Conversion of biomass boiler emission concentration data for comparison with Renewable Heat Incentive emission criteria

Report for Defra

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Contact:

Robert Stewart
AEA Technology plc
Gemini Building, Harwell, Didcot, OX11 0QR
t: 0870 190 6575
e: Robert.stewart@aeat.co.uk

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AEA is certificated to ISO9001 and ISO14001

Author:

Robert Stewart

Approved By:

Geoff Dollard

Date:

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Signed:

Executive summary

Defra commissioned AEA to develop a methodology for translating the RHI emission criteria of 30g/GJ PM and 150g/GJ NOx into emission concentration data, or vice versa.

This guidance provides details of how test houses can convert emission concentrations to the units of the RHI emission criteria.

The conversion guidance is intended for boilers burning wood or woody biomass based on literature values; additional conversion factors for other solid biomass fuels are also provided.

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1 Introduction

The Renewable Heat Incentive (RHI)[1] is intended to provide long-term support for renewable heating technologies as part of the UK Government's strategy to reduce carbon emissions. Heating from use of biomass boilers is one of the key bioenergy technologies supported by the RHI but the Government also recognises the importance of controlling emissions from the burning of biomass. The RHI has introduced emission limits for total particulate matter (PM) and oxides of nitrogen (NOx) :

Pollutant	NOx	PM
Emission limit, g/GJ	150	30
Note : The emission limits are expressed as grammes of pollutant per GigaJoule of net energy input. Nitrogen oxides are expressed as nitrogen dioxide (NO_2).		

Defra has published guidance on how operators can demonstrate compliance with the RHI emission criteria[2]. The Defra guidance envisages that suitably accredited test houses will provide an RHI emissions certificate (RHI-ec) based on accredited measurements[3].

In general, emission measurements are reported as emission concentrations, for example mg/m^3 (at specified reference conditions). Defra commissioned AEA to develop a methodology for translating the RHI emission criteria of 30g/GJ PM and 150g/GJ NOx into emission concentration data, or vice versa, and to produce what is in effect a ready-reckoner.

This guidance provides details of how test houses can convert emission concentrations to the units of the RHI emission criteria.

The conversion guidance is for wood or woody biomass based on literature values summarised in Annex A, additional conversion factors for other solid biomass fuels are provided at Annex B.

[1] Details here : http://www.decc.gov.uk/en/content/cms/meeting_energy/renewable_ener/incentive/incentive.aspx
[2] Defra RHI guidance : http://archive.defra.gov.uk/environment/quality/industrial/guidance/rhi-guidance.pdf
[3] Tests undertaken prior to October 2012 by a test house which was not at the time accredited in accordance with ISO 17025 will be acceptable if, by 1 October 2012, the test house was accredited to that standard.

2 Basis of conversion

There are a number of ways to get from a measured emission concentration to a g/GJ 'emission factor'. Some methods require measurement of fuel consumption, flue gas flow and analysis of fuel samples. However sampling facilities and metering on boiler installations are often not ideal which can lead to high uncertainties in some of these measurements (particularly when testing outside a laboratory environment).

The approach described in this guidance minimises measurement burdens for applicants and avoids sources of uncertainty associated with measurement of fuel flow, flue gas flowrate and (for wood) fuel sampling and analysis. The approach is based on use of the stoichiometric flue gas volume for the fuel – either based on a default stoichiometric flue gas volume or a flue gas volume determined by analysis of the fuel.

2.1 Theory

Combustion of any fuel requires air (oxygen) and produces flue gas. For a given quantity of fuel it is possible to calculate the theoretical (stoichiometric) dry flue gas volume generated from combustion of the fuel and hence the total dry flue gas volume of the combustion products and excess air at specified reference conditions including oxygen content (the specific dry flue gas volume). Typically such calculations assume flue gases behave as ideal gases but more sophisticated models can incorporate corrections for real gas behaviour.

It is possible to convert an emission concentration to a g/GJ emission factor using a specific dry flue gas volume factor (SDFGV).

Essentially :

EF = [Conc] x (SDFGV) ÷ 1000

Where :

EF = Emission Factor, g/GJ net heat input

[Conc] = Pollutant concentration, mg/m^3 dry flue gas at 0°C, 101.3 kPa and at a defined Oxygen concentration

(SDFGV) = Specific dry flue gas volume per GJ net heat input, m^3/GJ - for dry flue gas at 0°C, 101.3 kPa and at the same defined oxygen concentration as the pollutant concentration.

