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EXPLANATORY & GUIDANCE document (E&G-d) on IED-based (draft) Waste Incineration BREF and BAT conclusions

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ANNEX 4

**On the calculation of energy efficiency
according to BAT conclusions**

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Abbreviations

Please, see **Annex 1** to this E&G-d.

Foreword

The calculation of energy efficiency of waste incineration plants is tackled in different parts of the BREF, not only in BAT conclusions, and the calculation method is different from the traditional way of calculating it.

This annex 4 aims to summarise all the information given in the BREF document (not limited to the BAT conclusions) together with background information exchanged during the Waste Incineration BREF review in regards of energy efficiency, in order to provide a simple guide on how to calculate the energy efficiency of a waste incineration plant incinerating mostly municipal or other non-hazardous waste according to the requirements of the BAT conclusions. Plants dedicated to hazardous waste, clinical waste or to sewage sludge are not covered by this document.

1. Background information

1.1 The WI TWG subgroup on energy issues

At the kick off meeting of the WI BREF review on 19-22 January 2015 in Seville, it was concluded to establish 3 subgroups, of which one on energy issues, pursuant to the BREF Guidance 2012/119/EU.

The purpose of this WI TWG subgroup on energy issues was to support the review of the WI BREF with respect to energy issues and:

- determine parameters important to the determination of BAT and BAT-AEPLs on energy efficiency and energy recovery;
- advise the data collection and questionnaire development subgroup (See **Section 1.2 below**) on the information to be collected with respect to energy issues and define the most appropriate methodology for collecting the data for the types of plant under the scope of the WI BREF review;
- propose draft general and descriptive texts for insertion in the WI BREF related to energy efficiency and energy recovery in line with the format and content of the BREF Guidance

1.2 Data collection: Annex II of the Questionnaire

During the data collection for the WI BREF, information on energy efficiency have been gathered through the Annex II of the questionnaire, which on request of the EIPPCB was developed by the Energy subgroup of the TWG mentioned in **Section 1.1 above**. The Annex II (as the other parts of the questionnaire) was compiled by the waste incineration plants operators.

In this Annex II, developed in particular for MSW and ONHW incinerators, the energy efficiency of a line, a group of lines, a plant or parts of it is calculated using different formulas depending on the specific setup. In the questionnaire, these specific setups are presented in cases, described below.

The BAT-AEELs presented in BAT conclusions (see **Section 1.3**) refer to these cases, in particular the gross electrical efficiency generally refers to case 1, while the gross energy efficiency refers to case 2. An excerpt of the questionnaire with a short description of the cases is presented below:

A2.1.11	CASE 1: Reference line (or Grouped lines) able to expand its/their full steam flow into condensing turbines. [Electricity oriented plant]
a	Please put 1 if the reference line (or Grouped lines) send(s) all steam available to condensing steam turbine(s) [Electricity only line(s)]
b	Please put 1 if the reference line (or Grouped lines) is/are able to send all steam available to condensing steam turbine(s) by closing the bleeds (except for self-use). [Electricity oriented CHP line(s)]

Table 4-1: Data collection Questionnaire, Annex II, Sheet “Energy Efficiency”. Possibilities for CASE 1

A2.1.12	CASE 2: Reference line (or Grouped lines) able to export its/their full heat/steam flow either as heat/steam or to (a) back-pressure turbine(s). [Heat oriented plant]
a	Please put 1 if the reference line (or Grouped lines) export(s) all heat/steam available as heat/steam [Heat only line(s)]
b	Please put 1 if the reference line (or Grouped lines) is able to send all steam available as heat/steam or to back-pressure turbine(s) (i.e. not to condensing turbines). [Heat oriented CHP line(s)]

Table 4-2: Data collection Questionnaire, Annex II, Sheet “Energy Efficiency”. Possibilities for CASE 2

In order to avoid summing up the energy in form of electricity and in form of heat when the plant (or part of it) is operated in CHP mode and is equipped with a condensing turbine, it was decided to evaluate instead its energy performance in the situation where all the available steam is fully expanded in the turbine (down to condensation pressure). This of course leads to a lower “overall” efficiency, a factor that has been considered for the setting of BAT-AEELs.

However, summing up electricity and heat can in general be done if the plant is delivering its steam production to a backpressure turbine, since in this case the latent heat of condensation remains in the low-pressure steam which is afterwards exported or exchanged in a heat exchanger.

To cope with the rare cases of plants (or lines) neither entirely in case 1 nor in case 2, the subgroup decided to not calculate in the questionnaire the energy efficiency, but introduced the concept of a separation in two virtual parts, as below:

A2.1.13	-	Is the Reference line (or Grouped lines) feeding (a) condensing turbine(s) and able to export a part of the steam flow as HP steam (not sent to the condensing turbine(s) and/or feeding in parallel (a) back-pressure turbine(s)?	Yes/no	If yes your plant will be considered as composed by a virtual part mainly oriented to heat production and another virtual part mainly oriented to electricity production. In order to avoid to complexify the data collection, no more information is requested from you in this sheet.
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Table 4-3: Data collection Questionnaire, Annex II, Sheet “Energy Efficiency”. Description of the special case

This applies for instance to plants which on one hand fully expand only a part of the produced steam flow into a condensing turbine and, on the other hand, either directly export (e.g. to a nearby industry) a part of the steam flow (not sent through the whole condensing turbine) or feed in parallel one back-pressure turbine.

