Systems Evaluation of Refuse as a Low Sulfur Fuel Part III: Air Pollution Aspects

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ABSTRACT

Part III discusses air pollution control requirements for power boilers firing municipal refuse in a series dealing with the extent to which solid waste can reduce sulfur dioxide emulsion when the waste is used as a fuel for power generation.

Particulate emissions from refuse and combined refuse - fossil fuel firing are discussed, based on a review of both European and domestic experience with refuse firing; straight fossil fuel; and combined firing.

For the case of combined firing, an additional air pollution control requirement is sulfur dioxide absorption, and two alternative systems are recommended. In one system, a high energy scrubber is used for particulate collection. In the alternate system, an electrostatic precipitator is instead used. In either system, particulate control is followed by absorption of SO_2 in an alkaline base absorption tower.

Special cases of split stream of refuse versus fossil-fuel combustion products are discussed.

Overall conclusions are that particulate emission control for refuse or combined-fired boilers is entirely feasible. High-performance particulate control for such plants has been well demonstrated both here and abroad. Development of applicable SO_2 controls continues on domestic fossil-fueled units, with commercialization attained by, or imminent with, several suppliers.

INTRODUCTION

The work reported in this paper was completed under a subcontract to Envirogenics (1) with funding provided by NAPCA (now EPA) under Contract CPA 22-69-22. Foster-Wheeler Corporation, also a subcontractor (2); Cottrell Environmental Systems, and Envirogenics, were charged with several responsibilities:

1) To assess the extent to which refuse; when used as a fuel to generate steam or power; can aid in reducing the scope of the domestic problem of atmospheric emissions of SO_2.

2) To detail those systems which would hold the most promise for utilizing refuse as a fuel to generate steam or power.

Cottrell Environmental Systems' participation included a detailed review of European and domestic experience with air pollution control in power generating systems: either fossil, refuse, or combined-fired. In addition, ambient air quality standards and required levels of atmospheric emission control were projected through 1985. Finally, air pollution control techniques were developed for the systems identified (as in item 2).

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The assignment was undertaken under the premise that refuse is a fuel. As a fuel, it is higher in ash and moisture, and lower in heating value and sulfur than most fossil fuels. It has a negative value, in that the hauler, whether private or public, is charged a fee for its ultimate disposal. This negative value suggests that refuse can be used as a particularly economical fuel to provide marketable, recovered energy.

Fortunately, ultimate analyses [29,30] of refuse from almost any city in the United States show remarkable similarities: It is, in fact, a fuel with reasonably consistent and predictable properties. These properties vary seasonally and undergo long-term changes as a result of the dynamic nature of our culture; for example, per capita refuse generation, as well as heating value, are steadily increasing.

The assignment considered the design and operating variables of as-yet-hypothetical, modern, efficient boiler systems, as well as the pollutant-forming properties of their refuse fuel, and detailed required air pollution control. By far, the bulk of the assignment considered dry filterable particulate emissions and their control.

In addition, a concentrated effort was made by others [2] to document sulfur balances for fossil vs. refuse-fired systems.

THE AIR POLLUTION PROBLEM

SOURCES OF DATA

In considering the air pollution potential of refuse-firing, it is required to examine and project the pollutant-forming properties of domestic refuse. Kaiser [29, 31, 32] has provided a wealth of refuse composition data, and other investigators [30, 33, 34] have correlated refuse composition to atmospheric emissions.

Generally, when refuse is burned in an efficient boiler system, the pollutants anticipated, along with corresponding primary influence variables, are those listed in Table 1.

TABLE 1. POLLUTANTS AND PRIMARY INFLUENCE VARIABLES ANTICIPATED WHEN REFUSE IS BURNED IN AN EFFICIENT BOILER SYSTEM

POLLUTANT	MAJOR VARIABLES
1) Dry, Filterable Particulate	Superficial grate velocity and boiler/furnace geometry
2) Condensible Particulate	Not known – probably related to refuse composition and combustion efficiency
3) Sulfur Oxides	Fuel composition
4) Chloride	Fuel composition
5) Nitric Oxides	Temperature and excess air

The specification of air pollution control techniques for any point source requires the confident prediction of the quantitative emission problem. Further, the emission problem must be related to the design and operating variables of the source process. So it is in the case of refuse or refuse-coal firing. An immediate objective is to establish relationships between the critical influence variables and the emission problem. A review of the literature and an analysis of demonstrated technology formed the base from which emission relationships are established. They further form the base from which applicable control technique selection, applicability, performance, operability, and economics can be developed.

