GUIDANCE NOTE 29

ALTERNATIVE FUELS – ENERGY INPUTS

BASIS OF ENERGY INPUTS

GN29.1

For CHPQA all fuel energy inputs must be based on actual gross calorific value (GCV) in the as-fired condition. GCV is also referred to as higher calorific value (HCV) or higher heating value (HHV). Since determination of calorific value (CV) in the laboratory is normally based on dry fuel, knowledge of the moisture content of the fuel as fired is also required.

CALORIFIC VALUE

GN29.2

For solid and liquid fuels the CV determined in the laboratory using a bomb calorimeter is GCV at constant volume. For solid fuels this is normally carried out on air-dried fuel (i.e. a sample of fuel that has been allowed to dry to equilibrium with its surroundings in dry well-ventilated surroundings). Since the residual (inherent) moisture remaining in the sample has an effect on the determined CV, this moisture is determined separately by drying a weighed sample at 105°C in an oven until no further weight loss occurs. A correction is then applied to give the GCV on a dry fuel basis.

Other calorific values, namely GCV at constant pressure, Net CV (NCV) at constant volume and NCV at constant pressure are derived by calculation from the laboratory determination using equations presented in BS 7420:1991.

GN29.3

For gaseous fuels the CV determined in the laboratory using a gas calorimeter is GCV at constant pressure. Other CVs are derived from the laboratory determination using equations presented in BS 7420:1991. With sophisticated gas analysis techniques that are now available, CV calculated from the analysis using standard CV data for the constituent components of the gas has largely superseded the use of gas calorimeters.

GN29.4

The distinction between GCV at constant volume and GCV at constant pressure (a function of the hydrogen and oxygen contents of the fuel) is unimportant, as it is normally less than the uncertainty associated with the determination.

GN29.5

The distinction between GCV and NCV is important. In the determination of GCV the products of combustion are cooled to 15°C. This means that almost all of the water vapour, whether formed from the combustion of the hydrogen within the fuel or through the evaporation of the fuel's moisture content, is condensed to liquid water. This condensation gives up latent heat, which is therefore included in the GCV. Proponents of NCV claim that because this latent heat is not recoverable in combustion plant such as boilers, it ought to be discounted. This results in the NCV, which is more representative of the heat obtainable in practice from the combustion of the fuel (note however that condensing economisers do recover and utilise some of the latent heat.)

The difference between GCV and NCV depends on the moisture content and the hydrogen content of the fuel. For natural gas, which is effectively dry and is composed predominantly of methane (25% hydrogen and 75% carbon by weight) NCV is approximately 10% lower than GCV. For most dry fuels the difference is less than 10%, typically 4% – 6% for coals and oil fuels but can be much greater for fuels that contain large proportions of moisture. For wood containing 60% moisture the ratio NCV/GCV is approximately 0.75.

DETERMINATION OF CALORIFIC VALUE

GN29.6

For gaseous alternative fuels it is recommended that continuous gas analysis by chromatograph or equivalent is undertaken, with data processing used to determine the component analysis and CV. Where moisture in the sample is removed before analysis, this too must be quantified to determine the CV in the as-fired condition. In the absence of continuous analysis, regular samples should be taken for off-line laboratory analysis with sufficient frequency that a reliable record of CV can be maintained.

GN29.7

For solid and liquid alternative fuels the CV should be determined by calorimetry using samples that have been collected and prepared in accordance with the appropriate standards. Determination of as-fired moisture content is also required. It is appreciated that representative sampling of some alternative solid fuels presents significant practical difficulties. However, even where one of the alternative approaches outlined below is acceptable, a supporting regime of sampling and analysis, including determination of moisture content, is required.

GN29.8

For solid and liquid alternative fuels, an alternative to calorimetry, which nevertheless still requires representative sampling, is to determine the ultimate (elemental) analysis of the fuel. This requires the determination of the carbon, hydrogen, sulphur, oxygen and nitrogen contents. The resulting analysis may then be used with an empirical formula to calculate the CV.