One or several parts (where steam is fully expanded in a condensing turbine) may be assimilated to an electricity-oriented line/group of lines/plant (Case 1 above). Other part(s) (without turbines or equipped with a back-pressure turbine) may be assimilated to a heat orientated line/ group of lines/plant (Case 2). However, in some rare cases, this may also not be possible for some parts of the plants or even the whole plant.

It is worth noting that this rare case does not apply in case the steam extracted from the condensing turbine is used for the general self-use: in fact if any bleed is necessary for the Rankine cycle (e.g. the steam for the deaerator and/or to pre-heat feedwater or secondary air) or for the flue gas cleaning system, then it will be counted in another way (See [Section 3.2 below](#)) and in this case, the steam flow should not be split.

Some terms changed slightly from the Questionnaire to the BAT conclusions (e.g. grouped line was removed, to create the more general term “part of a plant”)

1.3 Energy efficiency in WI BREF Final Draft BAT Conclusions

The following text [in blue](#) is copied directly from the text of the BAT conclusions (Chapter 5) of the Waste Incineration BREF Final Draft. This is an excerpt of the relevant parts regarding the calculation of energy efficiency.

The necessary information to calculate energy efficiency are given in different parts of the BAT conclusions. The first is the Section of definitions, where boiler efficiency and part of an incineration plant are defined:

*For the purposes of these BAT conclusions, the following general **definitions** apply:*

<i>Boiler efficiency</i>	<i>Ratio between the energy produced at the boiler output (e.g. steam, hot water) and the waste's and auxiliary fuel's energy input to the furnace (as lower heating values)</i>
<i>Part of an incineration plant</i>	<i>For the purposes of determining the gross electrical efficiency or the gross energy efficiency of an incineration plant, a part of it may refer for example to:</i> <ul style="list-style-type: none"> <i>• an incineration line and its steam system in isolation;</i> <i>• a part of the steam system, connected to one or more boilers, routed to a condensing turbine;</i> <i>• the rest of the same steam system that is used for a different purpose, e.g. it is directly exported.</i>

In the following Section on General considerations, the BAT-AEELs are mentioned for the first time, and the paragraph quoted below describes how they are expressed, depending on the type of plant. This Section also includes the formula on how to calculate the gross electricity efficiency and the gross energy efficiency.

Energy efficiency levels associated with the best available techniques (BAT-AEELs)

The BAT-AEELs given in these BAT conclusions for the incineration of non-hazardous waste other than sewage sludge and of hazardous wood waste are expressed as:

- gross electrical efficiency in the case of an incineration plant or part of an incineration plant that produces electricity using a condensing turbine;*
- gross energy efficiency in the case of an incineration plant or part of an incineration plant that:*
 - produces only heat, or*
 - produces electricity using a back-pressure turbine and heat with the steam leaving the turbine. This is expressed as follows:*

Gross electrical efficiency:

$$\eta_e = \frac{W_e}{Q_{th}} (Q_b / (Q_b - Q_i))$$

Gross energy efficiency:

$$\eta_h = \frac{W_e + Q_{de} + Q_{he} + Q_i}{Q_{th}}$$

Where:

- W_e : electrical power generated, in MW;
- Q_{he} : thermal power supplied to the heat exchangers on the primary side, in MW;
- Q_{de} : directly exported thermal power (as steam or hot water) less the thermal power of the return flow, in MW;
- Q_b : thermal power produced by the boiler, in MW;
- Q_i : thermal power (as steam or hot water) that is used internally (e.g. for flue-gas reheating), in MW;
- Q_{th} : thermal input to the thermal treatment units (e.g. furnaces), including the waste and auxiliary fuels that are used continuously (excluding for example for start-up), in MWth expressed as the lower heating value.

The BAT-AEELs given in these BAT conclusions for the incineration of sewage sludge and of hazardous waste other than hazardous wood waste are expressed as boiler efficiency. BAT-AEELs are expressed as a percentage. The monitoring associated with the BAT-AEELs is given in BAT 2.

Information on when and how to calculate energy efficiency are given in BAT-c 2, while BAT-c 20 includes the BAT-AEELs for both gross electrical efficiency and gross heat efficiency, as below:

BAT 2. BAT is to determine either the gross electrical efficiency, the gross energy efficiency, or the boiler efficiency of the incineration plant as a whole or of all the relevant parts of the incineration plant.

Description

In the case of a new incineration plant, or after each modification of an existing incineration plant that could significantly affect the energy efficiency, the gross electrical efficiency, the gross energy efficiency, or the boiler efficiency is determined by carrying out a performance test at full load.

