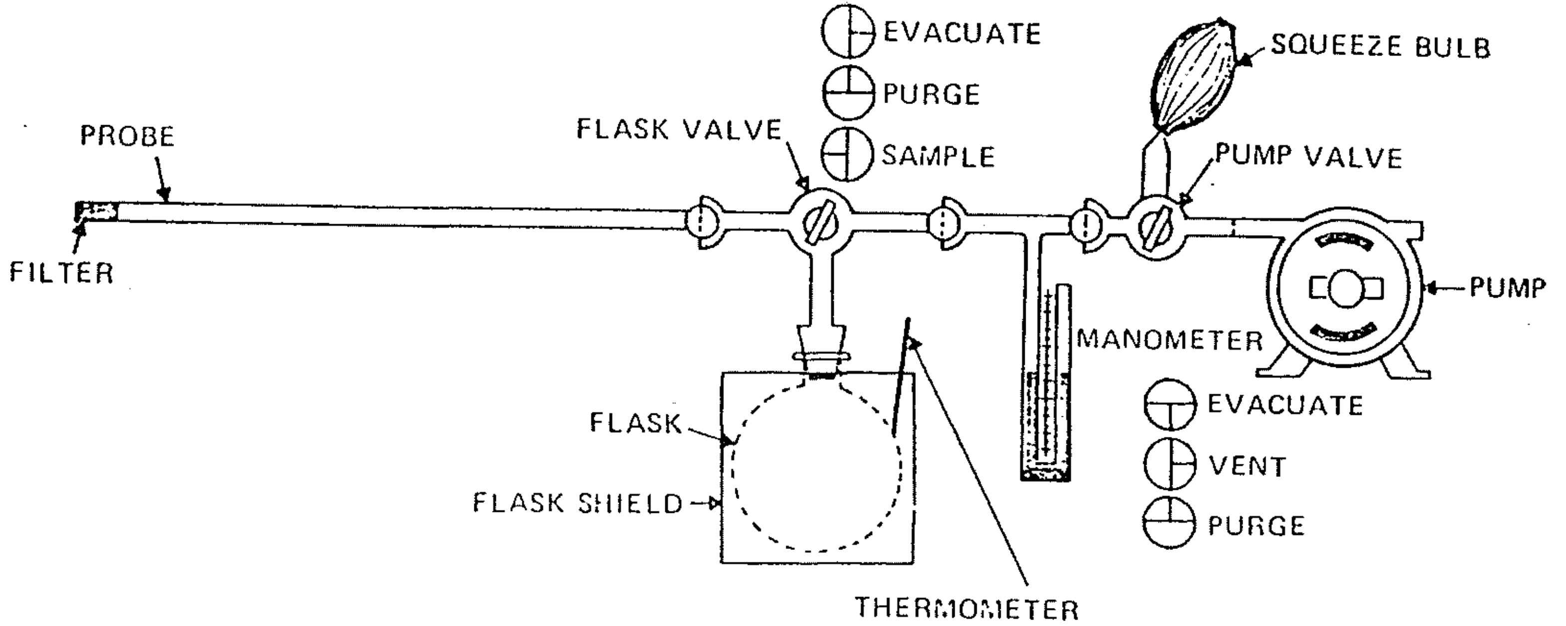
EPA METHOD 6

FIGURE 2

ROY F. WESTON, INC.
WESTON WAY
WEST CHESTER, PA. 19380
PHONE (215) 692-3030
TELEX 835348

WESTON

YORK SHIPLEY, INC.
York, Pennsylvania



NITROGEN OXIDES

EPA METHOD 7 SAMPLING TRAIN

FIGURE 3

W.O. #1259-01

ROY F WESTON
WESTON WAY
WEST CHESTER, PA 19380
PHONE (215) 692-3030
TELEX 83-5348

TEST PROCEDURES

Particulate Matter

Two test ports were located in the stack at 90° to each other at a point 1.3 stack diameters downstream of the stack outlet and 3.7 stack diameters upstream of the nearest flow disturbances in that direction. The flow disturbance criteria dictated by EPA Method One required 28 sampling points, 14 per traverse axis. See Figure 4 for sample point locations and distances. Figure 5 illustrates port locations.