Air pollution control experience with U.S. incinerators and utility boilers provided much of the inputs to the project. However, the most significant contribution was from European experience, with its near-direct applicability. A number of plants, all located in Germany, were selected for study on the basis of an overall representation of boiler and grate designs and firing modes.

The selected plants are:

Munich North, Unit No. 1A

Munich North, Unit No. 2

Stuttgart-Münster, Unit No. 28

Stuttgart-Münster, Unit No. 29

Düsseldorf-Flingern, Unit No. 1

In accordance with standard German practice, the formal contract acceptance tests for each of these plants were performed by the Technischer Überwachungs-Verien (TÜV). The TÜV is a German state-agency that reviews and approves final designs and performs acceptance tests on virtually all capital equipment of this type.

Transcripts of TÜV acceptance test data were procured and reviewed for these plants. Steam generator tests and dust collector tests were performed concurrently. Dust collector testing was by simultaneously sampling the inlet and outlet using UOP-type samplers. In one case, flue layouts precluded inlet sampling, and integrated hopper-catches, confirmed by furnace material balances, were used to determine collector inlet dust concentration.

DEVELOPMENT OF DATA

Several alternate techniques of predicting particulate emissions from the systems under study are possible. Regarding the coal combustion side of the system, its respective contribution to the air pollution problem is readily predicted from the literature (35, 36). The refuse-inspired component of the particulate problem is predicted by employing Stenburg's correlations [33] of underfire air velocity versus particulate emissions for domestic refuse.

Stenburg's correlation has been substantiated by two unrelated domestic investigators and is a reasonable technique for predicting grate-fired refuse emissions. As shown later, the furnace geometry also plays an important role in influencing emissions.

It is curious that the European investigators have not published relationships based on the domestic concept of underfire air velocity and refuse fly ash emissions. The second unit (Unit No. 2) installed at the Munich North plant ultimately emitted substantially less fly ash than was anticipated [15] by the designers. The latter considered several possible reasons for this unexpected phenomenon and qualitatively concluded that lower furnace velocities (and higher residence times for burnout in suspension) are the chief reasons. In reviewing these considerations, a comparison of the combustible content of the fly ash for Unit No. 2 versus Unit No. 1 (Table 2) indicates that this might indeed be true.

The European designers are confounded by an additional consideration: European refuse is characterized by much greater seasonal variations than American refuse. This is concluded to be a result of a greater use of coal for heating in Europe than in the U.S., and a correspondingly higher ash content (during winter months) in European municipal refuse. Andritzky has observed [37] higher fly ash boiler emissions and lower size distributions in winter months, as a concluded result of seasonal refuse variations.

Under fire air rates for the bulk of the units were not included in the TÜV dust collector test reports. One value was reported for Stuttgart in the TÜV boiler report, but analysis for comparison with Stenburg's data is impossible, since refuse composition is absent.

Applying the foregoing techniques to the systems under consideration [7, 2], the refuse-inspired particulate loadings are determined at 50 percent excess air for grate combustion. For the case of suspension burning, no estimates were made. It is obvious that suspension firing of refuse should result in significantly higher particulate emissions. With grate combustion, pneumatic or aerodynamic forces elutriate particles from the fuel bed. In suspension burning, the fuel is, in fact, dispersed throughout the furnace before and during combustion.

EUROPEAN PLANTS

Table 3 details the physical aspects of each unit under consideration. Table 4 describes the air pollution control systems under study.

An overall summary of dust collector test data has been tabulated and presented in Table 5. For convenience, both metric and English units are presented where applicable. The tabulation also includes a variety of calculated data characterizing the design versus actual precipitator performance. Migration velocities, electrical energization data, and gas velocities are included.

Migration velocity, or precipitation rate, is a quantitative measure of precipitator performance. This indicator was used to assess the relative applicability of the electrostatic precipitator process through a variety of operating modes (temperature, firing mode, etc.). This technique was necessary due to the dearth of creditable dust resistivity data.

Migration velocity values have been computed from the Deutsch [38] equation:

$$\text{Precipitator Collection Efficiency, } \% = 1 - e^{\frac{-A}{V} W}$$

where: e = Napier base logarithm

A = Precipitator collection electrode surface, ft^2

V = Gas Flow, ft^3/sec.