The factor of 1000 is to convert milligrammes to grammes. The key part is that the reference conditions of the volume components of the concentration and the specific flue gas volume need to be the same – a dry flue gas at 0°C, 101.3 kPa and at the same defined oxygen concentration. Typically the reference oxygen content for wood combustion is 6, 10 or 11%.

2.2 Specific dry flue gas volume

A number of stoichiometric and specific flue gas volumes for wood were sourced from literature and the internet (details at Annex A). For the purposes of the RHI calculation a specific dry flue gas volume based on the minimum value found in the literature has been used[4].

Specific dry flue gas volumes for wood, m^3/GJ (net heat input, dry gas at 0°C, 101.3 kPa)					
Oxygen content, % (dry)	0 (stoichiometric)	6	10	11	[N] (where [N] is the O_2 concentration)
Specific dry flue gas volume, m^3/GJ	253	354	483	531	253 x (21÷(21-[N]))

Note that the specific dry flue gas volume can also be calculated from the fuel analysis – this may be relevant for non-wood biomass fuels.

2.3 Emission concentrations

It is presumed that an accredited test house can develop standardised (mg/m^3) emission concentrations from measured data – the EN Standards EN13284-1 (for PM) and EN 14792 (NOx) each provide guidance on how to develop standardised emission concentrations from measured concentrations.

2.4 RHI Criteria as concentrations at different reference conditions

The following table provides a quick reference to check whether emission concentrations are likely to meet the RHI criteria.

Pollutant	RHI Criteria, g/GJ net thermal input	Emission concentrations at specified O_2 (%, dry), mg/m^3 (dry gas at 0°C, 101.3 kPa)				
		0	6	10	11	[N]
PM	30	119	85	62	56	30 x 1000 ÷ 253 x ((21-[N])÷21)
NOx	150	593	423	311	282	150 x 1000 ÷ 253 x ((21-[N])÷21)

2.5 Other biomass fuels

Annex B provides some specific dry flue gas volumes for other solid biomass fuels including straw and other crop products. These have been determined using analysis data from BS EN 14961 Pt 1 on solid biomass fuel classes[5] and a calculation methodology based on energy, ash and moisture content described in BS EN 12952 Pt 15 describing acceptance test procedures for water-tube boilers[6].

[4] This gives some benefit to boilers which have emissions close to the RHI emission threshold however, the benefit is small (the minimum specific dry flue gas volume is within 6% of the mean literature volume) and is unlikely to be significant in terms of air quality impacts from an individual installation.
[5] BS EN 14961-1:2010 Solid biofuels. Fuel specifications and classes. General requirements
[6] BS EN 12952-15:2003 Water-tube boilers and auxiliary installations. Acceptance tests

Annexes

Annex A - Specific dry flue gas volumes from literature

Source	Specific dry flue gas volume (stoichiometric) m^3/GJ dry gas at 0°C, 101.3 kPa, and 0% O_2	Specific dry flue gas volume (10%, O_2) m^3/GJ dry gas at 0°C, 101.3 kPa, and 10% O_2	Fuel	Comment
USEPA Method 19	262	502	Wood	Converted from stoichiometric volume at 20'C and for gross heat input.
USEPA Method 19	272	522	Wood bark	
Danish CHP report	272	519	Wood	Converted from stoichiometric volume.
Danish CHP report	270	515	Straw	
Engineering toolbox	278	530	Wood	Converted from stoichiometric volume on fuel mass basis, net fuel CV from EN303-5 applied.
Technical data on fuel	273	521	Wood	Converted from wet stoichiometric volume on fuel mass basis.
EPUK guidance on biomass	253	483	Wood	Converted from stoichiometric volume, generic wood analysis.
Analysis :			**Percentage of mean**	
Min	253	483	94.1	
Max	278	530	103.3	
Average	269	513		
Median	272	519		
Std Deviation	8.4	15.9	3.1	

References :