The sampling probe nozzle remained for 2.5 minutes at each of the fourteen points, resulting in thirty-five minutes sampling for each traverse, and a total test time of seventy minutes.

During sampling, gas stream velocities were monitored by insertion of a calibrated "S" type pitot tube into the stack adjacent to the sampling probe. A type K thermocouple and direct reading potentiometer measured the temperature of the gas stream at each point. The velocity was observed immediately after positioning the probe at each sampling point, and sampling rates were adjusted to maintain isokinetic sampling. Temperature measurements were made at the filter holder, the dry test meter inlet and outlet, and of the gas sample at the final impinger. Test data were recorded every 2.5 minutes for the entire test period. Test data and test results can be found in Tables 1, 2 and 3.

Sulfur Dioxide

The heated probe was positioned at a point of average gas velocity in the stack and allowed to remain at that point throughout the duration of the test. The sampling rate was adjusted to 0.1 cubic feet per minute for a total test time of thirty minutes. Two repetitions constitute a test run.

Nitrogen Oxides

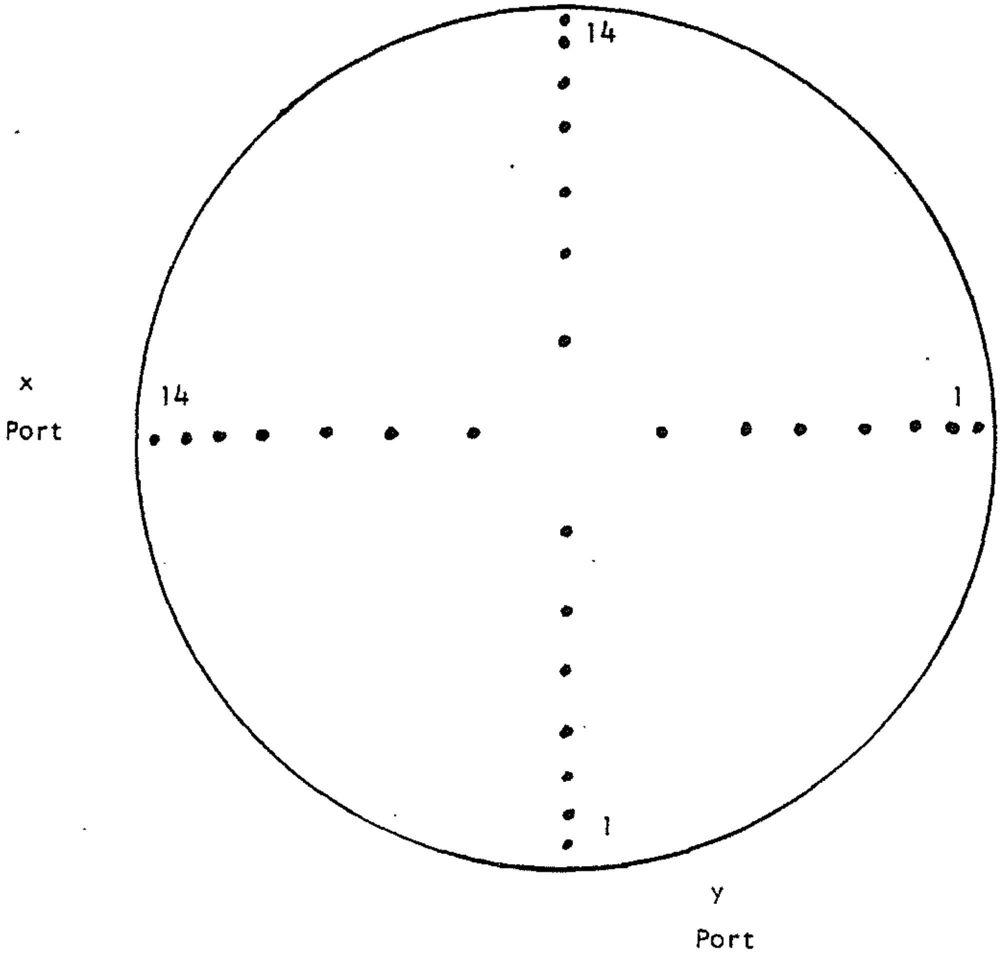
The probe was positioned near the center of the stack. The flask was evacuated to a pressure of less than three inches of mercury absolute and the flask temperature was recorded. After purging the probe with stack gas, the 3-way valve was positioned to allow a sample to enter the flask for fifteen seconds. The method requires that four grab samples be collected per test run.