W = Migration Velocity, ft/sec.

Analysis of these (Table 5) precipitation ratio data results in a number of interesting conclusions:

The bulk resistivity of American low-sulfur coal fly ash is known to peak at approximately 320 F [39]. In comparison, precipitation rates on low-sulfur-coal-only precipitator operation at Munich North, Unit No. 1 (260 F) and Unit No. 2 (310 F) indicate that fly ash resistivity peak occurs at a gas temperature considerably lower ($<$250 F) than fly ash from American low-sulfur coal. Ultimate composition, particularly silicates and alumina content is suspected as the reason.

This indicates that European experience with electrostatic precipitation of fly ash from low-sulfur coals is not directly applicable to American low-sulfur coals.

In analyzing European precipitator performance on refuse-only firing, the lowest precipitation rates;

TABLE 2. FLY-ASH PROPERTIES – SELECTED EUROPEAN COMBINED-FIRED PLANTS

	Particle Size Distribution % Less Than Indicated Size in μ	Combustibles %	Bulk Resistivity Ohm – cm at °F.
Munich North, Unit No. 1A	Not Available	6.5 Refuse Only 15 Combined Firing 20 to 30 Coal Only	Not Available
Munich North, Unit No. 2	5 < 10*	3.4** Combined Firing	2×10^9 at 320°F*
Düsseldorf-Flingern, Unit No. 1	13 < 10 (TÜV Test 1) 23 < 10 (TÜV Test 2) 20 < 10*	6.6 Refuse Only	6×10^7 at 432°F
Stuttgart-Münster, Unit No. 28	Not Available	9.7 Combined Firing	Not Available
Stuttgart-Münster, Unit No. 29	Not Available	8.3 Combined Firing	Not Available

* – Source: Ref. 30 based on integrated hopper samples
** – Source: Ref. 15
Note: All other data per TÜV Reports.

TABLE 3. BACKGROUND PLANT DATA

PLANT	MUNICH NORTH		MUNICH NORTH	DÜSSELDORF-FLINGERN	STUTTGART-MÜNSTER	
Unit No.	1A	1B	2	1 & 3	28	29
Service Date	1964	1964	1966	1965	1965	1965
Furnace Type	Combined-Fired Twin Chamber	Combined-Fired Twin Chamber	Combined-Fired Single Chamber	Refuse Only	Combined-Fired	Combined-Fired Twin Chamber
Refuse Grate						
Type	Backward Recip. Feed	Backward Recip. Feed	Backward Recip. Feed	Roller or Drum	Backward Recip. Feed	Roller or Drum
Mfgr.	Martin	Martin	Martin	VKW	Martin	VKW
O'All Area, Ft^2	605	605	1035	275	543	550
Refuse Rate						
Short Tons/Day	660	660	1060	250	530	530
lbs/hr	55,000	55,000	88,500	20,800	44,300	44,300
Aux. Fuel	Coal	Coal	Coal	None	Oil	Oil
APC Equipt.						
Type	Elect. Pptr.	Elect. Pptr.	Elect. Pptr.	Elect. Pptr.	Elect. Pptr.	Elect. Pptr.
Mfgr.	Lurgi	Lurgi	Lurgi	Lurgi	Rothemühle	Rothemühle
Rated Flow, ACFM.			Various	Various	172,000 ACFM	172,000 ACFM
Collection Efficiency, %	99.53	99.5	99+	99+	98	98