In the case of an existing incineration plant that has not carried out a performance test, or where a performance test at full load cannot be carried out for technical reasons, the gross electrical efficiency, the gross energy efficiency, or the boiler efficiency can be determined taking into account the design values at performance test conditions. For the performance test, no EN standard is available for the determination of the boiler efficiency of incineration plants. For grate fired incineration plants, the FDBR guideline RL 7 may be used.

BAT 20

Table 5.1: BAT-associated energy efficiency levels (BAT-AEELs) for the incineration of waste

BAT-AEEL (%)				
Plant	Municipal solid waste, other non-hazardous waste and hazardous wood waste		Hazardous waste other than hazardous wood waste (1)	Sewage sludge
	Gross electrical efficiency (2) (3)	Gross energy efficiency (4)	Boiler efficiency	
New Plant	25-35	72-91(5)	60-80	60-70 (6)
Existing plant	20-35			

Table 4-4 (of this Annex 4): BAT-AEELs in the Waste Incineration BREF BAT conclusions

(1) The BAT-AEEL only applies where a heat recovery boiler is applicable.

- (2) The BAT-AEELs for gross electrical efficiency only apply to plants or parts of plants producing electricity using a condensing turbine.*
- (3) The higher end of the BAT-AEEL range can be achieved when using BAT 20 f.*
- (4) The BAT-AEELs for gross energy efficiency only apply to plants or parts of plants producing only heat or producing electricity using a back-pressure turbine and heat with the steam leaving the turbine.*
- (5) A gross energy efficiency exceeding the higher end of the BAT-AEEL range (even above 100 %) can be achieved where a flue-gas condenser is used.*
- (6) For the incineration of sewage sludge, the boiler efficiency is highly dependent on the water content of the sewage sludge as fed into the furnace.*

2. Boundaries of the calculations

In order to properly assess the energy efficiency level of a Waste Incineration plant, it is necessary to define the boundaries of the calculation. Chapter 3 of the WI BREF provides a very clear description on how to define the boundaries.

2.1 Description of the boundaries

In Chapter 3, Section 3.5.1 page 266 WI BREF Final Draft says:

- 1. The energy efficiency relates the input chemical energy contained in waste (normally expressed as the LHV) with the useful energy produced (electrical and thermal) that is recovered rather than being dissipated (through the flue-gas, cooling system, radiation, etc.). Where relevant, other energy inputs are taken into account (e.g. support fuels, electrical or steam energy). The energy efficiency of a waste incineration installation is often expressed as a percentage. The energy efficiency can be used to compare the performance of different technical units and systems. For comparability, it is important to ensure that energy efficiency figures are calculated in a consistent manner. This requires taking into account the following, when calculating the energy efficiency: The boundaries of the system/calculation need to be clearly defined [...]*
- 2. All energy inputs need to be accounted for [...]*
- 3. Own energy consumption and internal energy flows need to be accounted for in a consistent manner [...]*
- 4. All assumptions need to be made clear and consistently adhered to [...]*

A different approach is used in this document, based on the identification of different cases that are internally comparable: 1) plants mainly oriented towards the destruction of waste, such as plants dedicated to the incineration of hazardous waste (other than hazardous wood waste) and of sewage sludge; 2) plants mainly oriented towards the production of electricity with a condensing turbine; 3) plants mainly oriented towards the production of heat/steam, possibly in combination with a back-pressure turbine; 4) hybrid plants where different parts of the plant may have a different orientation. Detailed examples of several cases are presented in Annex 8.2. Furthermore, the relevant time dimension needs to be univocally fixed, either as a short-term status (e.g. at the time of a performance test, typically lasting around 8 hours) or over a certain period of time (e.g. as an annual average). The energy efficiency data presented in this section are in principle derived from the performance test that the plant underwent to check its real performance when it was first commissioned or after significant changes. However, the performance test data were not available in all cases: while performance tests are generally carried out for furnaces/boilers and for turbo-generator sets, this is not the case for district heating heat exchangers or for direct export systems for steam or hot water. The nominal design values initially provided by the suppliers and/or updated operating data were used as an alternative.

The energy efficiency may be assessed at the level of the waste incineration plant, with the system boundary shown in Figure 3.86 (figure below), or at the level of a part of the waste incineration plant in cases where the amounts of energy recovered by different parts of the plant cannot be appropriately summed together for example.