One such formula that has been widely adopted for biofuels is that published by the US Institute of Gas Technology (IGT) in the Coal Conversion Systems: Technical Data Book (1978). Although originally derived from data on coal, the formula has been shown to give acceptable results for a wide range of carbonaceous materials including biomass and chars.

$$GCV_{dry}\text{, MJ/kg} = 0.341C + 1.322H - 0.12(O+N) + 0.0686S - 0.0153Ash$$

Where:

C = carbon weight % in dry fuel

H = hydrogen weight % in dry fuel

O = oxygen weight % in dry fuel

N = nitrogen weight % in dry fuel

S = sulphur weight % in dry fuel

Ash = ash weight % in dry fuel.

GN29.9

For solid alternative fuels, particularly biomass, there is a vast amount of data in the public domain. The ASME Research Committee on Industrial and Municipal Wastes published two reports in 1974 and 1978. This was expanded in 1986 under the sponsorship of the DOE Office of Renewable Technology to provide information on more than 600 substances in Thermodynamic Data for Biomass Conversion and Waste Incineration (Solar Energy Research Institute), later published by ASME. This can be accessed via the Information Bridge of the US DOE Office of Scientific and Technical Information (OSTI) at http://www.osti.gov/bridge as document 7038865.

The Energy Research Centre of the Netherlands (ECN) maintain the "PHYLLIS" database for biomass and waste[1]. This contains data on over 2,400 substances, including CVs based on calorimetry and calculated from ultimate analysis. This uses the IGT formula (referring to it as the Milne formula after one of the authors of the DOE reports) as shown in GN29.8 to calculate CVs.

EXPRESSION OF CALORIFIC VALUE AND CONVERSIONS

GN29.10

For CHPQA the relevant CV is the gross calorific value as-fired (GCV_{af}). This takes account of the moisture content of the fuel at the CHP boundary. Often the term "as-received CV" is used, meaning the CV taking account of the moisture content as received at the laboratory before any laboratory processing or conditioning. Providing there is no change in moisture content between the stockpile and the laboratory the two CVs are identical. For consistency with other sources this will be assumed to be correct and the abbreviation GCV_{ar} will be used instead of GCV_{af}.

GN29.11

The majority of analytical determinations on solid fuels are carried out on samples that have been air-dried until in equilibrium with the laboratory atmosphere. The results reported under these conditions are reported on the air-dried (ad) basis, but for most purposes it is necessary, and the results are more meaningful, if they are corrected to other bases, for example dry (dry), dry ash-free (daf) or, rarely for biomass, dry mineral matter-free (dmmf).

Calculation of GCV_{ar} from the dry or dry ash-fee bases are:

$$GCV_{ar} = GCV_{dry} \times (100 - m) / 100$$

$$GCV_{dry} = GCV_{daf} \times (100 - Ash_{dry}) / 100$$

Where:

m = moisture (as received), weight %

[1] https://phyllis.nl/Browse/Standard/ECN-Phyllis

= 100 x weight of moisture / (weight of dry fuel + weight of moisture)

Ash_{dry} = ash content (dry basis), weight %

GN29.12

Since some published data is reported in terms of NCV it is important to be able to convert between the two bases.

The conversions presented below require knowledge of the hydrogen content and ash content of the fuel as well as the moisture content:

$GCV_{dry} = NCV_{dry} + (2.442 \times 8.936 \times H_{dry}) / 100$

$NCV_{dry} = GCV_{dry} - (2.442 \times 8.936 \times H_{dry}) / 100$

$NCV_{ar} = NCV_{dry} \times (100 – m)/100 – 2.442 \times m / 100$

$NCV_{dry} = NCV_{daf} \times (100 – Ash_{dry}) /100$

Where:

GCV = gross calorific value, MJ/kg

NCV = net calorific value, MJ/kg

m = moisture (as received), weight %

H_{dry} = hydrogen content (dry basis), weight %

2.442 = latent heat of vaporisation of water at 25°C, MJ/kg

8.936 = kg of water formed by combustion 1-kg of hydrogen

Table GN29-1 illustrates the relationship between GCV and NCV as a function of moisture content. The table applies to wood fuels with a typical hydrogen content of 6% by weight (dry).