TABLE 4. ELECTROSTATIC PRECIPITATOR DESIGN DATA – SELECTED EUROPEAN COMBINED-FIRED PLANTS

PLANT	MUNICH NORTH	MUNICH NORTH	DÜSSELDORF-FLINGERN	STUTTGART-MÜNSTER	STUTTGART-MÜNSTER
Unit No.	1	2	1-4	28	29
Date Commissioned	1964	1966	1965	1965	1965
Type System	Elect. Pptr.	Elect. Pptr.	Elect. Pptr.	Elect. Pptr.	Elect. Pptr.
Equip. Mfgr.	Lurgi	Lurgi	Lurgi	Rothemühle	Rothemühle
Pptr. Design Details:					
Number of Pptrs.	1/Blr.	1/Blr.	1/2 Blrs.	1/Blr.	1/Blr.
Number Ducts	34	84	28	42	42
Duct Width m/in.	0.24/9-1/2	0.24/9-1/2	0.226/8-1/2	0.2225/8-3/4	0.2225/8-3/4
Duct Height m/ft.	7.5/24.6	8.35/27.4	6.27/20.6	7.75/25.4	7.75/25.4
Duct Length m/ft.	8.88/29.1	9.6/31.5	5.75/18.9	5/16.4	5/16.4
Total Proj. Coll. Area (m^2)	4525	13,500	2020	3250	3250
Total Proj. Coll. Area (ft^2)	48.700	145,000	20,800	35,000	35,000
Inlet Cross-Sect. Area (m^2)	61.2	168	37.8	72.5	72.5
Inlet Cross-Sect. Area (ft^2)	658	1810	406	780	780
Elect. Energization: No. T-R Sets	Two-650MA	Two	Two	One 500 MA	One 500 MA
Operating Voltage, Max. D-C	76 kv	–	–	–	–
Number Bus Sections	2/Series	2/Series × 2 Parallel	2/Series	2/Series	2/Series
Design Gas Velocity (Max. ft/sec)	3.4	3.16	3.7	3.67	3.67

TABLE 5. SUMMARY OF PERFORMANCE DATA

Plant/Unit		Munich North, Unit No. 1						
Test Number		1/1	1/2	2/1	2/2	3	1	2
Firing Mode		Coal Only		Coal & Refuse		Refuse Only	Coal	Coal
Rated Gas Volume M^3/sec @ °C Ft^3/sec @ °F. (V Design)		46.3 @ 140 163.5 @ 284	46.3 @ 140 163.5 @ 284	62.5 @ 160 2200 @ 320	62.5 @ 160 2200 @ 320	—— ——	162 @ 150 5720 @ 302	162 @ 150 5720 @ 302
Actual Gas Volume M^3/sec @ °C. (Measured at Pptr. Outlet) Ft^3/sec @ °F. (V Actual) 10^3 ACFM @ °F		51.7 @ 119 1830 @ 247 104 @ 247	53.3 @ 125 1880 @ 257 108 @ 257	69.3 @ 154 2440 @ 310 140 @ 310	69.3 @ 154 2440 @ 310 140 @ 310	50.9 @ 157 1800 @ 315 103 @ 315	163.2 @ 153 5770 @ 308 345 @ 308	164.3 @ 156 5800 @ 313 348 @ 313
Percent of Rating, %		112%	115%	111%	111%	——	101%	101
Anticipated Pptr. Inlet Dust Conc., gm/Nm^3 gr/SCF		4.5 1.97	4.5 1.97	4.5/15.9 1.97/6.95	4.5/15.9 1.97/6.95	15.9 6.95	5-20 2.19-8.75	5-20 2.19 8.75
Actual (Test) Pptr. Inlet Dust Conc., gm/Nm^3 gr/SCF		5.47 2.39	5.59 2.44	11.71 5.12	19.75 8.64	15.47 6.76	2.694 1.18	3.449 1.51
Actual (Test) Pptr. Outlet Dust Conc., gm/Nm^3 gr/SCF		0.0241 0.0105	0.0743 0.0325	0.0292 0.0128	0.0407 0.0178	0.0177 0.00774	0.0203 0.0089	0.038 0.0166
Guarantee Collection Efficiency (Corrected for Actual Test Conditions per Manufacturer's Correction Factors), %		97.94	97.49	99.25	——	——	97.97	98.00
Actual (Test Collection Efficiency), %		99.56	98.67	99.75	99.79	99.89	99.24	98.30
Pptr. Design Gas Velocity at Rated Volume (V)	m/sec ft/sec	0.756 2.48	0.756 2.48	1.02 3.35	1.02 3.35	—— ——	0.960 3.15	0.960 3.15
Pptr. Actual (Test) Gas Velocity (V)	m/sec ft/sec	0.845 2.77	0.871 2.86	1.132 3.714	1.132 3.714	0.832 2.73	0.971 3.19	0.978 3.21
Relative pptr. Size, Design Based on rated flow (A/V)	sec/m. sec/ft.	97.73 29.80	97.73 29.80	72.40 22.07	72.40 22.07	—— ——	83.33 25.41	83.33 25.41
Relative pptr. Size, actual Based on actual flow (A/V)	sec/m. sec/ft	89.52 26.68	84.90 25.88	65.30 19.91	65.30 19.1	88.90 27.10	87.72 25.22	82.17 25.05
Design pptr. Performance w (w design)	ft/sec	0.130	0.124	0.222	——	——	0.153	0.154
Actual pptr. performance w (w actual)	ft/sec	0.203	0.167	0.301	0.323	0.251	0.193	0.180
Pptr. Electrical Energization Data								
A Secondary Kilovolts Inlet (KV) (Inlet/Outlet)		41.2/44.4	40.8/43.7	30/34	31/34	32/33	38.2/37.2	37.2/37.8
B Secondary Mill-amps (MA) (Inlet/Outlet)		260/308	240/381	600/560	640/650	640/650	850/940	585/795
C Input Power (AXB) (Kilowatts) (Inlet/Outlet)		10.7/13.7	9.79/16.6	18.0/19.0	19.8/22.1	20.5/21.4	26.5/34.9	21.8/29.3
D Power Density-Watts per 1000 ACFM (Inlet/Outlet)		103/126	90.6/154	128.6/136	141.7/157.9	198.8/208	76.9/101	62.5/84.2
E Power Density-Watts per Ft^2 C.E. (Inlet/Outlet)		.220/.281	.201/.342	.370/.391	.407/.454	.421/.440	.183/.241	.150/.202
F Field Strength-Kilovolts per inch (Inlet/Outlet)		0.87/0.94	0.86/0.92	0.63/0.72	0.65/0.72	0.68/0.70	0.80/0.77	0.77/0.80
G Sparking Intensity/Frequency		——	——	——	——	——	——	——