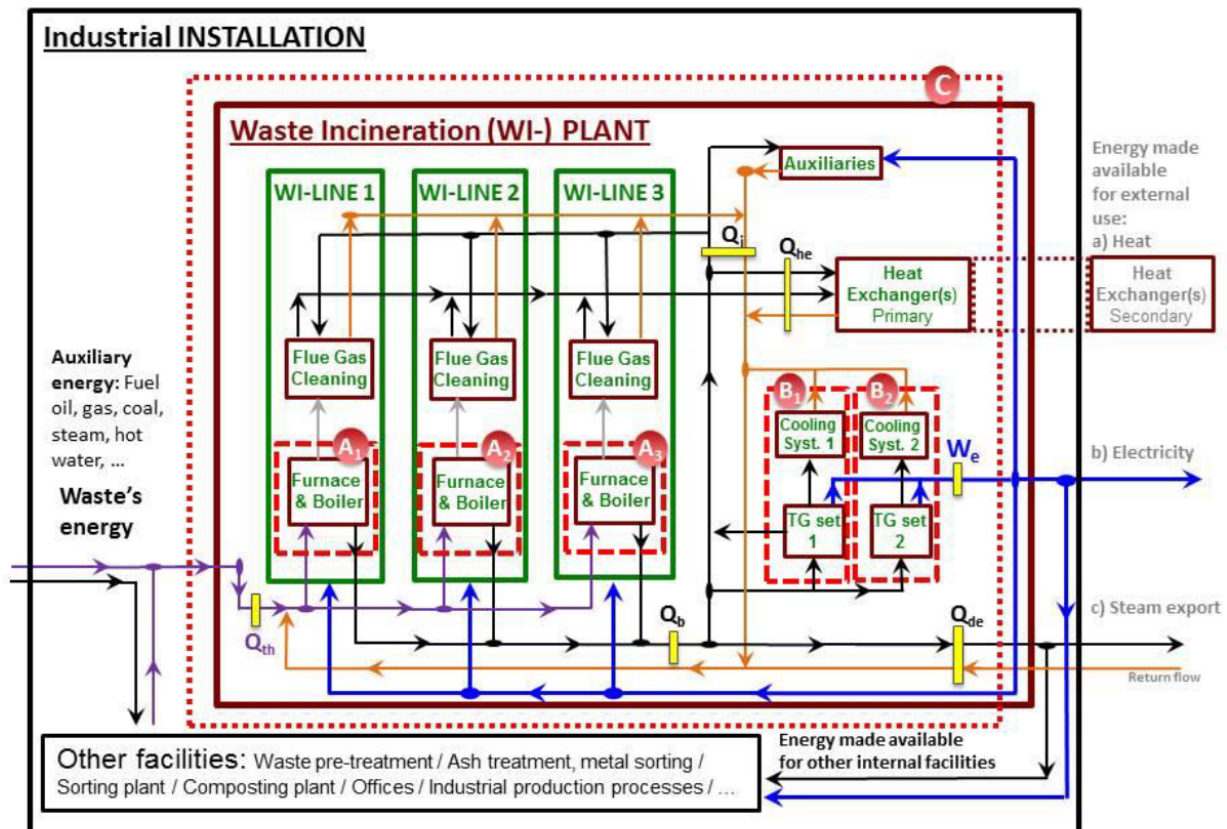


Figure 4-1 (of this Annex 4): System boundary of the Waste Incineration plant for the calculation of energy efficiency

Figure 3.86: System boundary used for the calculation of the energy efficiency

NB:

A = Energy recovered by the boiler. Boiler performance test.

B1 & *B2* = Energy generated by the turbo-generator sets. Turbo-generator performance test.

C = Gross energy made available by the WI plant, including energy used for self-consumption of the WI plant as well as energy made available for use outside the WI plant (within and/or outside the installation).

Figure 3.86 shows the energy balance boundaries representative of the energy efficiency concepts that are generally used within this document for the determination of the energy efficiency, which refer to gross, rather than net, energy efficiency. This means determining the energy efficiency in terms of all the energy that is made available by the WI plant, including: the energy used by the plant itself for internal uses (e.g. to run the flue-gas cleaning system); the energy used by the broader installation (e.g. to run a waste pre-treatment plant that may be on site); and the energy available for export.

In Figure 3.86, the energy flows are depicted using the following colour code:

in purple, the energy input into the furnace(s), as waste as well as auxiliary fuels;

in grey, the energy contained in the flue-gas at the exit of the boiler;

in black, the energy contained in the steam and/or hot water generated in the heat recovery boiler(s) as well as recovered in the flue-gas cleaning system (for instance when using flue-gas condensation);

in orange, the return flows of the steam/hot water system;

in blue, the electricity that is generated by the turbo-generator sets, used within the plant or the broader installation, or exported.

The red dotted line (C) represents the boundary of the gross energy efficiency calculation used to determine the energy efficiency of the plants that participated in the 2016 data collection for the review of the WI BREF. In this context, the following quantities are identified in Figure 3.86:

- *W_e* is the electrical power generated, in MW;
- *Q_{he}* is the thermal power supplied to the heat exchangers on the primary side, in MW;

- *Q_{de} is the directly exported thermal power (as steam or hot water) less the thermal power of the return flow, in MW;*
- *Q_b is the thermal power produced by the boiler, in MW;*
- *Q_i is the thermal power (as steam or hot water) that is used internally (e.g. for flue-gas reheating), in MW;*
- *Q_{th} is the thermal input to the thermal treatment units (e.g. furnaces), including the waste and auxiliary fuels that are used continuously (excluding for example for start-up), in MWth expressed as lower heating value.”*

3. Formulas for the calculation of the energy efficiency

As it is clear from the text of the BAT conclusions, two different formulas are used in the BREF for the calculation of energy efficiency, which is then to be confronted against one or the other BAT-AEELs of BAT-c 20 for MSW and ONHW. The use of one or the other formula depends on the type of plant (or part of incineration plant). Before analysing the formulas, it is crucial to understand how the values for the calculation should be taken, depending on the case.

