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HEATING VALUE OF GASES FROM BIOMASS GASIFICATION

**Report prepared for: IEA Bioenergy Agreement,
Task 20 - Thermal Gasification of Biomass**

Lars Waldheim, Torbjörn Nilsson

TPS Termiska Processer AB

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ABSTRACT

On behalf of the International Energy Agency Bioenergy Agreement subcommittee on Thermal Gasification of Biomass, an enquiry was sent to a number of organisations involved in gasification activities asking about the methods and data sources that are used for the heating values of the components forming the gases produced in gasification and similar processes.

The result of the approximately dozen replies received is that thermodynamic data from any of the common sources could be used to estimate sufficiently accurately the heating values for gases. For the bulk gas components, the component data used by various organisations had a standard deviation of less than 1 %. Even if one single set of component data was used globally, the error associated with the analysis of the gas components contributes more to the total uncertainty.

However, the data used in any application should be verified, as there is always a risk of (human) errors being introduced when copying data from one application/source to another, as was also manifested in the replies to the questionnaire.

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1 Background

During the last few years, there has been an effort to consolidate the various practices used within the area of biomass renewable energy and gasification of biomass. Since 1998 there have been several new initiatives to standardize biomass fuel and their characterisation, and also the procedures for sampling and measurement of tar in the gasifier product gas.

In addition to these efforts, it was suggested at a meeting of the International Energy Agency Bioenergy Agreement, Task 20 - Thermal Gasification of Biomass, in Bruxelles in March 1998, to review the fuel gas component energy content data used for estimating the heating value of the gasifier product gas. TPS was requested to carry out this assessment. The purpose was to determine if the heating value of the fuel gas, reported by various entities, were significantly influenced by the particular set of component thermochemical data used by these entities. The reason for deviations in such data could be due to combination of the following factors;

- Original data sources show a spread in the heating value of fuel gas components
- Early data in hand book tables may originate from the time when the O16 atomic mass reference was still in use, while current data is on the C12 atomic mass reference, thus seemingly causing a spread between sources
- Errors in transferring the original data to handbook tables or equivalent
- Errors in transferring data from the handbook tables to the user calculations
- Errors in conversion of HHV to LHV
- Errors in conversion of imperial to SI units, or vice versa
- Errors when referring to standard conditions, i.e. that the temperature reference for scf and Nm³ differs by some degrees
- Etc., etc.

To limit the scope of this study, but still produce useful results, the format of the assessment included distributing a survey to various active biomass gasification developers questioning what data was used for the gas component LHV and HHV combustion energy etc, and the corresponding sources, and to compile the results to assess if there were significant deviations.

There was no intention to follow the reference trees back to original data sources, nor to make a review and evaluation of the original sources, as in both cases this would involve far too much effort, given that the existence of significant deviations had not been verified.

2 Result from the Enquiry Replies

An inquiry, see Appendix 3, was sent on behalf of IEA subcommittee on Thermal Gasification of Biomass. It was sent to 80 addressees, see Appendix 4, by email. The addresses all had connection to handling of gases from gasification of biomass. Following questions were given:

1. Unit and standard state for heating value of gases.
2. Components used for calculation of heating value of gases
3. Definition of tar, BTX etc.
4. Average molar weight of lumped components
5. Definition of combustibles in dust

Answers to these questions were returned by 11 addressees, while 4 instead chose to give comments to the inquiry. The full answers are contained in Appendix 1 and comments in Appendix 2.

Rainer Beckman wrote, “*On the pure gas side there is no problem with the heating value. Thermodynamic data for all significant gas species are available and should not vary much between different sources*”. Richard Bain showed that this was not the case, by giving 8 different definitions of the unit for amount of gas. The participants preferred the following units, giving predominance for SI units:

Table 1. Preferred units and basis for calorific value for gas.

