OPERATING PARAMETERS
Reliable Means to Continuously Monitor Facility Performance

RICHARD SCHERRER
Ogden Martin Systems, Inc.
Fairfield, New Jersey

ABSTRACT

Energy sales are a major source of revenues for modern mass-burn waste-to-energy facilities. Due to the heterogeneous nature of the fuel, the heat input and the resulting energy output may vary over a wide range. Since continuous testing of the fuel heating value is impractical, another method must be used to determine that the facility is being operated in an efficient manner. Monitoring of specific parameters that bear directly on operating performance will ensure that the facility is continuously operated at the highest achievable efficiency for any fuel composition.

The paper presents an analysis of the appropriate application of operating parameters and describes the contract principles as established in several recent Resource Recovery Service Contracts that assure the recipient of the energy revenues of maximum income and provide a just means to establish penalties for operator inefficiency or nonperformance.

INTRODUCTION

Modern mass-burn resource recovery facilities provide an efficient, environmentally acceptable, but not inexpensive way to help dispose of an ever-increasing amount of municipal and commercial solid waste. To cover the costs of amortization, operation and maintenance of a facility there are generally only two major sources of revenues available. Tipping fees (or user fees) and revenues from the sale of energy in the form of electric power or steam. Other income, such as may be obtained from secondary materials recovery sales, is comparatively small and often unpredictable. Income from the sale of energy is the dominant controllable revenue stream, while tipping fees are used to fill the gap between total costs and energy revenues. The formula:

Tipping Fee = Cost − Energy and Materials Recovery Revenue(s)

makes it clear that any improvement or maximization of the revenue stream results in a lower tipping fee because operation and maintenance costs and debt service are predetermined and constant except for escalation. Since the unit value of the energy stream ($/kWh or $/1000 lb steam) is established through long-term contracts with the energy user(s), maximization of the quantity of energy is critical to maximize energy revenues. The quantity of the recovered energy is dependent on the heating value of the solid waste fuel and the combustion and heat cycle efficiencies.

FACILITY EFFICIENCIES

The heating value inherent in the solid waste fuel is beyond the control of the facility operator. Since it is, for all practical purposes, impossible to accurately monitor a constantly varying fuel heating value on a continuous basis, other means to determine that the facility is operated at optimal efficiency levels must be found. Two connected, but relatively unrelated facility process cycles, the combustion cycle and the thermal cycle, must be monitored for efficient operation. The combustion cycle includes the combustion of the fuel with the aid of oxygen in the combustion air, creating a hot flue gas and ash. The heat in the flue gas is recovered in a steam generator (boiler). This steam then circulates through the thermal cycle where it drives a turbine generator. Some of the steam is used for plant internal services, such as condensate and boiler feedwater heating, etc. Most of the steam is condensed and reintroduced into the boiler. Make-up feedwater is added to cover losses due to boiler blowdown and sootblowing. A simplified illustration of the two cycles can be found in Fig. 1.

Let us look at the definition of efficiency for each cycle:

(a) Combustion Cycle (Boiler Efficiency) (per ASME PTC 4.1)

$$\text{Efficiency} = 1 - \frac{\text{Heat Losses}}{\text{Energy Input} + \text{Heat Credits}}$$

			% of Total (Typical)
Heat Losses	=	Dry flue gas losses	12
		+ Moisture loss in flue gas	14
		+ Latent heat in residue	0.2
		+ Losses due to combustibles in residue	0.5–1.5
		+ Radiation losses	0.5
		+ Manufacturers margin or losses unaccounted for	0–1.5
Energy Input	=	Chemical heat in fuel	98–99
Heat Credits	=	Heat in combustion air	0–1.5
		Latent heat in fuel, others	0–0.5

As indicated in the above illustration, boiler efficiency depends primarily on flue gas losses, which in turn are a direct result of the combustion process. It should be noted that flue gas losses in refuse incinerators are approximately twice as high as those found in most fossil fuel burning boilers. The main reasons are a high moisture content in the fuel and high excess air rates of approximately 90–110%. The amount of moisture in the fuel is beyond the operator's control and can not easily be measured, but the amount of excess air is controlled by the operator and measured continuously as oxygen concentration in the flue gas. A further measurement relating to the efficiency of the combustion process is the amount of carbon monoxide (CO) which indicates the degree of combustion of volatile organic compounds. In addition, CO levels are regulated by environmental permit conditions and measured continuously. Several states' air quality permits require a 99.8% or higher combustion efficiency which is defined as:

$$\frac{CO_2}{CO_2 + CO} \times 100$$

Dry flue gas losses are mainly the result of the flue gas temperature at the exit of the steam generating equipment, e.g., economizer.