Table GN29-1 – Relationship between GCV and NCV

Wood Fuel Calorific Values						
Dry Net CV	MJ/kg	18.3				
Hydrogen % (dry)	Wt %	6.00				
Latent heat of vaporisation of water	MJ/kg	2.442				
Moisture	wt %	0	10	20	30	40
= moisture / (moisture + dry wood)						
Net CV (as received)	MJ/kg	18.300	16.226	14.152	12.077	10.003
Hydrogen content (as received)	wt %	6.0	5.4	4.8	4.2	3.6
Gross CV (as received)	MJ/kg	19.608	17.648	15.687	13.726	11.765
Dry Gross CV	MJ/kg	19.608	19.608	19.608	19.608	19.608
Gross/Net CV (dry)		1.071	1.071	1.071	1.071	1.071
Gross/Net CV (as received)		1.071	1.088	1.108	1.136	1.176
Moisture	wt %	50	60	70	80	90
= moisture / (moisture + dry wood)						
Net CV (as received)	MJ/kg	7.929	5.855	3.781	1.706	-0.368
Hydrogen content (as received)	wt %	3.0	2.4	1.8	1.2	0.6
Gross CV (as received)	MJ/kg	9.804	7.843	5.883	3.922	1.961
Dry Gross CV	MJ/kg	19.608	19.608	19.608	19.608	19.608
Gross/Net CV (dry)		1.071	1.071	1.071	1.071	1.071
Gross/Net CV (as received)		1.237	1.340	1.556	2.298	N/A

DETERMINATION OF ENERGY INPUTS

GN29.13

Whenever possible, energy inputs shall be determined by the direct method, i.e.

$$\text{Energy input, MJ} = \text{Mass of fuel as-fired, kg} \times GCV_{ar}\text{, MJ/kg}$$

$$\text{Energy input, MWh} = \text{Energy input MJ} / 3{,}600$$

This imposes three requirements:

- Measurement of the weight of fuel used (GN29.14);
- Measurement of, or reliable data on, its GCV_{dry} (GN29.15);
- Measurement of its moisture content (GN29.16).

GN29.14

For solid and liquid fuels an acceptable method of measuring fuel inputs is based on deliveries (weighbridge tickets) and opening and closing stocks, except where a change in moisture content in stock occurs, e.g. dewatering of solid waste can occur. Other methods for solid fuels include belt weighers and grab weighers providing these are calibrated as required under CHPQA. For liquid and gaseous fuels in-pipe flow measurement is appropriate, again with appropriate calibration.

GN29.15

For all fuels the direct method requires reliable CV data. In cases where the fuel is reasonably homogenous this is a relatively simple matter of regular sampling and analysis, or continuous analysis for gases. However, for some solid fuels the very nature of the fuel means that representative sampling and/or sample preparation is problematic. In the case of municipal solid waste (MSW), refuse derived fuel (RDF) and secondary refuse fuel (SRF) it may be appropriate to determine the make-up of the waste in terms of its components (e.g. paper, cardboard, organic matter, various plastics, wood, disposable nappies, etc.).

CVs of the components may then be determined or obtained from databases. Moisture contents of the components are also required (GN29.16.).

Standards dealing with “Characterisation of Waste – Sampling of Waste Materials” are BS PD CEN/TR 15310:Parts 1-5:2006 and BS EN 14899:2005.

GN29.16

For solid and liquid fuels, the collection of reliable data on moisture content is necessary in order to derive GCV_{ar}. This is particularly important where the moisture content is variable. For non-homogenous fuels the moisture content of the component parts may be required.

GN29.17

For fuels where the measurement of mass flow or derivation of a representative CV is not feasible it may be possible to devise a more reliable value of the energy input by an adaptation of the losses method (GN14.11). This will still require moisture content data for the fuel as well as recording of the boiler steam output and regular measurement or recording of the boiler flue gas temperature and its oxygen content. This approach will be site-specific since the calculation depends on the particular boiler design (e.g. air pre-heaters, soot blowers, feedwater heating arrangements). Sites proposing to use this approach for self-assessment must present the calculation method, all supporting information and an example spreadsheet to CHPQA for prior approval.

GN29.18

For all energy inputs it is necessary to derive the level of uncertainty associated with the value used and where necessary to apply the excess uncertainty adjustment factor FOI as for conventional fuels. In addition, any meters that are used in the derivation of the energy inputs need to be regularly calibrated in compliance with an agreed schedule.