	Unit	Number of users
Mass	m ³ at 273.15 K, 0.1013 Mpa	6
	g-mole	5
	kg	1
Entahlpy	J at 298.15 K, 0.1013 Mpa	11
	cal at 298.15 K, 0.1013 Mpa	1
Net or gross	Net	4
	Gross	2
	either	5
Dry or wet	Dry basis	2
	not specified	9

The heating value of combustibles in dust may comprise a considerable part of the heating value of a dusty gas, but only 2 participants mentioned the use of calorific values of the dust. The combustibles in dust are usually measured by combustion to constant weight at about 600°C. One participant soaks the ash sample with CH₂Cl₂ for removing condensed tar before the analysis. One participant made calorimetric analyses of the ash samples, and three responders used ultimate analysis to ensure that the carbon fraction of the combustibles is determined.

Tar usually includes C₆H₆ and heavier carbon compounds that are soluble in CH₂Cl₂. Tar may also comprise a considerable fraction of the heating value of a gas, even if it is cleaned and dried. Tar contents are measured from the condensates by 4 participants. Light tar components are probably measured by gas chromatography direct on gas samples by 3 participants, while 4 participants do not mention anything about tar sampling.

The calorific value of C₆H₆ was stated by 7 participants, and 3 participants also gave calorific values for some other tar molecules. Only 2 participants give lumped calorific values for tar. One organisation uses 30 MJ/kg for all tar. This is a low value and can only valid for tar with a high moisture or oxygen content, i.e. typical for low temperature formation.

Molar weight for tar is used when estimating the density and the calorific value per mole or m³ for a tarry gas. Molar weights for tar was given by 4 participants, of which 3 gave rather high values, that cannot reflect the usually very high fraction of benzene in tar. It is of course possible to use individual molar weights for main tar components as benzene and naphthalene, and this might be the practice by some participants, although it is not mentioned.

Thermodynamic data from different sources should not differ much, and with a few exceptions they do not. Table 1 shows thermodynamic data used by different companies, all entries converted to MJ/Nm³.

Table 2. Calorific values in MJ/Nm³.

Component	H2	CO	CH4	C2H6	C2H4	C2H2	Company
HHV	12.745	12.633	39.819	70.293	63.414		TU Wien
	12.769	12.622	39.781	69.693	63	58.059	NREL
	12.753	12.626	39.721	69.595	62.952		ECN
	12.766	12.641	39.847	70.402	63.998	58.975	DMT
	12.761	12.634	39.747	69.636	62.989	58.039	Carbona
	12.76	12.617	39.663	69.511	63.042	57.934	Univ. Sherbrook
	12.758	12.631	39.739				Vattenfall
	12.761	12.634	39.75	69.642	62.994	58.022	Nykomb
LHV	10.783	12.633	35.883	64.345	59.457		TU Wien
	10.788	12.622	35.814	63.748	59.036	56.078	NREL
	10.789	12.626	35.796	63.704	59.024		ECN
	10.8	12.6	35.8	63.71		56.03	Verenum
	10.757	12.641	35.787	64.333	59.938	56.924	DMT
	10.748	12.634	35.725	63.605	59.011	56.028	Carbona
	10.793		35.81				Vattenfall
	10.8	12.634	35.823	63.756	59.07	56.06	Nykomb
	10.797	12.635	35.821	63.749	59.068		TPS
	10.789	12.630	35.812	63.744	59.033	56.088	Bioelettrica
Component	C3H8	C3H6	i-C4H8	i-C4H10	n-C4H10	C6H6	Company
HHV	101.242	93.576	125.088	133.119	134.061		TU Wien
	99.091	91.879				142.893	NREL
						147.299	ECN
	101.794	94.343	121.843	131.972	133.981	146.329	DMT
	99.108	91.894		128.502		147.385	Carbona
	98.244					147.143	Univ. Sherbrook
	99.116	91.902	120.696	128.207	128.513	147.398	Nykomb
LHV	93.215	87.575	116.934	122.91	123.81		TU Wien
	91.163	85.934				141.41	NREL
						141.408	ECN
	93.548	88.191	113.806	121.592	123.517	140.301	DMT
	91.066	85.862		118.449		141.352	Carbona
	91.268	86.016	112.848	118.703	118.703	141.512	Nykomb
	91.164	85.925	113.371	117.668	118.569	159.502	Bioelettrica
Component	NH3	H2S	Company				
HHV	13.072	25.105					ECN
		25.07					Kvaerner
	17.245	25.7					DMT
	17.094	25.123					Carbona
	25.096						Nykomb
LHV	10.128	23.142					ECN
		23.12					Kvaerner
	14.189	23.69					DMT
	14.079	23.134					Carbona
	14.132	23.152					TPS
	23.113						Bioelettrica

