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Project Summary

Assessment of Energy Recovery Potential of Industrial Combustion Equipment

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An assessment was conducted to evaluate the waste heat content and energy recovery potential of flue gases from 30 industrial combustion devices. Pollution controls on nine of the devices were evaluated to estimate energy requirements and particulate reduction; energy requirements were compared with incremental emissions at electric utilities supplying power for the pollution controls. Metal processing furnaces had the highest waste heat content in the exhaust gas (57%–86% of fuel heat input). The remaining devices and waste heat content range were: Internal Combustion Engines (21 and 38%), Mineral Kilns (11–55%), Petroleum Process Heaters (14–38%), Boilers (10–41%), and Gas Turbine Combined Cycles (15 and 16%). Energy recovery by combustion air preheat, process heat utilization, or heat engine cycles was evaluated on a preliminary basis and appears to be practical for many of the devices. Energy requirements for particulate emissions control were found to be less than 2.0 percent of heat input. The recoverable energy exceeded pollution control energy in seven of nine cases by a ratio of from 2 to 49. The particulate reduction on a mass basis at the industrial facilities ranged from 7.3 to 23,000 times the incremental mass of total emissions generated at electric utilities supplying power to operate the control equipment.

This Project Summary was developed by EPA's Hazardous Waste Engineering Research Laboratory, Cincinnati, OH, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

The purpose of this study was to determine the energy recovery potential and pollution control energy consumption of industrial combustion devices for which site-specific operation data had been previously gathered in two other EPA projects. The study results are intended to serve as specific examples of energy usage and waste heat recovery potential of these boilers and process units. It is not intended that quantitative conclusions that are generally applicable throughout the industry could be reached by this study.

The project scope incompassed combustion and emissions data from industrial combustion devices tested under EPA Contracts 68-02-2144 and 68-02-2645. These devices consisted of petroleum process heaters, mineral kilns, metal processing furnaces, boilers operating with unconventional fuels, internal combustion engines and gas turbine cycles.

The full report considers waste heat recovery for three purposes: (1) combustion air preheat, (2) process heat, and (3) heat engine operation. The analysis determined the amount of energy recoverable for each purpose, the capital cost of waste heat recovery, cost benefits due to fuel savings and ex-

Table 1. *Combustion Device Summary*

Combustion Device	Location/ Unit-Test*	Fuel	Heat Input, MW	Stack Temp., °K	Pollution Control
Petroleum Process					
Heaters	4-4	Gas/Oil	30.9	550	No
(Natural Draft)	4-6	Refinery Gas (RG)	31.1	557	No
	5/1	RG	18.5	478	No
	5/2	RG	10.1	481	No
	7/1	RG	15.5	592	No
	7/2	RG	15.1	780	No
	7 (2645)*	Natural Gas (NG)	15.9	693	No
	7 (2645)*	NG/No. 6 Oil	14.3	687	No
(Forced Draft)	12/1-1	RG	22.5	396†	No
	12/1-8	RG/No. 6 Oil	22.5	398†	No
	12/2-1	RG	10.2	563	No
	12/2-2	No. 6 Oil	10.2	556	No
Mineral Kilns					
Clay	1-1	NG	12.4	330†	No
Cement	3-2	Coke	69.9	558†	Multicyclone and Baghouse
Cement	9-1A	NG	61.4	422†	Electrostatic Precipitator
Cement	9 (2645)*	Coal	57.1	494†	No
Lime	6 (2645)*	No. 6	15.6	527†	No
Metal Processing Furnaces					
Aluminum	6-1	Natural Gas (NG)	6.5	1211	No
Aluminum	6-3	No. 2 Oil	7.1	1208	No
Steel OH	14-1	NG/No. 6 Oil	30.3	550†	Electrostatic Precipitator
Steel Reheat	16/1-17	NG	24.6	730	No
Steel Soaking Pit	16/2-1	NG	2.3	1583	No
Boilers	10/1-1	Wood/NG	75.3	533†	Multicyclone and Venturi Scrubber
	10/2-2	Black Liquor	140.3	425†	Electrostatic Precipitator
	13-6	Wood/Coal	25.5	478†	Multicyclone
	11-1	CO/RG	94.9	589	Multicyclone
	19-53	No. 2	5.0	543	No
	19-97	No. 6	5.8	527	No
	19-181	NG	5.7	538	No
	200-G-2	NG	11.7	496†	No
	200-24	No. 6	11.2	491†	No
	3 (2645)*	Wood/Coal	29.4	489†	Multicyclone
	5 (2645)*	Wood/Oil	78.0	513†	Multicyclone and Venturi Scrubber
Internal Combustion	2-1	NG	3.2	622	No
Engines	15-1	No. 2 Oil	1.3	475	No
Gas Turbine	7/3-1	Refinery Gas (RG)	202	456	No
Combined Cycles	8-1	RG	519.9	499	No

**(2645) indicates devices tested under Contract 68-02-2645, remaining were tested under Contract 68-02-2144.*
†This combustion device has an existing heat recovery unit.

istance of a demand for that form of recovered energy at the site.