1. USEPA Method 19 : US Environmental Protection Agency Method 19 available here : http://www.epa.gov/ttn/emc/promgate/m-19.pdf (table 19-2, Fd values). Converted to net thermal input basis using calorific values for wood published in DUKES (Digest of UK Energy Statistics) published by DECC here : http://www.decc.gov.uk/assets/decc/11/stats/publications/dukes/2293-dukes-2011-annex-a.pdf
2. Danish CHP report : Nielsen, M et al, Emissions from decentralised combined heat and power (CHP) plants 2007 - Energinet.dk Environmental project no. 07/1882. - Project report 5 – Emission factors and emission inventory for decentralised CHP production. NERI Technical Report No. 781, 2010. Here : http://www.dmu.dk/en/news/artikel/emission_factors_for_decentralized_combined_heat_and_power_chp_plants/
3. Engineering toolbox : flue gas volumes for different fuels including dry wood. Here : http://www.engineeringtoolbox.com/fuels-air-flue-gas-d_170.html Net CV for dry wood in EN303-5 applied.
4. Technical data on fuel, Rose and Spiers (1971), stoichiometric flue gas analysis and calorific value for wood provided.
5. EPUK guidance on biomass : units conversion spreadsheet available here http://www.environmental-protection.org.uk/biomass/ a stoichiometric flue gas volume for wood can be derived from emissions sheet.

Annex B - Specific dry flue gas volumes for straw and other solid biomass fuels

Solid biomass type	BS EN 14961 Pt 1 typical analysis for solid biomass (dry basis)			BS EN 12952 Pt 15, Stoichiometric dry flue gas volume (dry basis)		Specific dry flue gas volume (stoichiometric volume per unit of net heat input)			Dry flue gas vol. at 10% O_2
	CV(Gross)	CV(Net)	Ash	Based on gross CV	Based on net CV	Based on gross CV	Based on net CV	Average	Average
	MJ/kg	MJ/kg	%	m^3/kg	m^3/kg	m^3/GJ	m^3/GJ	m^3/GJ	m^3/GJ
Coniferous wood	20.5	19.1	0.3	4.80	4.80	251	251	251	479
Broad-leaf wood	20.1	18.9	0.3	4.69	4.75	248	251	250	477
Coniferous wood (bark)	20.4	19.2	1.5	4.78	4.82	249	251	250	477
Broad-leaf wood (bark)	20.0	19.0	1.5	4.67	4.77	246	251	249	475
coniferous wood	20.5	19.2	3.0	4.81	4.83	251	251	251	479
broad-leaf wood	19.7	18.7	5.0	4.61	4.70	247	251	249	475
Willow (salix)	19.9	18.4	2.0	4.65	4.62	253	251	252	481
Poplar	19.8	18.4	2.0	4.62	4.62	251	251	251	480
Straw (wheat, rye, barley)	18.8	17.6	5.0	4.38	4.42	249	251	250	477
Straw (oilseed rape)	18.8	17.6	5.0	4.38	4.42	249	251	250	477
Grain (wheat, rye, barley)	18.0	16.5	2.0	4.15	4.14	252	251	251	480
Grain (rape)	28.1	26.6	4.3	6.80	6.71	256	252	254	485
reed canary grass (summer)	17.7	16.6	6.5	4.10	4.17	247	251	249	475
reed canary grass (spring)	17.8	16.5	6.9	4.13	4.14	250	251	251	478
grass (hay)	18.0	17.1	7.0	4.18	4.29	244	251	248	473
Miscanthus	19.0	17.7	4.0	4.43	4.44	250	251	251	478
Olive cake (crude)	20.4	19.4	10.0	4.82	4.88	249	252	250	477
Olive cake (spent)	19.9	16.6	7.4	4.67	4.15	282	251	-	-
Olive kernels	19.7	18.3	2.8	4.60	4.60	251	251	251	480
Grape cake (crude)	20.7	16.7	7.9	4.88	4.19	292	251	-	-
Almond, hazel, pinenut shells	19.5	18.3	2.0	4.54	4.58	249	251	250	477
Rice husk	15.7	15.4	18.0	3.63	3.86	236	251	-	-
Sunflower husk	20.5	19.5	4.8	4.82	4.90	247	251	249	476
Pennsylvania malva	19.0	17.7	2.8	4.42	4.44	250	251	250	478

Note :

Analyses are typical values for various materials provided in BS EN 14961 Pt 1 and are on a dry basis.

Flue gas volumes are calculated using equations provided in BS EN 12952 Part 15 from fuel analysis in BS EN 14961 Pt 1 and are for a dry gas at STP (0°C, 101.3 kPa) and at stoichiometric (0% O_2) unless noted otherwise.

AEA
The Gemini Building
Fermi Avenue
Harwell
Didcot
Oxfordshire
OX11 0QR

Tel: 0870 190 1900
Fax: 0870 190 6318

www.aeat.co.uk