Table 3 gives standard deviations in the used values, after some exclusions of individual values, see the lines below the table.

Table 3. Standard deviations, %.

Component	H2	CO	CH4	C2H6	C2H4	C2H2
HHV	0.06	0.06	0.14	0.52	0.61	0.74
LHV	0.18	0.09	0.11	0.44	0.56	0.63
Component	C3H8	C3H6	i-C4H8	i-C4H10	n-C4H10	C6H6
HHV	1.41	1.26	1.86	1.89	2.41	0.31
LHV	1.25	1.19	1.61	1.89	2.40	0.36
Component	NH3	H2S				
HHV	0.62	1.07				
LHV	0.32	0.98				

The excluded values are:

LHV(H2) from TUWien, where 2 digits seem to be given in wrong order.

LHV(C2H4) from Verenum, which is obviously for C2H2

HHV(C6H6) from NREL, which is not in agreement with their LHV(C6H6)

LHV(NH3) and HHV(NH3) from ECN which are very low.

LHV(C6H6) from Bioelettrica which has a printing error.

The standard deviations for the main components in gases from biomass are quite low in table 2. The German sources, DIN51850 and Messer-Griesheim, "Gase-Handbuch" give higher values for the heat of combustion of C2 – C4 compounds than the US sources. However, the fraction of these compounds in gases from biomass is low.

It is interesting that almost every participant uses unique sources for his thermodynamical data. The exception is that two participants cited the 5th edition of "Perry's Chemical Engineers' Handbook" and another two the 6th edition, and one cites the 7th edition.

Used sources are:

1. DIN 51 850, April 1980
2. Annual Book of ASTM Standards, Vol 05.05, D3588-91 Standard Practice for Calculating Heating Value, Compressibility Factor and Relative Density of Gaseous Fuels.
3. API; Technical Data Book – Petroleum Refining, metric edition, vol 1 and 2. Washington, American Petroleum Institute, 1977 – 1981.
4. STFI, 1989
5. Barin, Thermochemical data or pure substances, VCH (1993)
6. Barin, Thermochemical data or pure substances, VCH (1995)
7. Knacke, 1991
8. Messer Griesheim: Gase-Handbuch, 90.1101, 3rd edition, Frankfurt
9. Große, et. Al. : Arbeitsmappe für Mineralölingenieur, VDI-Verlag Düsseldorf, 1962
10. Perry´s "Chemical Engineers´ Handbook" 5th edition page 3-145

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12. Perry's Chemical Engineers' Handbook 7th ed.
13. Rossini, F D, Selected Values of Physical and Thermodynamic Properties of Hydrocarbons and Related Compounds, Am. Petroleum Inst. Research Proj. 44, Carnegie Institute of Technology (1952)
14. Projet BIOSYN; Report IREQ N0 1; Mass & Energy Balances; 1986
15. Handbook of Chemistry & Physics, 66th Ed., 1985-1986
16. Reid, Sherwood, Prauznitz, "Properties of Gases and Liquids"
17. Hougen, Watson, Ragatz, "Chemical Process Principles" Part 1. 2nd Ed. Wiley I E. (1966)

3 Discussion and Conclusion

In general, it can be concluded that the "human factor" is one of the main causes of introducing deviations. When selecting a data source, the number of sources used indicate that the initial choice of one particular set of component is most likely done on a convenience basis, i.e. the closest and most familiar reputable handbook in the bookshelf is picked and accepted, rather than trying to look for more universal standards such as DIN, NBS or equivalent, or by selecting the handbook based on reference to such sources.