Flue gas moisture losses stem from moisture in the fuel and combustion air and from hydrogen in the fuel. These factors are beyond the operator's control and therefore can not be effected by inefficient operating practices. Also it is at present not possible to continuously and accurately measure the flue gas moisture content.

(b) Thermal Cycle Efficiency

$$\text{Efficiency} = \frac{\text{Net energy from power generator}}{\text{Energy in steam from boiler to turbine}}$$

While the overall thermal cycle of the facility can be rather complicated, it is controlled and kept in balance automatically. It is also to a large extent dependent on inherent efficiencies of equipment that will not change due to operator influence. There are, however, impacts possible due to operator negligence. If the operator fails to operate the steam condensing system and its associated cooling system efficiently (e.g., not enough fan cooling in the case of either a forced draft cooling tower or an air-cooled condenser) the turbine backpressure (vacuum) will deteriorate and energy efficiency will decline. Using manufacturer provided efficiency curves for the condensing and cooling equipment, a comparison of ambient conditions and achievable performance can be made and checked against the actual performance.

OPERATING PARAMETERS

Several parameters of the combustion process and thermal cycle indicate if a facility is operated efficiently. Those parameters that can easily be monitored on a

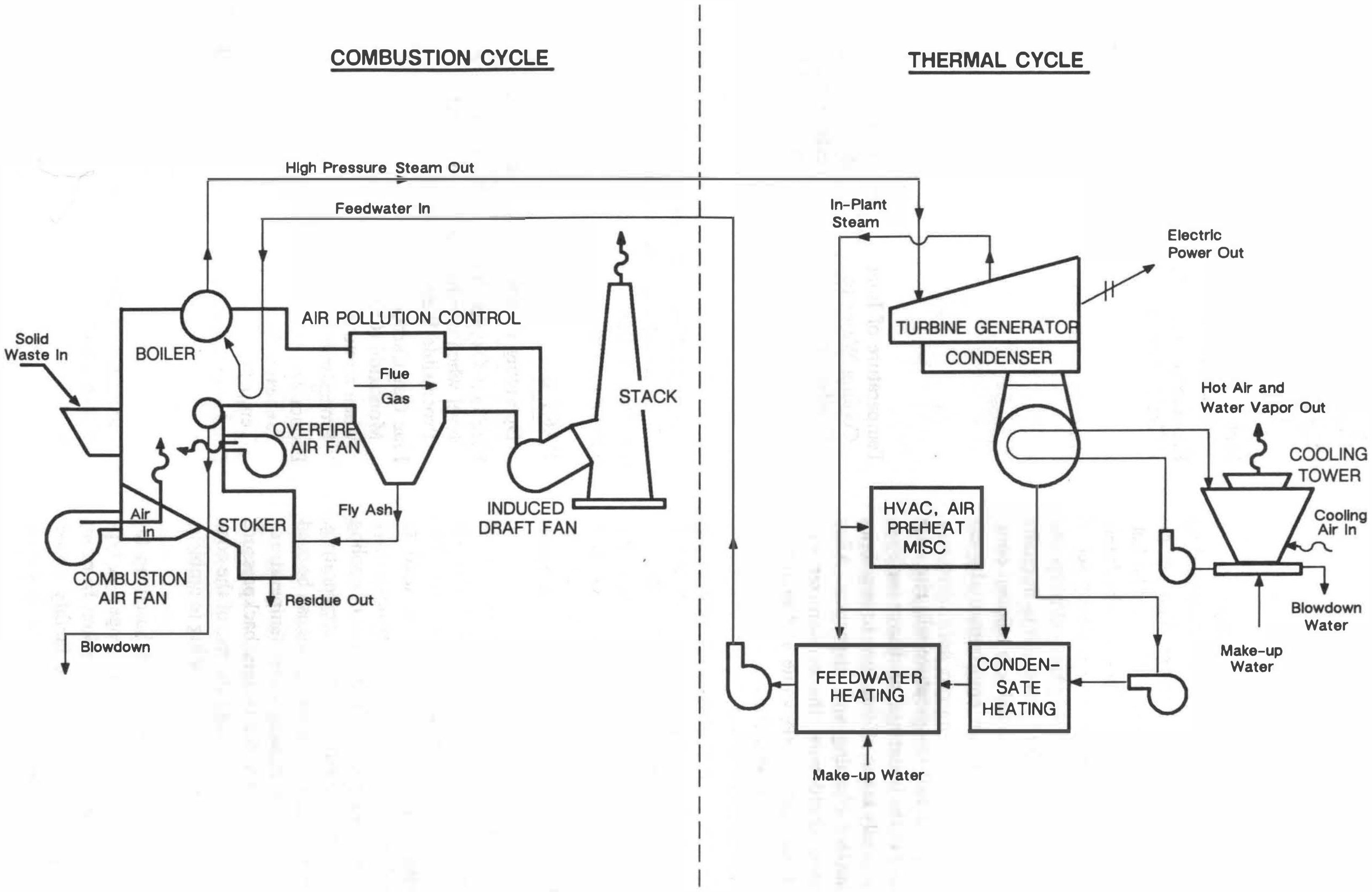

FIG. 1 SIMPLIFIED RESOURCE RECOVERY FACILITY CYCLE DIAGRAM

continuous basis with readily available plant instrumentation are:

(a) Economizer exit temperature.
(b) Oxygen (O_2) in flue gas.
(c) Carbon Monoxide (CO) in flue gas.
(d) Turbine exhaust pressure.
(e) Cooling water temperature (if applicable).

A set value of these parameters can be determined by using facility design data. These design data are established by engineering calculation. Due to the heterogeneous nature of refuse as a fuel, an absolutely steady combustion and adherence to a steady set of parameters can not be achieved for practical purposes. The operating parameters must be allowed to fluctuate within certain limits not only to achieve efficient combustion but also to do so in an environmentally acceptable manner.