3.1 Performance test or design values?

According to the text of BAT-c 2, the preferred option is that the values for the calculation of the energy efficiency are taken “*by carrying a performance test at full load*”.

In waste incineration plants a performance test is usually carried out on the following pieces of equipment:

- boiler(s), example of guideline for the performance test is the FDBR RL 7, derived from DIN 1942 or DIN EN 12952-15 (indirect method)
- the turbine generator set(s), for which example of guidance is the IEC 60953-1/2 or the DIN 1943

A performance test verifies that the equipment can achieve its guaranteed parameters and function as intended, and is usually carried out after the commissioning period or retrofit of a plant (usually 2 to 4 months).

However, no performance test is usually carried out on the heat exchangers for district heating or on the steam direct export system, since it is generally not possible to use these parts at full load for several hours (as these parts rely on the customer to use all the produced heat). For these parts, nominal design values are used instead for the calculation of energy efficiency.

Several cases are possible when calculating energy efficiency, depending on the nature of the plant:

- New plants will need:
 - Before getting the permit, design nominal values for all the pieces of equipment, so that the plant is able to achieve the BAT-AEELs required by BAT-c 20.
 - When the plant starts industrial operation, after commissioning:
 - to carry out performance test(s) on the new pieces of equipment (on which it is possible to carry out a performance test) and
 - nominal design values for the other parts
- Existing plants which will be subject to modification that could significantly affect the energy efficiency, will need:
 - For the pieces of equipment subject to the modification:
 - Before updating the permit: design nominal values for the pieces of equipment affected by modification, so that the plant is able to achieve the BAT-AEELs required by BAT-c 20.
 - After updating the permit, to carry out performance test(s) on the new equipment subject to modification (if relevant)

- For the pieces of equipment not subject to the modification:
 - Before and after updating the permits, existing (if available) or new (if technically feasible) performance test(s) for the equipment not affected to any modification and nominal design values at performance test conditions for the other parts
- Existing plants which have been subject to modification that could significantly affect the energy efficiency will need:
 - Existing (if available) or new (if technically feasible) performance test(s) on the relevant pieces of equipment which have been subject to the modification. In this case, an existing performance test(s) made at the time of the modification can be used.
 - Existing (if available) or new (if technically feasible) performance test(s) on the relevant pieces of equipment which have not been subject to any modification. In this case, an existing performance test(s) made before the modification can be used.
 - nominal design values at performance test conditions for the other parts
- Existing plants which have **not** been subject and will **not** be subject to modification that could significantly affect the energy efficiency, will need:
 - Existing (if available) performance tests on the relevant pieces of equipment and nominal design values at performance test conditions for the other parts

The reference performance test(s) in existing plants could be the initial test made when the equipment has been initially taken over and therefore could have been carried out years before the calculation of the energy efficiency that is required by these BAT conclusions.

A performance test may be (or have been) carried out on one or more boilers and turbine(s) in different moments for the different components, due to the availability of staff and measurement instruments. This must be taken into account when calculating energy efficiency. If the performance test on the steam turbine is not made (or has not been made) at the same time as the boiler performance test, a factor of correction should be taken into account in order to adapt the thermal input (and then the power output) of the steam turbine to the steam output of the boiler, due to the fluctuations in regards of these parameters that always occur.

When performance test(s) is not available and cannot be made, nominal design values at performance test conditions should be used instead.

3.1.1 Performance test of the boiler(s)

Guidance on the performance testing of the boiler for grate furnace waste incineration plants can be found in the FDBR guideline 7, as referenced in the BAT conclusions. The performance test of one (or more) boiler(s) is usually conducted for a duration of 4 to 8 hours in nominal design condition. Usually boiler efficiency is calculated through a heat loss method (the direct method cannot be used in waste incineration plants, due to the fact that is practically impossible to determine the heating value of the waste input as random samples are usually not representative): this is made through a heat balance, which takes into account the determination of the useful heat, all accountable heat losses, heat credits to calculate the unknown gross heat input from waste.

Where in the course of the performance testing it is impossible to establish the guaranteed boundary conditions, the measured values shall be corrected to guarantee condition.

For the calculation of energy efficiency according to BAT conclusions, relevant parameters taken from the performance test of the boiler are the thermal input of the waste (and auxiliary fuels used continuously) – Q_{th} – and the heat output, in terms of thermal power of the steam (or hot water) produced – Q_b –.

3.1.2 Performance test of the steam turbine(s)

The steam turbine(s) performance test is made to determine the general steam consumption of the turbine unit under nominal design conditions and further to determine whether the manufacturer's guarantees had been complied with. Guidance for the turbine's test can be found in IEC 60953-1/2.

The main parameter to be taken from the performance test for the calculation of the energy efficiency according to the BAT conclusions is the thermal input to the turbine and the gross power output – W_e -, after the corrections made due to any observed departure from the guarantee's conditions.