Total Hydrocarbons

Stack gas was drawn through the two flasks simultaneously for five minutes. The stopcocks were then closed to secure the sample, which was removed to the on-site temporary installation of the gas chromatograph for analysis.

FIGURE 4

Sampling Point Locations

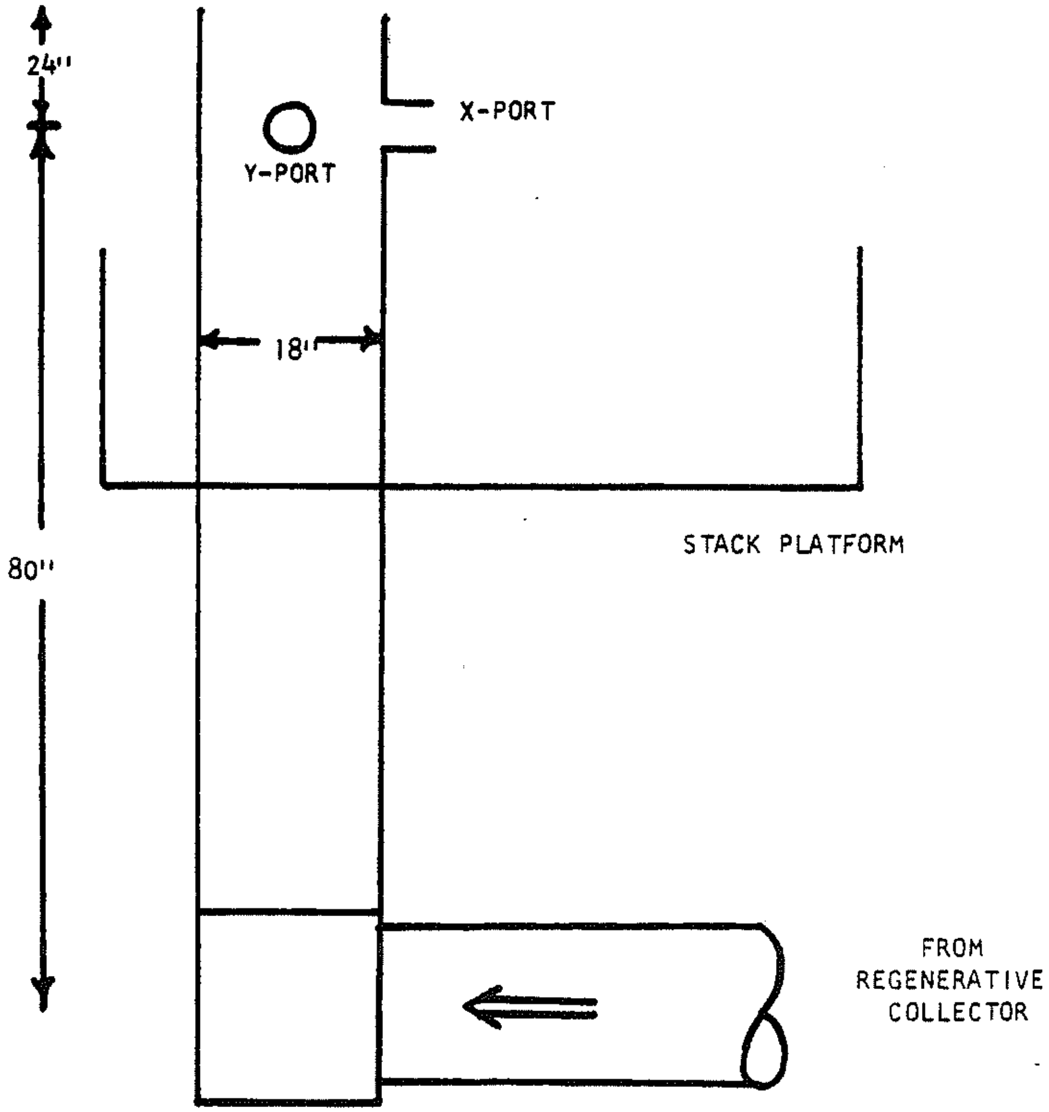


Traverse Point No.	Distance From Near Wall in.	Traverse Point No.	Distance From Near Wall in.
1	1	8	11 3/8
2	1	9	13 1/8
3	1 3/4	10	14 3/8
4	2 5/8	11	15 3/8
5	3 5/8	12	16 1/4
6	4 7/8	13	17
7	6 5/8	14	17

YORK-SHIPLEY, INC.
York, Pennsylvania

Sampling Port Location

FIGURE 5



SAMPLE RECOVERY

A consistent procedure was employed for sample recovery. One person was assigned the task of cleaning an entire sampling train and recovery of the samples.

Particulate Matter

The sample recovery was conducted in the following manner:

1. The total liquid in impingers One, Two, and Three was measured and placed in a glass container fitted with a teflon liner (Sample 1).
2. The impingers, connectors, and back half of the filter holder were rinsed with distilled water once, and then added to Sample 1.
3. The impingers, connectors, and back half of the filter holder were rinsed once with acetone into a separate glass container (Sample 2).
4. The glass fiber filter was removed from the holder with tweezers and replaced in the original container (petri dish), along with any loose particulate and filter fragments. (Sample 3).
5. The silica gel was removed from the last impinger and immediately weighed.
6. The probe brush was pre-rinsed with acetone, which was discarded. The probe and nozzle were separated and rinsed into a glass container with acetone while brushing a minimum of three times. The brush was again rinsed with acetone into the same glass container (Sample 4).
7. The front half of the filter holder was also rinsed once with acetone into Sample 4.
8. Blanks of acetone and distilled water were retained for analysis.

Sulfur Dioxide

The sample recovery was performed in the following sequence:

1. The contents of Impinger One was discarded.
2. The contents of Impingers Two and Three were placed into a polyethylene container (Sample 1).
3. Impingers Two, Three and Four and the glass connectors were rinsed with distilled water into Sample 1.
4. A blank of hydrogen peroxide was retained for analysis.

Nitrogen Oxides

The sample recovery was conducted according to the following procedure:

1. The sample flask was shaken for five minutes and allowed to remain quiescent for a minimum of sixteen hours.
2. The flask was again shaken for two minutes.
3. The final flask pressure and temperature was recorded.
4. The contents were transferred to a polyethylene container. (Sample 1).
5. The flask was rinsed with 10 ml of distilled water into Sample 1.
6. The contents of Sample 1 was made alkaline to litmus with 1.0 N sodium hydroxide solution.
7. A blank of reagent was retained for analysis.

Hydrocarbons

The sample handling proceeded in the following manner:

1. The flasks were heated to a temperature slightly higher than the stack temperature.
2. A 100 ml syringe fitted with a hypodermic needed was utilized to withdraw a portion of the sample.
3. Moisture condensation was removed from the flask and placed in a glass container.

ANALYTICAL PROCEDURES

Particulate Matter

The distilled water samples from the impingers and impinger wash (Sample 1) were extracted with three 25-ml individual portions of ether and chloroform to remove any organics in the water sample. The ether-chloroform extraction was evaporated at ambient pressure and temperature in tared beakers to a constant residue weight; a blank of the either-chloroform mixture was carried through the evaporation procedure.

The water samples were then evaporated to dryness in tared beakers by means of a steam bath. A sample of the distilled water was also treated as a blank.

The acetone impinger wash sample (Sample 2) was evaporated at ambient temperature and pressure to a constant residue weight.