(a) The economizer exit temperature will rise over time due to fouling of the boiler heat exchange surfaces. Boilers are periodically taken off line (one to two times per year) for surface cleaning and inspection. After these maintenance shutdowns, the economizer exit temperature will be again at set value and gradually start to rise until the next shutdown.

(b) Oxygen will fluctuate with a change in fuel composition and with the need to increase excess air for fuels with an elevated heating value to accomplish complete combustion of the volatile compounds.

(c) Carbon monoxide will fluctuate as well, but rather than establishing a range it is more practical to determine an absolute maximum value. This value can never be greater than air quality permit conditions allow.

(d) Turbine exhaust pressure can be established within a narrow range to the upside and is only dependent on load and cooling water temperature. Condenser manufacturer design curves can be used to determine set values for turbine back pressure.

(e) Cooling water temperature is a result of cooling tower operation and ambient wet bulb temperature. Cooling tower manufacturers design curves can be used to establish set values for cooling water temperature.

For air cooled condensers, the turbine backpressure will be established directly through the use of the condenser manufacturer's design curve relating to ambient dry bulb temperature.

Operating parameters are established based on facility design data and tolerance levels (range). A typical listing of operating parameters as taken from an existing Service Contract between the facility owner and the design, build and operate contractor is shown hereafter:

PART A

Operating Parameter	Tolerance Level
Flue Gas Oxygen (O_2) level	+1.5% of Company's Operating Condition (daily average)
Flue Gas Carbon Monoxide (CO) level	200 ppm (daily average)
Economizer Exit Flue Gas Temperature	Company's Minimum Operating Conditions + 75°F (daily average)
Condenser Vacuum	+0.5 in. Hg of Condenser manufacturer's rated performance as determined from performance curve supplied by Company (daily average)
Temperature of Inlet Cooling Water to Condenser	+5°F of Cooling Tower Manufacturer's rated performance as determined from performance curve supplied by Company (daily average)

The Operating Conditions for each of the parameters shall be as set forth in Part B. The tolerance levels identified in Part A will then be applied to those Operating Conditions.