Secondly, also when considering the number of excluded data from the replies to this enquiry, the human involvement when transferring data from the source and to the user data bank and onwards into various applications becomes quite apparent. Minor and less noticeable deviations are introduced when changing the units from the source to the ones found convenient for use.

It can be noted as a matter of curiosity that the cited source for information is different for the various editions of Perry's "Chemical Engineers' Handbook", hopefully the 7th editions have better data than the previous editions, which are apparently still, for convenience and familiarity, in use.

Disregarding the human factor, the data from the enquiry replies give for most components standard deviations of less than 1%, in particular for the most prominent components of the gas. Only for the C3-C4 alkane/alkene hydrocarbons, the standard deviation is above 1% but always less than 3%. Given the low concentration of these in a typical biomass gas, their contribution to the heating value is so low that it can be disregarded, and thus the observed spread in the data becomes irrelevant.

Secondly, when looking at the bulk components, if e.g. LHV data for CO, H₂, CH₄ and C₂H₄ is selected from Table 1 at random, deviations will be both above and below the average and thus most likely level out to less than 1%, when weighted together.

The procedure for establishing the gas heating value in most cases is that the gas is analysed for its composition, and the heating value is estimated from this analytical report and the component data. The weak link in this case is the analyses itself, involving calibration procedures, sampling, sometimes combining analytical data from different equipment e.g. TCD, IR, GC, MS etc. used for various components, correct for air leakages, water vapour and deviations from summing to 100% by normalisation etc. Even if individual components can, in principle, be measured as accurately as 1%, in practice the individual gas components in the ensemble of a gas analysis probably have higher errors.

When combining the gas component heating value with the gas component concentration as measured, the resulting error becomes less than the sum of the errors as the individual errors are independent. When summing up the total heating value from the individual terms, the error will decrease, as deviations are at random above and below the average. Thus, the resulting error becomes less than the error in the input data. By doing this calculation for a gas consisting of 15% of CO and H₂, respectively, 5% CH₄ and 1% C₂H₄ having an estimated heating value, using TPS data, of 5.90 MJ/Nm³, the relative value of improving the data can be assessed. This is illustrated in Table 4 below.

Table 4.

Spread in LHV component data %	Error in component analysis data %	Error in total LHV %	Absolute error MJ/Nm³
1	0	0,5	0,03
1	1	0,7	0,04
0	1	0,5	0,03
1	2	1,2	0,07
0	2	1,1	0,06
1	3	1,7	0,10
0	3	1,6	0,09

As can be seen, the difference between the 1% spread, or error, in component data resulting from this enquiry and a perfect set of component data having no error, is very small in relation to the error introduced by the gas component concentration data. Even if concentration data were perfect with no error, the significance would be low. In effect the analysis above indicate that calculations from measured data should only be given at most with to significant digits.

Therefore, a spread limited to below 1% in the individual component data used by various parties does not significantly distort a comparison of the estimated heating value reported. Establishing one single set of data for general use, compared to the data from a limited number of sources does not yield any major improvement in comparison of reported heating values.

However, it is recommended that each organisation from time to time check the data used in various applications against the source database, as information can be distorted during transfer and combination from more than one source.

Appendix 1
Returned Questionnaires

A1.1 Technical university of Vienna

Name of the organisation	Technical University of Vienna, Institute of Chemical Engineering, Fuel and Environmental Technology
Street Address	Getreidemarkt 9/159
ZIP Code	A-1060
Town	Vienna
State	Austria
Country	Vienna
Person responsible for filling in the questionnaire	Dipl.-Ing. Dr. Reinhard Rauch
Job title	scientific assistant
Phone	+43 1 58801 15954
Fax	+43 1 58801 15999
e-mail	rrauch@mail.zserv.tuwien.ac.at

1. **Which unit do you prefer for the energy content of a gas and its components?**
(e. g. gross BTU of combustion per standard cubic feet, net MJ of combustion per m³, kcal of formation per mole, net MJ/kg etc.).

kJ/Nm³

If you use volume as the basis of the preferred unit, please state the temperature and pressure which defines the standard volume, as this definition sometimes deviates from the more commonly adopted definitions.