The glass fiber filter (Sample 3) was desiccated to a constant weight. The filter was subsequently extracted with benzene for hydrocarbons analysis. The acetone probe washings samples (Sample 4) and an acetone blank were transferred to tared beakers and evaporated to dryness at ambient temperature. The beakers were desiccated and dried to a constant weight.

All weight differences are reported to the nearest 0.5 milligram. All final weights are adjusted by the corresponding values of the appropriate blanks.

The weight of the material collected on the filter, plus the probe washings sample residue weight represents the particulate collected by the front half of the train. (EPA Method 5). The total weight of particulate collected includes the remaining residue weights of the impinger water sample, ether-chloroform extract residue, and acetone impinger wash residue, in addition to the front half weight of particulates. Test results are provided in Table 2.

Sulfur Dioxide

The contents of Sample 1 were transferred to a 50-ml volumetric flask and diluted to volume with distilled water. A 10-ml aliquot was combined with 40-ml of 80% isopropanol and titrated with barium perchlorate in the presence of thorin indicator. The blank was treated in a like manner.

Nitrogen Oxides

The contents of Sample 1 were transferred to a 100-ml beaker and allowed to evaporate to dryness on a steam bath. After cooling, the residue was triturated with 2-ml of phenoldisulfonic acid solution, reheated and cooled. After cooling, 20-ml of distilled water was added, followed by the addition of ammonium hydroxide to litmus. The contents were transferred to a 100-ml volumetric flask and diluted to volume with distilled water. The absorbance of the solution was measured using a spectrophotometer at 420 nm. The blank and a series of standards were treated in the same manner.

Hydrocarbons

A gas sample from each flask was injected in duplicate into a gas chromatograph (G.C.) utilizing hydrogen flame ionization. Prior to each sample run, a series of methane standards were injected into the G.C. The gas sample drawn through activated carbon yielded only methane hydrocarbons, while the sample without prior carbon adsorption provided total hydrocarbons. All hydrocarbon results are expressed as parts per million by volume methane.

YORK-SHIPLEY, INC.
York, Pennsylvania
Summary of Particulate Test Results

TABLE 2

Test Date	9-23-75
Test Time	1025-1150
Gas Flow	
Standard Cubic Feet/Minute, Dry[1]	2150.0
Actual Cubic Feet/Minute, Wet	3350.0
Particulate	
Probe Catch, mg	314.3
Filter Catch, mg	203.1
Front Half Subtotal, mg	517.4
Impinger Catch, mg	24.2
Ether/Chloroform Extraction, mg	4.0
Acetone Wash of Impingers, mg	3.7
Back Half Subtotal, mg	31.9
Total Catch, mg	549.3
Particulates	
EPA Method 5 (Front-Half Catch)	
Grains/SCF, Dry[2]	0.318
EPA Emission Standard, Grains/SCF, Dry	0.080
Pounds/Million BTU Input	1.01
EPA Emission Standard, Pounds/Million, BTU Input	0.10
Particulates	
Total Catch	
Grains/SCF, Dry[2]	0.3374
Pounds/Million BTU Input	1.07
Opacity	
Percent Opacity	5
EPA Emission Standard, Percent Opacity	20

---

[1] 70° F, 29.92 in Hg., Dry

[2] Grains Per Dry Standard Cubic Foot Corrected To 12% CO_2

YORK-SHIPLEY, INC.
York, Pennsylvania
Summary of Gaseous Test Results

TABLE 3

Test Date	9-23-75

Gas Flow

Standard Cubic Foot/Minute, Dry	2150.0
Actual Cubic Feet/Minute, Wet	3350.0

Sulfur Dioxide

Pounds/Million BTU Input[1]	0.121
EPA Emission Standard, Pounds/Million BTU Input	0.800

Nitrogen Oxides

Pounds/Million BTU Input[2]	0.177
EPA Emission Standard, Pounds/Million BTU Input	0.700

Total Hydrocarbons

Bed Temperature	1000°F	1500°F	2000°F
Gaseous, Total Hydrocarbons, PPM	20	22	< 1.0
Non-Methane Hydrocarbons, PPM	11	16	< 1.0
Particulate, Benzene Extractable, PPM	--	--	< 1.0
Condensate, Total Organic Carbon, PPM	323	32	59