Notes:
1) Nm^3 = corrected to 0°C. and 760 mm Hg. wet (1 mm H_2O = 0.0736 mm Hg)
2) All tests, unless noted, performed at full boiler steaming load.
3) All efficiency data calculated on basis of dust loadings at standard conditions, not in-situ, in accord with U.S. practice.
4) Precipitator sizing calculated from original metric units . . . recalculations in English units will compound rounding-off errors from unit-conversions.

Múnich North, Unit No. 2					Düsseldorf-Flingern		Stuttgart-Münster			
							Unit No. 28		Unit No. 29	
3	4	5	6	7	1	2	1	2	3	4
Coal (Low Load)	Coal + 40 tph Refuse	Coal + 40 tph Refuse	Coal + 40 tph Refuse	Coal + 40 tph Refuse	Refuse	Refuse	Refuse & Oil	Refuse & Oil	Refuse & Oil	Refuse & Oil
162 @ 150 5720 @ 302	204 @ 170 7200 @ 338	204 @ 170 7200 @ 338	204 @ 170 7200 @ 338	204 @ 170 7200 @ 338	44.0 @ 260 1550 @ 500	44.0 @ 260 1550 @ 500	81.4 @ 210 2870 @ 410	81.4 @ 210 2870 @ 410	81.4 @ 210 2870 @ 410	81.4 @ 210 2870 @ 410
115.4 @ 140 4170 @ 234 244 @ 284	197.6 @ 162 6960 @ 324 418 @ 324	204.2 @ 169 7210 @ 336 432 @ 336	181 @ 163 6390 @ 326 384 @ 326	190.7 @ 164 6740 @ 328 403 @ 328	43.0 @ 235 1520 @ 455 91 @ 455	43.5 @ 242 1535 @ 468 92 @ 468	77.5 @ 191 2740 @ 375 156 @ 375	63.0 @ 191 2220 @ 375 127 @ 375	79.8 @ 183 2820 @ 362 161 @ 362	55.0 @ 182 1940 @ 360 111 @ 360
71.3	96.81	100	88.7	93.5	97.7	98.9	95.2	77.4	98	67.7
5-20 2.19-8.75	5-20 2.19-8.75	5-20 2.19-8.75	5-20 2.19-8.75	5-20 2.19-8.75	9.5 3.94	9.5 3.94	4.25 1.81	4.25 1.81	4.25 1.81	4.25 1.81
2.176 9.51	7.000 3.06	7.000 3.06	7.418 3.24	3.804 1.66	11.0 4.81	13.1 5.69	3.82 1.67	4.18 1.83	3.35 1.47	2.52 1.10
0.0137 0.0060	0.0247 0.0105	0.0115 0.00503	0.0205 0.00896	0.0304 0.0133	0.038 0.0158	0.042 0.0184	0.0385 0.0169	0.0473 0.0207	0.0480 0.0210	0.00646 0.00283
99.55	99.55	99.50	99.72	99.54	98.85	98.95	98.5	99.5	97.9	99.5
99.37	99.65	99.84	99.72	99.20	99.67	99.68	98.22	98.87	98.57	99.74
0.960 3.15	1.21 3.98	1.21 3.98	1.21 3.98	1.21 3.98	1.16 3.82	1.16 3.82	1.12 3.68	1.12 3.68	1.12 3.68	1.12 3.68
0.687 2.26	1.176 3.86	1.215 3.99	1.08 3.53	1.135 3.72	1.14 3.74	1.15 3.77	1.07 3.51	0.869 2.85	1.10 3.61	0.759 2.49
83.33 25.41	66.18 20.18	66.18 20.18	66.18 20.18	66.18 20.18	45.91 14.00	45.91 14.00	39.93 12.17	39.93 12.17	39.33 12.17	39.93 12.17
116.9 35.64	68.32 20.83	66.11 20.16	74.59 22.74	70.79 20.58	46.98 14.32	46.44 14.16	41.94 12.79	51.59 15.73	40.73 12.42	59.09 18.02
0.213	0.268	0.263	0.291	0.267	0.408	0.319	0.328	0.435	0.317	0.435
0.142	0.271	0.319	0.258	0.235	0.399	0.406	0.315	0.285	0.342	0.330
--	32.2/32.6	30.5/32.2	32.2/32.2	32.2/32.8	31.5/29	31/29	--	--	26.5/21.8	26.8/22.4
--	750/720	735/870	600/660	620/684	265/267	313/310	--	--	484/588	503/575
--	24.2/23.5	22.4/28.0	19.3/21.3	20.0/22.4	8.3/7.7	9.7/9.0	--	--	12.8/12.8	13.5/12.9