0°C, 1013 mbar

2. **Which components do you take into account when you estimate the heating value of a gas?**

Please give the value and the corresponding unit for the heating value you use for these components. The source of the data, if available, can be entered as a number referring to the source reference list below the tables.

Component	H ₂	CO	CH ₄	C ₂ H ₆	C ₂ H ₄	C ₂ H ₂
HHV	12475	12633	39819	70293	63414	
LHV	10783	12633	35883	64345	59457	
Unit	kJ/Nm ³	kJ/Nm ³	kJ/Nm ³	kJ/Nm ³	kJ/Nm ³	
Data source #	DIN 51 850	DIN 51 850	DIN 51 850	DIN 51 850	DIN 51 850	

Component	C ₃ H ₈	C ₃ H ₆	CH ₃ OH	i-C ₄ H ₈	i-C ₄ H ₁₀	n-C ₄ H ₁₀
HHV	101242	93576		125088	133119	134061
LHV	93215	87575		116934	122910	123810
Unit	kJ/Nm ³	kJ/Nm ³		kJ/Nm ³	kJ/Nm ³	kJ/Nm ³
Data source #	DIN 51 850	DIN 51 850		DIN 51 850	DIN 51 850	DIN 51 850

Component	C ₆ H ₆	CH ₃ C ₆ H ₅	(CH ₃) ₂ C ₆ H ₄	C ₁₀ H ₈	CH ₃ C ₁₀ H ₇	Other
HHV						
LHV						
Unit						
Data source #						

Component	BTX	tar	light tar	heavy tar	black tar	Other
HHV						
LHV						
Unit						
Data source #						

Component	NH ₃	HCN	NO	N ₂ O	H ₂ S	COS	CS ₂	S _x
HHV								
LHV								
Unit								
Data source #								

List of references

Data source # 1	DIN 51 850, April 1980
Data source # 2	
Data source # 3	
Data source # 4	
Data source # 5	

3. How do you measure or estimate the tar contents in a gas, as individual components or mixtures of components lumped together as tar, heavy tar etc.?

The tar content is sum of heavy and light tars.

Measurement: A sample gas flow of the product gas is sucked isokinetic through a glass wool filter, which is constant heated at 150°C. In this filter the particulates and the heavy tars are separated from the gas. After this filter the gas is cooled to 15°C and washed in 2 impinger bottles with toluene. In the condensates of the cooler and the toluene the light tars are caught.

Analysis:

Heavy Tars: The difference of weight of Filter before and after extraction with toluene.

Light Tars: The condensates of the cooler and the toluene are extracted with additional toluene. Light tars are the rest after evaporation of the toluene.

4. Which average molar weight do you use mixtures of components lumped together as tar, heavy tar etc?

Tar is measured as described in 3 and the amount is given in g tar/Nm³ dry gas.

5. How do you measure or estimate combustibles in dust?

The filter which is described in 3 is heated for 8 hours at 600°C. Combustibles are the difference of weight before and after combustion. These combustibles are only fly coke, because the tar is measured before the combustion, as described in 3.

A1.2 UOP LLC

Name of the organisation	UOP LLC
Street Address	25 East Algonquin Road
ZIP Code	60017
Town	Des Plaines
State	Illinois
Country	USA
Person responsible for filling in the questionnaire	Lamar Davis
Job title	Process Design Engineer
Phone	847-391-3241
Fax	847-391-2974
e-mail	Ladavis@uop.com

- Which unit do you prefer for the energy content of a gas and its components?**
(e. g. gross BTU of combustion per standard cubic feet, net MJ of combustion per m³, kcal of formation per mole, net MJ/kg etc.).