PART B

Operating Parameter	Operating Condition
Flue Gas Oxygen (O_2) level when combusting Processible Waste	9% (wet flue gas) (daily average)
Flue Gas Carbon Monoxide (CO) level when combusting Processible Waste	200 ppm (daily average)
Economizer or Air Preheater Exit Temperature	430°F (daily average)
Condenser Vacuum	As shown on condenser performance curve (to be supplied by vendor of condenser)
Temperature of Inlet Cooling Water to Condenser	As shown on cooling tower performance curve (to be supplied by cooling tower vendor)

To understand the impact of the tolerance levels assigned to each parameter on overall facility performance we shall examine each parameter individually. For this purpose we assume that all other parameters are kept at the set position with zero tolerance level. Corresponding energy output of the facility is presented in kWh/ton of refuse, net for sale. The following example is based on the assumption that refuse with a higher heating value of 5000 Btu/lb (2778 kcal/kg) is processed.

Operating Parameter	Tolerance Level	Energy Output, net	
		(kWh/ton)	% Difference
Flue Gas Oxygen:	9%	590	
	10.5%	575	2.5
Carbon Monoxide:	No influence on energy output since no tolerance level allowed		
Economizer Exit Temperature:	430°F (221°C)	590	
	505°F (263°C)	560	5.1
Condenser Vacuum:	2.5 in. Hg abs. (64 mm Hg abs.)	590	
	3 in. Hg abs. (76 mm Hg abs.)	580	1.7
Cooling Water Temperature:	80°F (27°C)	590	
	85°F (30°C)	580	1.7

A very unlikely, but possible worst case scenario would occur if all operating parameters would happen to be at the extreme tolerance level. This case would impact net energy for sale as follows:

O_2	9%	10.5%
CO	200 ppm	200 ppm
Economizer Exit Temp.	430°F	505°F
Condenser Vacuum	2.5 in. Hg abs.	3 in. Hg abs.
Cooling Water Temp.	80°F	85°F
KWh/ton	590	540

This is a drop of 8.5% in energy output or expressed as range from average energy output:

565 ± 25 kWh/ton (±4.4%)

Actual, real world experience from operating plants indicates however that such fluctuations will be approximately ±2% or less.

This is a highly acceptable range of accuracy, especially when the nature of the fuel is taken into consideration. It beats any approximations to establish the heating value of the fuel by a large margin, and it does not rely on assumptions, but uses solely readily available facility instrumentation.

CONTRACTUAL ARRANGEMENTS

Although operating contracts, or Service Agreements as they are more commonly called, are drafted to the specific needs of each project, there is some standardization recognizable for the technical part of the agreements. Performance guarantees and testing procedures are straightforward and generally follow established outlines. Since operating parameters are also of a technical nature, their specifications should not cause any problems.

Operating parameters in Service Agreements are used to establish a clear guideline for the community to determine if any penalty payments are due by the operator for lack of efficient plant operation with a resultant shortage of energy sales.

To determine deficiencies, energy output is measured throughout the year. The year's total energy output is compared to the annual energy recovery guarantee in kilowatt hours per ton multiplied by the tons of acceptable waste processed. The annual energy recovery guarantee is by its very nature different from the acceptance or performance test guarantee. The test guarantee is linked to a specific fuel heating value. During a test, the actual heating value is determined and the actual energy output is accordingly adjusted. On the other hand the annual guarantee is based on an expected average heating value and takes into account such variables as maintenance shutdowns, change in ambient conditions, boiler start-ups and shutdowns, operations at reduced loads, etc.

If there is an energy shortfall in a given year, then the records of the operating parameters are researched to determine the days of noncompliance. For these days, the actual shortfall in energy output is used to determine payment of energy shortfall penalties.

A good energy revenue sharing program is, however, still the best way to encourage the operator to perform regular preventive maintenance and operate the plant at its highest achievable energy efficiency level. Such revenue sharing generally lets the operator keep 10–

20% of the energy revenues as part of his remuneration.

Should any of the contracting parties feel that the plant might have deficiencies, the fuel might be outside of the contractually agreed upon range or that any other irregularities exist, a formal performance test can be called at any time. It is generally agreed that the party who is at fault pays for the test or if the test shows that no deficiencies exist, the party who called the test pays for it.

CONCLUSION

Operating parameters are a meaningful tool to observe if the daily operation of a waste-to-energy facility is carried out in a fashion that produces the highest achievable combustion and energy recovery efficiencies.

The application of the operating parameters principle in Service Agreements allows for an easy determination of energy shortfall penalties.