--	57.8/56.2	51.9/64.8	50.3/55.3	49.5/55.7	91.7/85	105/97.7	--	--	79.7/79.6	121/116
--	.167/.162	.155/.193	.133/.147	.138/.155	.401/.372	.466/.432	--	--	.366/.366	.385/.368
--	0.68/0.69	0.65/0.68	0.68/0.68	0.68/0.69	0.74/0.68	0.73/0.68	--	--	0.61/0.50	0.61/0.51
--	--	--	--	--						

and presumably the highest resistivity values, occur at temperatures below 310 F. Values reported [34] for American refuse fly ash resistivity peak at approximately 425 F, dictating minimum precipitator gas temperatures of 450 F or more. In fact, the first incinerator precipitator installed in the United States are designed for 550 to 650 F operation.

As in the case of low-sulfur coal firing, European experience with electrostatic precipitation of refuse fly ash is not directly applicable to American conditions.

CATALOG OF SYSTEMS

Ten basic systems for firing refuse were synthesized [7, 2] in the assignment. From the standpoint of air pollution control, two very broad categories of system-types were obvious:

a) Those systems that ultimately provided a common or mixed volume of combustion gases for both the refuse and the fossil fuel combustion.

b) Those systems that provided separate flue gas paths for the refuse combustion and fossil fuel combustion products.

An early conclusion of the project was that air pollution control for refuse only was to be limited to high performance control of fly ash – the primary pollutant. In addition to fly ash control, air pollution control of fossil-fuel combustion products was to include sulfur oxide absorption.

With these ground-rules, it is apparent that air pollution control for separated flue-gas type systems [as in b) above] would be more economical, while sulfur oxide control applied to combined flue gases [as in a) above] would treat much larger gas volumes and decreased SO_2 inlet concentrations.

EMISSION CONTROL OBJECTIVES

With the foregoing categories and criteria established, stack emission objectives were developed so that control system performance requirements could be established. Air quality criteria for six large metropolitan areas were projected through 1985. The cities included: Chicago, St. Louis, Philadelphia, New York City, Washington, and New Haven.

Key air pollution control officials of each city were interviewed, then recontacted as successive interviews provided additional inputs. In addition, the federal thrust of air pollution control efforts was analyzed. A most probable scenario was assembled, with primary forcing functions assumed to be federal funding and resultant effects on air pollution control technological development. Classical "S" shaped funding and technology curves were then developed.