Carbon Monoxide

Percent CO[3]	< 0.1

---

[1] Average Of Two Consecutive Tests

[2] Average of Four Consecutive Tests

[3] Orsat Analyses - Sensitivity of Analysis - 0.1%

YORK-SHIPLEY, INC.
York, Pennsylvania

TABLE 4

Summary of Test Data

Test Data

Test Parameter	Particulate
Test Date	9-23-75
Test Time	1025-1150

Sampling

Sampling Duration, minutes	70.0
Nozzle Diameter, inches	0.251
Barometric Pressure, inches Hg	29.61
Average Orifice Pressure Drop, inches H_2O	0.738
Volume of Sample at Meter, cubic feet	32.42
Average Dry Gas Temperature at Meter, °F	82.4
Volume of Sample at Standard Conditions[1], cubic feet	31.38

Moisture

Total H_2O Collected, ml	70.0
Volume of H_2O Collected, cubic feet at standard conditions	3.32
Percent Moisture in Stack Gas by Volume	9.6
Mole Fraction of Dry Gas	0.904

Gas

% CO	9.6
% O_2	10.4
% CO	0.0
% N_2	80.0
Molecular Weight of Dry Stack Gas	29.95
Molecular Weight of Wet Stack Gas	28.81

Velocity

Pitot Tube Coefficient	0.845
Average SDE[2]	12.75
Average Stack Temperature, °F	281.4
Static Pressure of Stack, inches H_2O	+0.24
Stack Pressure, inches Hg absolute	29.63
Stack Velocity at Stack Conditions, feet minute	1898.0
Total Sampling Points	28.0

Flow

Stack Area, square inches	254.5
Dry Stack Gas Volume, standard cubic feet minute	2150.0
Stack Gas Volume at Stack Conditions, actual CFM	3350.0

Isokinetic Ratio

107.1

Process Operation

Charging Rate, as fired, lbs/hr.	751.0

---

[1] 70°F, 29.92 in Hg, Dry Basis.

[2] $$\text{SDE} = \sqrt{\underset{\text{in.}H_2O}{\Delta P} \times \underset{{}^{\circ}F}{(\text{Gas Temp.} + 460^{\circ})}}$$

Particulate Calculations

1. Volume of dry gas sampled at standard conditions: 70°F, 29.92 in. Hg, cu.ft.

$$V_{m_{std}} = \frac{17.7 \times V_m \left(P_b + \frac{P_m}{13.6}\right)}{(T_m + 460)} = \frac{17.7 \times 32.416\left(29.61 + \frac{.7375}{13.6}\right)}{(82.36 + 460)} =$$

$$= 31.382 \text{ cu.ft.}$$

2. Volume of water vapor at 70°F and 29.92 in. Hg, cu.ft.

$$V_{w_{gas}} = 0.0474 \times V_w = 0.0474 \times 70 = 3.318$$

3. Percent moisture in stack gas.

$$\%M = \frac{100 \times V_{w_{gas}}}{V_{m_{std}} + V_{w_{gas}}} = \frac{100 \times 3.318}{31.382 + 3.318} = 9.56$$

4. Mole fraction of dry gas.

$$M_d = \frac{100 - \%M}{100} = \frac{100 - 9.56}{100} = 0.9044$$

5. Average molecular weight of dry stack gas.

$$MW_d = \left(\%CO_2 \times \frac{44}{100}\right) + \left(\%O_2 \times \frac{32}{100}\right) + \left[(\%CO + \%N_2) \times \frac{28}{100}\right]$$

$$\left(9.6 \times \frac{44}{100}\right) + \left(10.4 \times \frac{32}{100}\right) + \left[(0 + 80.\ ) \times \frac{28}{100}\right] = 29.95$$

6. Molecular weight of stack gas.

$$MW = MW_d \times M_d + 18\,(1 - M_d) = .9044 \times 29.95 + 18\,(1 - .9044) = 28.81$$