3.1.3 Heat exchangers, direct export of heat and internal consumption

The formulas on energy efficiency include elements that are normally not assessed during the performance tests, as the thermal power exchanged in heat exchangers (Q_{he}), the thermal power of the direct steam exported (Q_{de}) and the internal consumption (as defined Q_i).

BAT-c 2 says that in case performance test cannot be carried out for technical reasons, design values are used instead (more details in the specific Section on gross energy efficiency below). Indeed, it could not be possible to use the heat exchanger or the direct export of heat at full load for a certain amount of hours as the demand depends strictly from the customers of the heat delivered.

3.2 The gross electrical efficiency formula

This formula applies to an incineration plant or part of an incineration plant that produces electricity using a condensing turbine:

$$\eta_e = \frac{W_e}{Q_{th}} (Q_b / (Q_b - Q_i))$$

Where:

- W_e is the electrical power generated, in MW;
- Q_b : thermal power produced by the boiler, in MW;
- Q_i : thermal power (as steam or hot water) that is used internally (e.g. for flue-gas reheating), in MW;
- Q_{th} : Thermal input to the thermal treatment units (e.g. furnaces), including the waste and auxiliary fuels that are used continuously (excluding for example for start-up), in MWth expressed as the lower heating value.

The gross electrical efficiency formula is composed of two main parts: the simple ratio between the gross power output and the thermal input ($\frac{W_e}{Q_{th}}$), and the correction factor for taking into account the internal consumption ($Q_b / (Q_b - Q_i)$).

In the first part, the thermal power input to the boiler (Q_{th}) is usually calculated during the performance test, at 100% thermal load (or corrected to it) (see Section 3.1.1).

The electrical power generated (W_e) corresponds to the gross power output and it is normally measured at the condensing turbine's generator terminals during the performance test on the turbine. Some corrections may be applied to the gross power output due to the difference between specified guarantee conditions and test conditions. Since the test is dependent on these conditions, any observed departure should become subject to a correction (such as cold source temperature). Examples and formulas for the calculation of these correction factors are given in IEC 60953-1/2 and in the example under Section 5.

The second part of the formula $((Q_b/(Q_b - Q_i))$ is similar to a correction factor, and has been introduced to take into account the possible internal consumption of heat in the plant that is not stopped during the performance test (or in performance test conditions), and that would be otherwise necessary to import or generate with other fuels.

It does not consider the heat that is used internally when it would result in an energy used in the production of steam/hot water by the boilers (e.g. the heat used for preheating the feedwater or the combustion air). It also includes the low-temperature heat of the cooling fluid if it is used usefully after the condenser inside or outside the incineration plant.

When the Q_i is equal to 0, this factor is equal to 1, and therefore has no impact, If $Q_i > 0$, the factor is >1 and increase the number resulting from the formula.

Examples of Q_i are the following:

- Steam used for reheating the flue gas
- Heat for flue gas cleaning system
- Soot blowers
- Steam driven devices such as pumps, compressors, vacuum pumps
- Heating, cooling and warm water of buildings, instruments, apparatus silos, greenhouses
- Energy used for steam trace heating
- Heat recovered from flue gas condensation¹

3.3 The gross energy efficiency formula

This formula applies to an incineration plant or part of an incineration plant that:

- produces only heat, or
- produces electricity using a back-pressure turbine and heat with the steam leaving the turbine. This is expressed as follows:

$$\eta_h = \frac{W_e + Q_{de} + Q_{he} + Q_i}{Q_{th}}$$

Where:

- W_e : electrical power generated, in MW;
- Q_{he} : thermal power supplied to the heat exchangers on the primary side, in MW;
- Q_{de} : directly exported thermal power (as steam or hot water) less the thermal power of the return flow, in MW;
- Q_i : thermal power (as steam or hot water) that is used internally (e.g. for flue-gas reheating), in MW;
- Q_{th} : thermal input to the thermal treatment units (e.g. furnaces), including the waste and auxiliary fuels that are used continuously (excluding for example for start-up), in MWth expressed as the lower heating value.

The gross energy efficiency formula has at the numerator several parameters to be summed up together, and at the denominator the thermal power in input.

Q_{th} and Q_i been already described above in [Section 3.2](#).

W_e , the electrical power generated, is the gross power output of the backpressure turbine, when operated at nominal load (during the performance test), measured at the generator terminal. As described in Section 3.2,

¹ The energy recovered in this way could also be used outside the WtE plant, but since it cannot be accounted elsewhere in the calculation, it should be added to the internal use.

some correction factors may be applied due to the different parameters between the guarantee's conditions and the test conditions.

