National Environment Agency Singapore

Measurement & Verification of Heating Systems

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1 Boiler System

Boilers are defined as vessels or tanks in which heat produced from the combustion of fuels such as natural gas, fuel oil, wood, or coal is used to generate hot water or steam for applications ranging from building space heating to electric power production or industrial process heat.

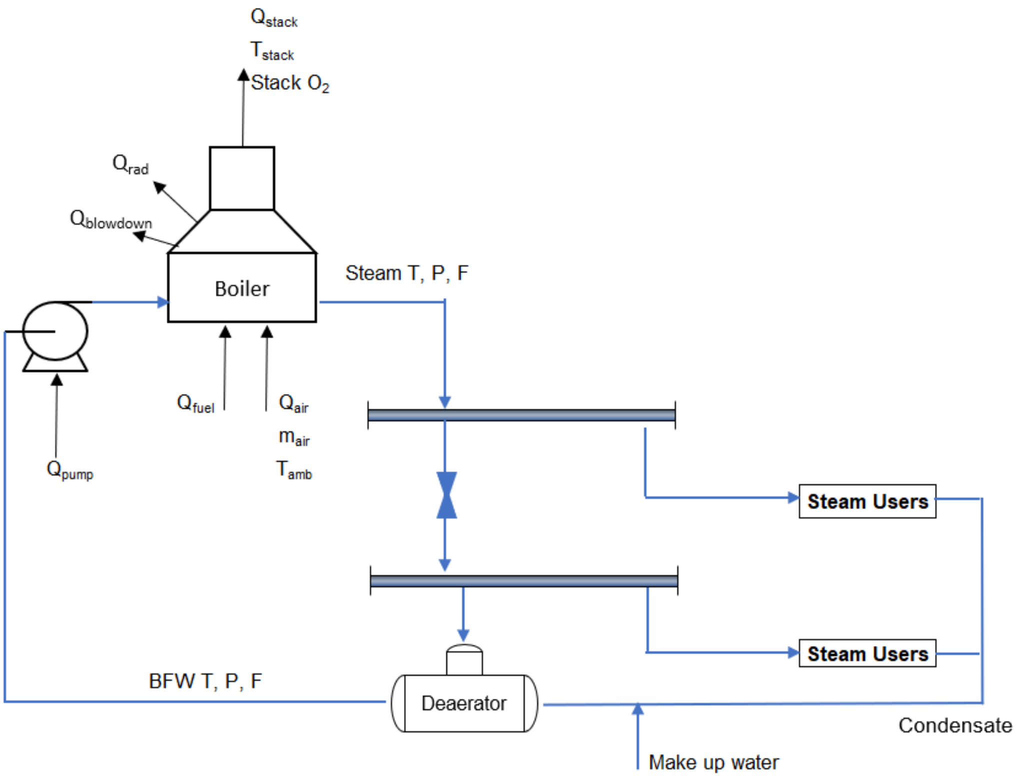

Figure 1: Main considerations for assessing the performance of boiler systems

Table 1: Key energy metrics for boiler systems

Energy System	Hierarchy	Metric	Method
Boiler equipment only	Energy performance indicator	Thermal efficiency (%)	Calculated
	Energy influencing variable	Stack temperature (°C)	Measured
	Energy influencing variable	Stack oxygen (%)	Measured
	Energy influencing variable	Steam flow (t/h)	Measured
General steam and condensate system	Energy performance indicator	BFW pump specific energy consumption (kW/unit throughput)	Calculated
	Energy influencing indicator	Condensate recovery (%)	Calculated
	Energy influencing variable	Deaerator pressure	Measured

Energy performance indicators: these are calculated values that allow the management and engineering team to track the overall performance of an equipment, process or even the whole site.

Energy influencing variables: these items represent elements within the system that can be manipulated to improve the efficiency of the equipment or process.

Figure 1 shows a schematic diagram of a typical boiler system. Table 1 shows a list of key metrics for a boiler system.

This measurement and verification (M&V) plan serves to outline the methodology for quantifying the energy improvement before and after the implementation of energy conservation measures relating to the boiler system.

2 Assessment of Baseline Energy Performance

2.1 Boiler thermal efficiency

The thermal efficiency of the boiler can be computed using the following methodology.

$$Heat\ Input = m_{fuel} \times LHV_{fuel} \qquad \textit{Eqn. 1}$$

$$Useful\ Heat\ Output_{baseline} = m_{steam} \times (H_{steam} - H_{BFW}) \qquad \textit{Eqn. 2}$$

$$E_{baseline} = \frac{Useful\ Heat\ Output_{baseline}}{Heat\ Input} \times 100\% \qquad \textit{Eqn. 3}$$

Where:

$E_{baseline}$	:	Baseline thermal efficiency of boiler (%)
Heat Input	:	Fired duty of boiler (MJ/h)
Useful Heat $Output_{baseline}$	:	Useful heat absorbed by BFW (MJ/h)
m_{fuel}	:	Mass flow rate of fuel (t/h)
m_{steam}	:	Mass flow rate of steam (t/h)
H_{steam}	:	Enthalpy value of steam (kJ/kg)
H_{BFW}	:	Enthalpy value of BFW (kJ/kg)
LHV_{fuel}	:	Lower heating value of fuel (kJ/kg)

Note: If the boiler has an air preheater that uses an external heat source, the heat duty of the preheater should be included as heat input into the boiler and so added to Eqn 1. If the air preheater uses only stack gases, this is not necessary as the air preheater is recovering energy from the boiler itself.