7. Stack velocity at stack conditions, fpm

$$V_s = 4359 \sqrt{\Delta P_s \times (T_s + 460)} \left[\frac{1}{P_s \times MW}\right]^{1/2} =$$

$$4359 \times 12.747 \left[\frac{1}{29.63 \times 28.81}\right]^{1/2} = 1897.98 \text{ fpm}$$

Where:

$CP = 0.845$
$4359 = 5128.8 \times Cp$
$5128.8 = \text{Constant}$

8. Stack gas volume at standard conditions*, SCFM

$$Q_s = \frac{0.123 \times V_s \times A_s \times M_d \times P_s}{(T_s + 460)} = \frac{0.123 \times 1897.98 \times 254.47 \times .9044 \times 29.63}{(281.4 + 460)} =$$

$$= 2147. \text{ SCFM}$$

9. Percent isokinetic

$$\%I = \frac{1032 \times (T_s + 460) \times V_{m_{std}}}{V_s \times T_t \times P_s \times M_d \times (D_n)^2} = \frac{1032 \times (281.4 + 460) \times 31.382}{1897.98 \times 70 \times 29.63 \times .9044 \times (.251)^2} =$$

$$= 107.1$$

10. Particulate: probe and filter, gf/SCF* dry basis corrected to 12% CO_2

$$C_{an} = 0.0154 \times \frac{m_f}{V_{m_{std}}} \times \frac{12}{\% \, CO_2} = 0.0154 \times \frac{517.4}{31.382} \times \frac{12}{9.6} = 0.3178$$

11. Particulate total, gr/SCF* Dry Basis corrected to 12% CO_2

$$C_{ao} = 0.0154 \times \frac{m_t}{V_{m_{std}}} \times \frac{12}{\% \, CO_2} = .0154 \times \frac{549.3}{31.382} \times \frac{12}{9.6} = 0.3374$$

12. Particulate: probe and filter, lb/million BTU

$$C_{aw} = \frac{0.00857 \times C_{am} \times Q_s}{\text{BTU input}} = \frac{.00857 \times .2539 \times 2150}{4.645} = 1.01$$

13. Particulate: Total, lb/million BTU

$$C_{ax} = \frac{0.00857 \times C_{ap} \times Q_s}{\text{BTU input}} = \frac{.00857 \times .2696 \times 2150}{4.645} = 1.07$$

---

*70°F, 29.92 in Hg

SULFUR DIOXIDE CALCULATIONS

Example: #1 SO_2

1. Sample Volume, SCF*

$$V_{m_{std}} = (Vm_f - Vm_i)\ (17.71)\ (\frac{Pm}{Tm}) =$$

$$(788.975 - 785.91)\ (17.71)\ (\frac{25.61}{531.5}) = 2.616$$

2. Concentration of Sulfur Dioxide, lb/million BTU

$$C_{SO_2} = \frac{7.05 \times 10^{-5} \times V_{titr} \times N_{titr} \times \frac{V_{soln}}{V_{aliq}} \times Q_s \times 60}{BTU\ input \times V_{m_{std}}} =$$

$$\frac{7.05 \times 10^{-5} \times 4.3 \times .0099 \times \frac{95}{25} \times 2147 \times 60}{4.645 \times 2.616} = .1209$$

---

*70 °F, 29.92 in Hg

NITROGEN OXIDES CALCULATIONS

Example: #1 NO_x

1. Sample Volume, ml, standard conditions*

$$V_{std} = 17.71\ (V_{flask} - 25)\ \left(\frac{P_f}{T_f} - \frac{P_i}{T_i} \right) =$$

$$17.71\ (2103 - 25)\ \left(\frac{30.19 - 0.5}{528} - \frac{29.61 - 27.0}{530} \right) = 1888.7$$

2. Nitrogen Oxides, lb/million BTU

$$C_{NO_x} = \frac{6.2 \times 10^{-5} \times \frac{M_{NO_x}}{V_{std}} \times Q_s \times 60}{\text{BTU input}} =$$

$$\frac{6.2 \times 10^{-5} \times \frac{195}{1888.7} \times 2147 \times 60}{4.645} = 0.1771$$

---

*70°F, 29.92 in. Hg