The study also determined the energy consumption by air pollution control technologies used on the combustion units. A comparison was made between this energy demand and the waste heat recoverable from each unit. In addition, the amount of air pollutants produced by an electric power plant in order to power each industrial pollution control device was compared with the reduction in emissions which that device achieved, in order to determine whether industrial pollution control was effectively reducing national emissions.

Study Limitations

The analyses reported are first order estimates of the cost-effectiveness of waste heat recovery techniques and of pollution control equipment. Because of this and because the report reflects a small sample of industrial combustion units, the results should only be used as an indication of which combustion devices are most likely to show benefits from waste heat recovery. Because there are many site-specific factors which can influence the cost-effectiveness of waste heat recovery, every combustion unit should be considered on its own merits. The assessments of pollution control energy consumption and emissions reduction were based on more limited data and had to be supplemented in some cases with estimates. As a result, the control technology analysis had a higher degree of uncertainty than the analysis of waste gas energy recovery.

Units Analyzed

Table 1 summarizes the combustion units which were field tested, showing the fuels they used, heat input and stack gas temperatures. The pollution control devices in use at the facilities are indicated. Column two shows the units location and the test run during which the data were collected, as discussed in full in the project report.

The test units were chosen because they were determined to be representative of those commonly employed by industry as of 1980. This determination was made from existing data and from contacts with manufacturers and trade associations. In addition, emphasis was placed upon selecting units within industries that are most significant in terms of national emissions of criteria pollutants and in terms of energy consumption. As a result, energy conservation at these sites have the potential for significantly reducing air pollution.

Analysis Procedure

The waste heat content of the exhaust gas was determined with reference to 298 K (77°F) with moisture in the flue gas condensed. Each combustion devise was examined to determine if exhaust gas energy recovery is practical, what recovery methods might be employed and the percentage of energy recovery that should be achievable. For combustion air preheat and process heat utilization an exhaust gas temperature of 400 K (260°F) was assumed, based on conservative application of limits recommended by a major heat recovery equipment manufacturer[1] and an assessment of the units already equipped with heat recovery that were included in this study. For heat engines a minimum inlet flue gas temperature of 533 K (500°F) and an exhaust gas temperature from the heat engine itself of 416 K (290°F) were taken as typical, as there is no ambient cold fluid input to the energy recovery system and the cold-end corrosion problem is less severe.

In all cases the lower limit of recoverable energy was taken to be 0.5 megawatts (MW), as this was considered a reasonable value to warrant capital expenditures.

The influence of economics and potential for utilizing the recovered energy were also analyzed. Installed costs for waste heat recovery technologies and the fuel savings that they should achieve were projected through simple first-order estimates and presented to show the relative economic merits rather than a complete return on investment. The potential for waste heat utilization (e.g., demand for steam at the facility) was also determined from information on other process units at each industrial site.

The operating energy requirements for the pollution control devices were estimated. These consisted of the direct energy consumption due to the pressure drop across the device and the peripheral equipment energy requirement associated with pumps, waste removal and disposal.

The emissions reductions were calculated by measuring flue gas particulate concentrations either upstream or downstream of the control device and then estimating device efficiency. The reduction in pollutants at the site was compared with the emissions generated at a power plant due to the electrical energy requirement of the control device.

Findings

Metal processing furnaces had the highest heat content in the exhaust gas (57-86% of fuel input). The remaining units and waste heat content ranges were: internal combustion engines (21 and 38%), mineral kilns (11-55%), petroleum process heaters (14-38%), boilers (10-41%) and gas turbine combined cycles (15 and 16%). Heat recovery by combustion air preheat and process heat utilization were found to be practical for many devices, but heat engine cycles had much less potential. Details on amounts of recoverable energy are provided in Table 2. Cost savings and potential for waste heat utilization are discussed in the project report.

Energy requirements for particulate emissions control were found to be less than 2.0 percent of heat input. The particulate reduction on a mass basis at the industrial facility ranged from 7 to 23,000 times the emissions from a thermal power plant which generated the electricity to operate the control technology equipment. The energy recovery potential exceeded pollution control energy in seven of nine cases by a ratio of from 2 to 49.

Conclusions

Based on the analysis of this limited number of units, the following conclusions regarding the potential for energy recovery of stack gas waste heat can be drawn.

1) Stack gas temperatures are sufficiently high (up to 1583 K) on many industrial devices to provide good potential for energy recovery.
2) Some industrial devices have little potential for energy recovery due either to low stack gas temperatures or low gas flow rates.
3) Where stack gas energy recovery appears feasible, the recovery potential ranges from 1.4 to 76 percent of the fuel heat input, dependent on stack temperatures and recovery method.
4) Metal processing furnaces provide the best potential for energy recovery, ranging from 34 percent to 76 percent of fuel heat input.
5) Internal combustion engines and gas turbine combined cycles appear to have the least potential for energy recovery.
6) Recovery of waste heat by process hot water or steam appears to offer the highest potential for energy recovery.
7) Combustion air preheat appears somewhat less favorable compared to process heat but is frequently employed because it does not require an external process in which to absorb the recovered heat.
8) Thermodynamic heat engine cycles do not appear favorable compared to process heat or air preheat.