2.2 BFW pump specific energy consumption

The power consumption of pumps can be determined by one of the following methods

- Use of readings from existing power meters

  Power consumption of pumps can be measured through the use of existing power meters or ammeters. If power meters are available, then power consumption information will be available for applying *Eqn. 4* below.

- Plot baseline operation on the pump curve

  Using the operating flow data of the pump, the pump curve can be used to determine the pump power consumption.

Specific energy consumption (SEC) of a pump can be computed by the following formula.

$$SEC_{baseline} = \frac{Pump\ Power_{baseline}}{Unit\ throughput} \quad \textit{Eqn. 4}$$

Where:

$SEC_{baseline}$	:	Baseline specific energy consumption of pump (kWh/t)
Pump $Power_{baseline}$	:	Baseline power consumption of pump (kW)
Unit $throughput_{baseline}$	:	Baseline pump fluid flow rate (t/h)

3 Assessment of Post-Implementation Energy Performance

The assessment of post-implementation energy performance of boiler follows the same approach as detailed in Section 2 above.

4 Quantification of Energy Performance Improvement and Cost Savings

Energy performance improvements to the boiler efficiency can be quantified as follow.

$$Energy\ performance\ improvement$$
$$= Useful\ Heat\ Output_{post} \times \left(\frac{1}{E_{baseline}} - \frac{1}{E_{post}}\right)$$ Eqn. 5

$$Annual\ energy\ performance\ improvement$$
$$= Energy\ performance\ improvement \times Op\ hrs$$ Eqn. 6

$$Annual\ cost\ savings$$
$$= Annual\ energy\ performance\ improvement \times Fuel\ cost$$ Eqn. 7

Where:

E_{post}	:	Post-implementation thermal efficiency of boiler (%)
Useful heat output$_{post}$	:	Post-implementation useful heat absorbed by BFW (MJ/h)
Op hrs	:	Number of operating hours in a year (hrs/yr)
Energy performance improvement	:	Energy performance improved compared to baseline (MJ/h)
Annual energy performance improvement	:	Energy performance improved for a year (MJ/yr)
Fuel cost	:	Cost of fuel (SGD/MJ)
Annual cost savings	:	Cost savings in a year (SGD/yr)

Pump energy performance improvements can be computed as follow.

$$Pump\ energy\ performance\ improvement$$ Eqn. 8
$$= Unit\ throughput_{post} \times \left(SEC_{baseline} - SEC_{post}\right)$$

$$Annual\ energy\ performance\ improvement$$ Eqn. 9
$$= Pump\ energy\ performance\ improvement \times Op\ hrs$$

$$Annual\ cost\ savings$$ Eqn. 10
$$= Annual\ energy\ performance\ improvement \times Tariff$$

Where:

SEC_{post}	:	Post-implementation specific energy consumption of pump (kWh/t)
Unit $throughput_{post}$	:	Post-implementation pump fluid flow rate (t/h)
Pump energy performance improvement	:	Pump power reduction compared to baseline (kW)
Op hrs	:	Number of operating hours in a year (hrs /yr)
Annual energy performance improvement	:	Energy performance improvement for a year (kWh/yr)
Tariff	:	Electricity tariff (SGD/kWh)
Annual cost savings	:	Cost savings in a year (SGD/yr)

5 Typical Scenarios Applicable to Boiler Systems

Generally, there are two types of projects that would affect the performance of the boiler system, namely:

- Modifications to boiler
- Changes in the steam consumption requirements

Modifications to boiler

Energy efficiency projects relating to modifying the boiler generally targets the main source of heat loss, which is through the flue gas. Improvements to heat recovery from stack flue gas, or the trimming of excess oxygen content in flue gas leads to better thermal efficiencies.

As these modifications only affect the thermal performance of the boilers (and do not lead to any change to the downstream demand of the heat energy), the baseline and post-implementation thermal efficiencies can be calculated using heat balance or empirical formula on the boiler, with measurement of the stack oxygen content, temperature of stack flue gas and inlet combustion air. This approach is detailed in the Assessment Framework for boilers.

Changes in the steam consumption requirements

Changes to steam consumption demand can be a result of increased process to process heat recovery, changes to process operations or product slates. These changes can be observed through supply steam flow, condensate recovery and an assessment of the steam users. The performance of both the boiler and the BFW pump may be affected.

The previous sections have provided information on how to establish the base line and quantify energy performance improvement and cost savings for these cases.

6 Instrumentation Requirements

The following section describes the list of critical parameters that should be measured using permanent instruments. The availability of these data will allow for continuous monitoring of boiler system efficiency.

- Fuel system
  - Fuel flow to each individual boiler
- Boiler
  - Stack temperature
  - Stack oxygen content
- Steam
  - Steam flow rate
  - Steam temperature and pressure
- BFW
  - BFW flow rate
  - BFW supply temperature
- Pump
  - Power

Other parameters such as the enthalpy values of steam and BFW, and the lower heating value of the fuel can be obtained from thermodynamics database or laboratory test results.

As per NEA guidelines, a 2-weeks measurement period is used when calculating the baseline or post-implementation heating system efficiency. The resolution of the collected data should be at least on an hourly basis.