Either is fine.

If you use volume as the basis of the preferred unit, please state the temperature and pressure which defines the standard volume, as this definition sometimes deviates from the more commonly adopted definitions.

60F 1 atmosphere Standard Conditions
 32F 1 atmosphere Normal Conditions

2. **Which components do you take into account when you estimate the heating value of a gas?**

Please give the value and the corresponding unit for the heating value you use for these components. The source of the data, if available, can be entered as a number referring to the source reference list below the tables.

For our work on this project, we did not provide heating values for any gas, so this section is not relevant.

Component	H ₂	CO	CH ₄	C ₂ H ₆	C ₂ H ₄	C ₂ H ₂
HHV						
LHV						
Unit						
Data source #						

Component	C ₃ H ₈	C ₃ H ₆	CH ₃ OH	i-C ₄ H ₈	i-C ₄ H ₁₀	n-C ₄ H ₁₀
HHV						
LHV						
Unit						
Data source #						

Component	C ₆ H ₆	CH ₃ C ₆ H ₅	(CH ₃) ₂ C ₆ H ₄	C ₁₀ H ₈	CH ₃ C ₁₀ H ₇	Other
HHV						
LHV						
Unit						
Data source #						

Component	BTX	tar	light tar	heavy tar	black tar	Other
HHV						
LHV						
Unit						
Data source #						

Component	NH ₃	HCN	NO	N ₂ O	H ₂ S	COS	CS ₂	S _x
HHV								
LHV								
Unit								
Data source #								

List of references

Data source # 1	
Data source # 2	
Data source # 3	
Data source # 4	
Data source # 5	

- 3. How do you measure or estimate the tar contents in a gas, as individual components or mixtures of components lumped together as tar, heavy tar etc.?**

We do not. This information is usually supplied by our customers.

- 4. Which average molar weight do you use mixtures of components lumped together as tar, heavy tar etc?**

No data to provide.

- 5. How do you measure or estimate combustibles in dust?**

We do not have need for this.

A1.3 National Renewable Energy Laboratory

Name of the organisation	National Renewable Energy Laboratory
Street Address	1617 Cole Blvd. MS 3311
ZIP Code	80401
Town	Golden
State	Colorado
Country	USA
Person responsible for filling in the questionnaire	Steve Deutch
Job title	Senior Scientist
Phone	1-303-384-6131
Fax	1-303-384-6103
e-mail	Steve_Deutch@nrel.gov

- Which unit do you prefer for the energy content of a gas and its components?**
(e. g. gross BTU of combustion per standard cubic feet, net MJ of combustion per m³, kcal of formation per mole, net MJ/kg etc.).

Gross MJ of combustion/kg

If you use volume as the basis of the preferred unit, please state the temperature and pressure which defines the standard volume, as this definition sometimes deviates from the more commonly adopted definitions.

For volume conversions the following values are used -
 If normal cubic meters (Nm³) – 273.2 K and 101.3 kPa.
 If standard cubic feet (SCF) – 60 oF (288.7 K) and 14.70 psia (101.3 kPa).

For conversion purposes -
 P = 101.3 kPa
 T = 273.2 K

2. **Which components do you take into account when you estimate the heating value of a gas?**

Please give the value and the corresponding unit for the heating value you use for these components. The source of the data, if available, can be entered as a number referring to the source reference list below the tables.