Q_{de} Represents the thermal power that is directly exported as steam or hot water (minus the thermal power of the return flow). Since it is normally not assessed during the performance test, in the Annex II of the questionnaire (see Section 1.2) it was calculated as the difference between the nominal thermal power of the export capacity and the nominal thermal power of the return flow, multiplied by a factor to take into account only the part of this nominal thermal power supplied by the plant or part of it when the turbine (if present) is connected and operated at nominal load, as in the example below:

Nominal thermal power export capacity	MW _{th}	57
Nominal thermal power of return flow	MW _{th}	10
Nominal thermal power	MW _{th}	47
Part of this Nominal thermal power supplied by the reference line (or the Grouped lines) at nominal load when connected turbine(s) is/are operated at nominal load (This should be 0 for condensing turbines with bleeds for export closed)	%	60%
Energy directly exported by the reference line (or the Grouped lines) Q_{de}	MW _{th}	28.2

Table 4-5: Data collection Questionnaire, Annex II, Sheet "Energy Efficiency". Example of calculation of the direct export of steam Q_{he} represents the thermal power supplied to heat exchangers on the primary side. As for Q_{de} , this parameter is not measured during performance test, and can be calculated from the nominal thermal power supplied to the heat exchanger, at the primary side, multiplied by the factor taking into account only the part of it which is exchanged when the turbine(s) is operated at nominal load.

Nominal thermal power to HE (at primary)	MW _{th}	10
Part of this Nominal thermal power supplied by the reference line (or the Grouped lines) at nominal load when turbines operated at nominal load (This should be 0 for condensing turbines with bleeds for export closed)	%	60%
Energy directly exported by the reference line (or the Grouped lines) Q_{he}	MW _{th}	6

Table 4-6: Data collection Questionnaire, Annex II, Sheet "Energy Efficiency". Example of calculation of the energy exported through heat exchanger(s) to e.g. a district heating system

Some examples of the proper use of these formulas are provided in the WI BREF **draft** document, in Annex 8.

3.3 Special cases

For most of the existing plants it is obvious whether the gross electrical efficiency or the gross energy efficiency should be applied. The general criterium is related to the type of turbine, and can be summarised as follow: if a plant is equipped with a condensing turbine where all the steam can be expanded (except the one for internal

use, Q_i , or the steam used for the cycle), then the gross electrical efficiency applies, if not, most often the gross energy efficiency applies.

Indeed, some special cases exist, in which neither one nor the other formula can completely apply to the plant. Examples of special cases are:

- A plant which **is able to expand only part of** the steam in the condensing turbine, and either export the rest directly as steam, or send the rest to a heat exchanger, dedicated e.g. to district heating. NB: this is not the case of plants that **can** expand all the steam in the condensing turbine, but don't always do it because they have the option to deliver heat (as direct heat export or to a heat exchanger). In this case, the plant fully fall under case 1, and it is simply solved as a gross electricity efficiency case.
- A plant which has both a condensing turbine and a backpressure turbine, in parallel.

To cope with these exceptions, the BREF allows to calculate the energy efficiency not only as plants but also as “part of an incineration plant”. This definition may refer to, for example:

- an incineration line and its steam system in isolation;
- a part of the steam system, connected to one or more boilers, routed to a condensing turbine;
- the rest of the same steam system that is used for a different purpose, e.g. it is directly exported.

Therefore, if the energy efficiency cannot be properly calculated with the formulas above, it can be divided into two (or more) parts, and the efficiency of each part should be calculated and checked against the BATAEELs of BAT-c 20.

For example, in the case of a plant equipped with a condensing turbine able to fully expand only part of the steam, while the rest is exported, the two parts can be considered as the two steam flows. One part will be then represented by the steam fully expanding in the turbine, and its efficiency will be calculated with the gross electrical efficiency formula, and the other part, which is exported, will be calculated with the gross energy efficiency formula. Of course, the thermal input (Q_{th}) will be divided proportionally between the two parts. An example of this case is provided in Section 5.

4. Example of energy efficiency calculation for a special case

Some examples of the energy efficiency calculation are provided in the WI BREF **draft**, in Annex 8.

Here an example for the calculation of the energy efficiency on a special case is provided.

This plant, with two incineration lines (and boilers) is equipped with a condensing turbine (divided in a high pressure and low-pressure turbine, HP and LP), but cannot expand all the steam in it, since the LP turbine is designed to expand only part of the steam. The reason is that the other part of the steam, at around 15 bar is exported to an industry nearby.

It is not possible therefore to calculate the efficiency of this plant entirely through either the formula of Gross electrical efficiency or the Gross energy efficiency.

A solution is to split the steam flow in two parts (see definition of “part of a plant”):

- One, consisting of the amount of steam that is then exported to the industry, pass only through the HP turbine, which so generates power between the inlet pressure and the pressure at which the steam is exported. The HP turbine will be considered as a virtual backpressure turbine, and to the power it generates the power of the steam exported will be added, as it happens in the formula of the Gross Energy Efficiency, which will be used for this part.

- The other is the amount of steam that can go through the whole turbine, and will correspond to the capacity of steam that the LP turbine can expand. Its efficiency will be calculated through the formula of the Gross Electrical Efficiency.