The following conclusions were drawn with regard to the pollution control device effectiveness and energy penalty for the units examined:

1) The emissions reduced at industrial plants are considerably greater than the emissions generated at power plants to operate the control equipment.
2) The energy recovery potential at industrial plants was considerably greater than the energy requirement for most pollution control devices.

Recommendations

As a result of this study, further research should be considered in the following areas.

1) Application of waste heat recovery on metal processing furnaces as this has the greatest potential for energy efficiency improvement.
2) Use of process heat as an option for waste heat recovery as compared with combustion air preheating, with emphasis on the petroleum industry.
3) Comparison of the results of this study with other studies of industrial energy use to improve the assessment of nationwide potential for industrial energy recovery.
4) Expansion of the study of pollution control energy to include SO_X removal equipment and additional particulate removal sites.

[1]Sales literature from the C-E Air Preheater Company, Wellsville, New York.

Table 2. Summary of Waste Energy Recovery Analysis

Combustion Device	Location/ Unit - Test	Fuel*	Fuel Heat Input, MW	Stack Temp., K	Waste Heat Content, %	Technically Applicable Energy Recovery Techniques Recoverable Energy, MW		
						Air Preheat	Process Heat	Heat Engine
Petroleum Process Heaters	4	Gas/Oil	30.9	550	24.3	2.1	2.4	(0.5)
(Natural Draft)	4	RG	31.1	557	24.1	2.2	2.3	(0.5)
	5/1	RG	18.5	478	20.5	0.7	0.7	--
	5/2	RG	10.1	481	13.9	(0.3)	(0.3)	--
	7/1	RG	15.5	592	27.1	1.4	1.7	(0.3)
	7/2	RG	15.1	780	38.4	2.5	3.3	0.7
	7 (2645)	NG	15.9	693	25.2	1.8	2.2	(0.5)
	7 (2645)	NG/No. 6	14.3	687	23.5	1.6	2.0	(0.4)
(Forced Draft)	12/1-1	RG	22.5	606	20.4	2.8**	1.9	(0.4)
	12/1-8	RG/No. 6	22.5	546	16.0	3.1**	1.4	(0.3)
	12/2-1	RG	10.2	563	35.3	0.6	0.9	(0.2)
	12/2-2	No. 6	10.2	556	20.6	0.7	0.8	(0.2)
Mineral Kilns								
Clay	1-1	NG	12.4	300	11.3	--	--	--
Cement, Dry Process	3-2	Coke/NG	68.9	558	12.9	--	3.2	0.6
Cement, Wet Process	9-1A	NG	61.4	422	55.0	--	0.9	--
Cement, Wet Process	9 (2645)	Coal	57.1	455	45.7	--	2.2	--
Lime	6 (2645)	No. 6	15.6	527	18.8	--	1.4	--
Metal Processing Furnaces								
Aluminum Melter	6-1	NG	6.5	1211	60.6	1.5	2.8	0.6
Aluminum Melter	6-3	No. 2	7.1	1208	61.5	2.2	3.4	0.7
Steel Open Hearth	14-1	NG/No. 6	30.3	550	60.0	--	--	--
Steel Reheat	16/1-17	NG	24.6	730	56.8	2.6	8.4	1.8
Steel Soaking Pit	16/2-7	NG	2.3	1583	86.3	1.0	1.7	0.4
Boilers	10/1-1	Wood/NG	75.3	533	40.9	6.5	7.5	--
	10/2-2	Blk Liq.	140.3	425	23.4	--	--	--
	13-6	Wood/Coal	25.5	478	22.4	1.1	1.2	--
	11-1	CO/RG	94.9	589	51.0	6.1	16.7	3.4
	19-53	No. 2	5.0	543	23.5	(0.3)	(0.3)	(0.1)
	19-97	No. 6	5.8	527	15.1	(0.3)	(0.3)	--
	19-181	NG	5.7	538	24.8	(0.3)	(0.3)	(0.1)
	200-G-2	NG	11.7	496	10.2	(0.5)	(0.4)	--
	200-24	No. 6	11.2	491	12.9	0.6	(0.4)	--
	3 (2645)	Wood/Coal	29.4	489	17.1	1.3	1.5	--
	5 (2645)	Wood/Oil	78.0	513	19.5	6.6	4.9	--
Internal Combustion Engine	2-1	NG	3.2	622	38.2	--	(<0.5)	(<0.5)
	15-1	No. 2	1.3	475	21.4	--	(<0.5)	--
Gas Turbine	7/3-1	RG	202	456	15.3	--	4.3	--
Combined Cycles	8-1	RG	519.9	499	16.1	--	17.4	--

*RG = Refinery Gas, NG = Natural Gas, Blk Liq. = Black Liquor, CO = Carbon Monoxide.
( ) = Recoverable energy less than 0.5 MW.
-- = Temperatures too low for recovery.
** = This heat recovery method is an existing installation.

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The complete report, entitled "Assessment of Energy Recovery Potential of Industrial Combustion Equipment," (Order No. PB 85-245 959/AS; Cost: $11.95, subject to change) will be available only from:
National Technical Information Service
5285 Port Royal Road
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