Component	H ₂	CO	CH ₄	C ₂ H ₆	C ₂ H ₄	C ₂ H ₂
HHV	286.20	282.9	891.63	1562.06	1412.06	1301.32
LHV	241.79	282.9	802.71	1428.83	1323.2	1256.9
Unit	kJ/g-mole	kJ/g-mole	kJ/g-mole	kJ/g-mole	kJ/g-mole	kJ/g-mole
Data source #	1	1	1	1	1	1

Component	C ₃ H ₈	C ₃ H ₆	CH ₃ OH	i-C ₄ H ₈	i-C ₄ H ₁₀	n-C ₄ H ₁₀
HHV	2220.99	2059.35				
LHV	2043.3	1926.1				
Unit	kJ/g-mole	kJ/g-mole				
Data source #	1	1				

Component	C ₆ H ₆	CH ₃ C ₆ H ₅	(CH ₃) ₂ C ₆ H ₄	C ₁₀ H ₈	CH ₃ C ₁₀ H ₇	Other – butenes
HHV	3202.74					2716.0
LHV	3169.5					2538.0
Unit	kJ/g-mole					kJ/g-mole
Data source #	1					1

Component	BTX	tar	light tar	heavy tar	black tar	Other
HHV						
LHV						
Unit						
Data source #						

Component	NH ₃	HCN	NO	N ₂ O	H ₂ S	COS	CS ₂	S _x
HHV								
LHV								
Unit								
Data source #								

List of references

Data source # 1	Annual Book of ASTM Standards, Vol 05.05, D3588-91 Standard Practice for Calculating Heating Value, Compressibility Factor and Relative Density of Gaseous Fuels.
Data source # 2	
Data source # 3	
Data source # 4	
Data source # 5	

3. How do you measure or estimate the tar contents in a gas, as individual components or mixtures of components lumped together as tar, heavy tar etc.?

Estimate tar content as two components.

Light tar = organics heavier than benzene (mwt > 78) and upto pyrene (mwt = 202). Individual components are measured by GC/Flame Ionization Detector. Unknown components not calibrated in the calibration standard are assigned the naphthalene response factor for purposes of quantitation.

Heavy tar = organic residue from evaporation of dichloromethane solution of collected tar samples. Determine the weight of residue from a fixed volume of DCM solution after evaporation at 105°C for two hours.

4. Which average molar weight do you use mixtures of components lumped together as tar, heavy tar etc?

Not used.

5. How do you measure or estimate combustibles in dust?

Combustibles in dust (solids) is measured by sample loss on ignition by heating in an air atmosphere at 575°C to constant weight.

A1.4 ECN

Name of the organisation	ECN
Street Address	Westerduinweg 3
ZIP Code	1755 LE
Town	Petten
State	
Country	Holland
Person responsible for filling in the questionnaire	C.M. van der Meijden
Job title	
Phone	+31 224 56 4582
Fax	+31 224 56 3487
e-mail	Vandermeijden@ecn.nl

1. **Which unit do you prefer for the energy content of a gas and its components?**
(e. g. gross BTU of combustion per standard cubic feet, net MJ of combustion per m³, kcal of formation per mole, net MJ/kg etc.).

MJ/m³_n LHV and HHV dry-base

If you use volume as the basis of the preferred unit, please state the temperature and pressure which defines the standard volume, as this definition sometimes deviates from the more commonly adopted definitions.

1.01325 bar and 0 °C

2. **Which components do you take into account when you estimate the heating value of a gas?**

Please give the value and the corresponding unit for the heating value you use for these components. The source of the data, if available, can be entered as a number referring to the source reference list below the tables.

Component	H ₂	CO	CH ₄	C ₂ H ₆	C ₂ H ₄	C ₂ H ₂
HHV	285.84	282.989	890.3	1559.88	1410.97	
LHV	241.827	282.989	802.32	1427.83	1322.94	
Unit	MJ/kmol	MJ/kmol	MJ/kmol	MJ/kmol	MJ/kmol	
Data source #	1	1	1	1	1	

Component	C ₃ H ₈	C ₃ H ₆	CH ₃ OH	i-C ₄ H ₈	i-C ₄ H ₁₀	n-C ₄ H ₁₀
HHV						
LHV						
Unit						
Data source #						

Component	C ₆ H ₆	CH ₃ C ₆ H ₅	(CH ₃) ₂ C ₆ H ₄	C ₁₀ H ₈	CH ₃ C ₁₀ H ₇	Other
HHV	3301.51					C ₇ H ₈ as C ₆ H ₆
LHV	3169.46					
Unit	MJ/kmol					
Data source #	1					