The output concluded that ambient air standards would be as given in Table 6.

TABLE 6. AMBIENT STANDARDS (PROJECTED 12/69)

	SO_2 24 hr. Avg. Max. Allow. PPM	SO_2 Annual Mean PPM	Particulate Annual Mean $\mu g/Nm^3$
For the immediate short-term	0.11	0.02-0.03	60-80
By 1985	0.03	0.01	30

It is of interest to note that the short-term standards are indeed close to actual values now established for several Air Quality Control Regions.

A very general indication of the order of magnitude of overall control requirements was then obtained by a comparison of Larsen's studies [40, 41] with the projected air quality standard. This, the final output of this excercise, indicated that approximately 95 percent SO_2 source control would be required to meet 1985 projected standards.

For particulate control, best-demonstrated technology of 99+% collection was evidenced in both domestic utility practice and in European combined fired practice. Thus, 99+% particulate control was concluded applicable, although the effectiveness of this level in meeting the 1985 projections was not considered.

CONTROL TECHNIQUES

As in the earlier case of characterizing the emission problem, the selection of control techniques also considered both domestic utility and European combined-fired practice. Regarding the latter, the state-of-the-art of particulate control is well-developed, with particulate collection efficiencies typically in the 98 to 99+% range. Stack discharges are reported to be optically clear. The motivation for such high-performance fly ash collection is State Regulation VD-2114, November 1966, which limits incinerators of over 20 TPD to a stack emission of 150 mg/Nm^3, which is equal to 0.066 grains/SCF.

The universally employed European fly ash collector is the electrostatic precipitator. No evidence of gaseous emission control is noted. This is concluded to be a result of the typically low sulfur content of both German coal and German refuse.

The result is a notable lack of German national concern for sulfur oxide emissions, in contrast to the American situation.

With respect to domestic utility practice, near-identical conclusions are drawn: the state-of-the-art of particulate control is well developed. Moore [42] shows that technological capability exceeds 99.5 percent collection of fly ash, and that newly installed fly ash collection capacity for coal-fired units averages over 97 percent (1966 data). Little evidence of gaseous emission control is noted. It is concluded that the state-of-the-art of gaseous emission control in the domestic utility industry is not well developed, but is advancing rapidly. The control techniques that hold the greatest promise are the alkaline-based scrubbing systems.

Three generic particulate collectors were evaluated–fabric filters, precipitators, and scrubbers. Using lined/stainless construction, the installed cost of scrubbers was nearly equivalent to that of conventional, mild-steel, electrostatic precipitators, while fabric filters were more expensive. When the required pressure drops, liquor, and pumping costs were analyzed, the precipitator evolved as the more cost-effective solution for either separate or combined flue gas paths, or for either refuse-only fly ash, or combined-firing fly ash. This evaluation did not assign coincidental value to scrubbers or fabric filters as SO_2 contractors. Since values approaching 95 percent SO_2 removal had never been reported for these devices, it was deemed necessary to use absorption towers.

Electrostatic precipitators for 99 percent collection efficiencies were then applied as particulate collectors, followed by alkaline absorption of SO_2 for the fossil-fuel combustion gases.

Technological constraints (in 1966) precluded detailed engineering of such SO_2 control techniques. In fact, the basis of the decision to specify wet absorption by alkaline liquors was largely founded in the fact that technology was evolving the most rapidly on this general category of system types. While the report leaves open the area of SO_2 chemistry, it can be assumed that either magnesium, calcium, or sodium based liquors would be applicable.

CONCLUSIONS

The broad conclusions of the study are that refuse can be used as a fuel to generate steam for power, and that refuse or combined-fired systems can be readily controlled to acceptable limits with largely demonstrated technology.

The study also concluded that the national SO_2 problem could be somewhat alleviated by the ultilization of refuse as a low sulfur fuel. However, order of magnitude reductions in the SO_2 problem are in order, but are not forthcoming merely from refuse utilization. Perhaps a more significant rationale for the use of refuse as a fuel is the cost-effectiveness of such use as a means of solving the national solid waste disposal problem, while preserving the quality of our air resources.

While European air pollution control experience is not directly applicable to American conditions, much can be learned from their enormous successes.

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