National Environment Agency Singapore

Measurement & Verification of Heating Systems

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1 Furnace System

The objective of a furnace is to increase the temperature of a process stream to a target temperature. For example, heating up a process stream before entering a fractionator such as in the Atmospheric Crude Distillation, providing the required reboiling duty as in the BTX unit, or reaching the desired temperature in a reaction system as in the Hydrotreating Process. The furnace also serves to provide enough heat for an endothermic reaction to take place (e.g. in the Ethane Cracker Unit).

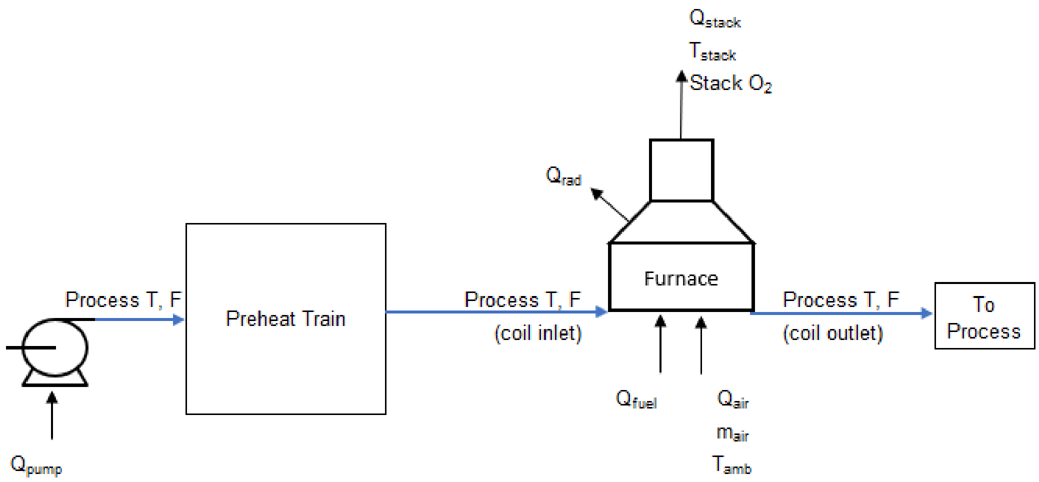

Figure 1: Main considerations for assessing the performance of furnace systems

Table 1: Key energy metrics for furnaces

Energy System	Hierarchy	Metric	Method
Furnace equipment only	Energy performance indicator	Thermal efficiency (%)	Calculated
	Energy influencing variable	Stack temperature (°C)	Measured
	Energy influencing variable	Stack oxygen (%)	Measured
Furnace preheat train	Energy performance indicator	Charge pump specific energy consumption (kW/unit throughput)	Calculated
	Energy influencing variable	Coil inlet temperature (°C)	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 furnace system. Table 1 shows a list of key metrics for a furnace 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 furnace system.

2 Assessment of Baseline Energy Performance

2.1 Furnace thermal efficiency

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

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

$$Useful\ Heat\ Output_{baseline} = m_{process} \times C_{p,avg} \times (COT - CIT) \qquad \textit{Eqn. 2}$$

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

Where:

$E_{baseline}$	:	Baseline thermal efficiency of furnace (%)
Heat Input	:	Fired duty of furnace (MJ/h)
Useful Heat $Output_{baseline}$	:	Useful heat absorbed by process stream (MJ/h)
m_{fuel}	:	Mass flow rate of fuel (t/h)
LHV_{fuel}	:	Lower heating value of fuel (kJ/kg)
$m_{process}$	:	Mass flow rate of process stream(t/h)
$C_{p,avg}$	:	Average specific heat capacities of the process stream at coil inlet/outlet (kJ/kg.K)
CIT, COT	:	Furnace coil inlet and outlet temperatures (K)

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

2.2 Furnace charge 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.

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

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 furnace systems follows the same approach as detailed in Section 2 above.

4 Quantification of Energy Performance Improvement and Cost Savings

Energy performance improvements to the furnace 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 furnace (%)
Useful heat $output_{post}$	:	Post-implementation useful heat absorbed by process stream (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 improvement 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 Furnace Systems

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

- Modifications to furnace
- Changes in the process heat requirements

Modifications to furnace

Energy efficiency projects relating to modifying the furnace 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 furnaces (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 furnace, 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 furnaces.

Changes in the process heat requirements

Changes to process heat demand can be a result of increased process to process heat recovery in the preheat train, changes to process operations, or product slates. These changes can be observed through the furnace coil inlet temperature (CIT) and coil outlet temperature (COT). Any changes in CIT or COT will directly affect the furnace load.

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 furnace efficiency.

- Fuel system
  - Fuel flow to each individual furnace
- Furnace
  - Stack temperature
  - Stack oxygen
- Process stream
  - Process stream flow
  - Furnace CIT
  - Furnace COT
- Pump
  - Power

Other parameters such as the specific heat capacity of process stream, and lower heating value of fuel can be obtained from design data 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.