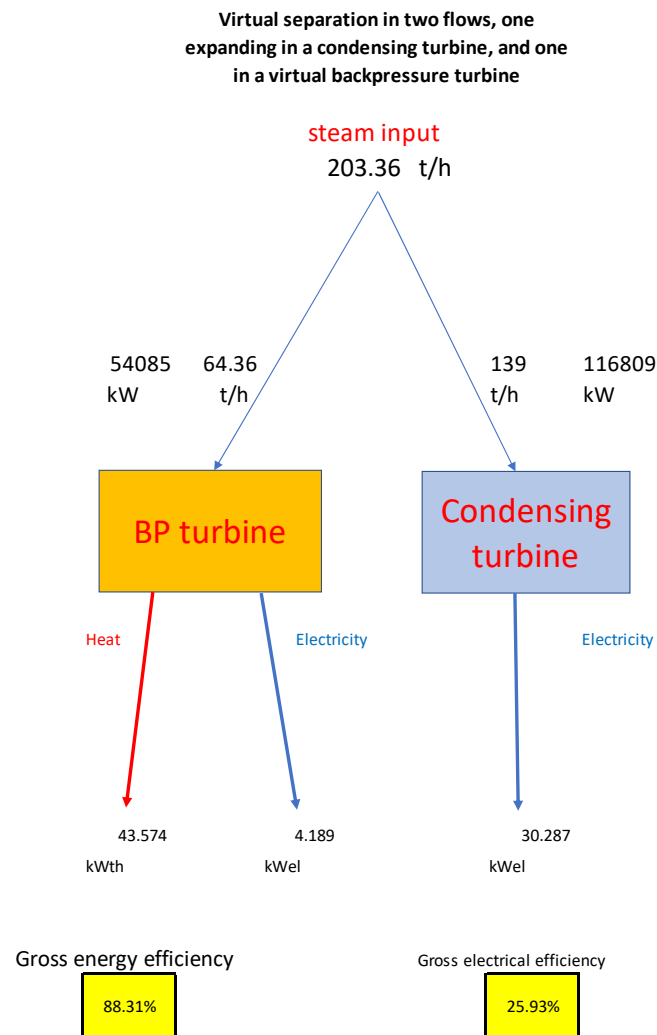


Figure 4-2: scheme of the virtual separation of the waste incineration plant

#	Parameter	Line 1	Line 2	Total
A	Waste input [t/h]	24.72	25.18	49.90
B	Waste input [kg/s]	6.87	6.99	13.86
C	Waste NCV [MJ/kg]	12.33	12.33	
D	Total Energy input [MW]	84.652	86.242	170.894
E	Steam production [t/h]	100.41	102.95	203.36
F	Temperature [°C]	399.99	400.06	
G	Pressure [bar(a)]	53.1	53.2	
H	Specific Enthalpy	3190.9	3191.0	
I	Enthalpy of water input [kJ/kg]	454.8	455.2	
Turbine: Condensing turbine				
J	Gross Power Output [MW]		33.745	
K	Gross Power Output corrected [MW]*		34.476	
Steam export				
L	Amount [t/h]		64.36	
M	Temperature[°C]		236.5	
N	Pressure [bar]		14.863	
O	Specific enthalpy [kJ/kg]		2892.1	

Table 4-7: Parameters of the Waste incineration plant (line 1 and 2)

Part of the plant n.1				
#	Parameter	Value	origin	Related term
P	Steam flow to the industry [t/h]	64.36	From performance test document	
Q	Total Energy input [MW]	54.085	= D * P / E	Q_{th}
R	Thermal power output [MWth]	43.574	= P * (O - I) / 3.6	Q_{de}
S	Enthalpy after HP turbine	2956.7	From performance test	
T	Power production [MWel]	3874.6	= P * (H - S) * η_e	W_e

$$\eta_h = \frac{W_e + Q_{he} + Q_{de} + Q_i}{Q_{th}} = 87.73\% \quad \eta_e = 92.5\% \text{ is the factor that takes into account mechanical and electrical losses}$$

Part of the plant n.2				
#	Parameter	Value	Origin	Related term
U	Steam flow to the turbine [t/h]	139	= E - P	
V	Total Energy input [MW]	116.809	= D * U / E	Q_{th}
W	Pressure at the condenser [bar]	0.072	Performance test document	
Y	Power output [MW]	30.601	= K - T	W_e

$$\eta_e = \frac{W_e}{Q_{th}} \times \left(\frac{Q_b}{Q_b - Q_i} \right) = 26.2\% \quad Q_i = 0$$

Table 4-8: Calculation of energy efficiency for part 1 and part 2

*Correction factor							
Correction Coefficients Gross Power Output							
Process steam pressure				δ_1	0.99730	out of correction curve range	
Extraction flow no. 1 correction				δ_2	1.00430	Process steam mass flow and t prim. air	
Make up water temperature				δ_3	1.00050		
Cold water to condenser temperature				δ_4	1.00000	temperature kept constant at 22.00°C	
Secondary air temperature				δ_5	1.00130	HP steam output correction for t sec. air	
Ageing Steam Turbine (IEC 953-2)				δ_6		separate calculation	
Correction Factor GPO Π (δ_1 δ_6)					1.00340		
Correction to match the nominal thermal load					1.01812		

Table 4-9: Correction factors in the calculation of energy efficiency

The efficiencies of the two parts should not be summed up to calculate the total efficiency.