Component	BTX	tar	light tar	heavy tar	black tar	Other
HHV						
LHV						
Unit						
Data source #						

Component	NH ₃	HCN	NO	N ₂ O	H ₂ S	COS	CS ₂	S _x
HHV	293							
LHV	227							
Unit								
Data source #								

List of references

Data source # 1	API; Technical Data Book – Petroleum Refining, metric edition, vol 1 and 2. Washington, American Petroleum Institute, 1977 – 1981.
Data source # 2	
Data source # 3	
Data source # 4	
Data source # 5	

- 3. How do you measure or estimate the tar contents in a gas, as individual components or mixtures of components lumped together as tar, heavy tar etc.?**

Benzene, toluene and xylene individually

SPA method: nicolas individual tar components (up to roughly 300 mol. Weight)

- 4. Which average molar weight do you use mixtures of components lumped together as tar, heavy tar etc?**

?

- 5. How do you measure or estimate combustibles in dust?**

Sample is ashed in and oven at 575 °C for 12 hours.

A1.5 Kvaerner Chemrec AB

Name of the organisation	Kvaerner Chemrec AB
Street Address	Box 1033
ZIP Code	651 15
Town	KARLSTAD
State	
Country	Sweden
Person responsible for filling in the questionnaire	Anders Nilsson
Job title	Process Engineer
Phone	+46 54 194600
Fax	+46 54 194896
e-mail	Anders.nilsson@kvaerner.com

1. **Which unit do you prefer for the energy content of a gas and its components?**
(e. g. gross BTU of combustion per standard cubic feet, net MJ of combustion per m³, kcal of formation per mole, net MJ/kg etc.).

MJ/m³

If you use volume as the basis of the preferred unit, please state the temperature and pressure which defines the standard volume, as this definition sometimes deviates from the more commonly adopted definitions.

0 °C, 1 atm

2. **Which components do you take into account when you estimate the heating value of a gas?**

Please give the value and the corresponding unit for the heating value you use for these components. The source of the data, if available, can be entered as a number referring to the source reference list below the tables.

Component	H ₂	CO	CH ₄	C ₂ H ₆	C ₂ H ₄	C ₂ H ₂
HHV	12.75	12.625	39.72			
LHV	10.789	12.625	35.796			
Unit	MJ/m ³	MJ/m ³	MJ/m ³			
Data source #	2,3	2,3	2,3			

Component	C ₃ H ₈	C ₃ H ₆	CH ₃ OH	i-C ₄ H ₈	i-C ₄ H ₁₀	n-C ₄ H ₁₀
HHV						
LHV						
Unit						
Data source #						

Component	C ₆ H ₆	CH ₃ C ₆ H ₅	(CH ₃) ₂ C ₆ H ₄	C ₁₀ H ₈	CH ₃ C ₁₀ H ₇	Other
HHV						
LHV						
Unit						
Data source #						

Component	BTX	tar	light tar	heavy tar	black tar	Other
HHV						
LHV						
Unit						
Data source #						

Component	NH ₃	HCN	NO	N ₂ O	H ₂ S	COS	CS ₂	S _x
HHV					25.07			
LHV					23.12			
Unit					MJ/m ³			
Data source #					1			

List of references

Data source # 1	STFI, 1989
Data source # 2	Barin, 1995
Data source # 3	Knacke, 1991
Data source # 4	
Data source # 5	

3. **How do you measure or estimate the tar contents in a gas, as individual components or mixtures of components lumped together as tar, heavy tar etc.?**

4. **Which average molar weight do you use mixtures of components lumped together as tar, heavy tar etc?**

5. **How do you measure or estimate combustibles in dust?**

A1.6 Verenum research

Name of the organisation	Verenum research
Street Address	Langmauerstrasse 109
ZIP Code	8006
Town	Zurich
State	
Country	Switzerland
Person responsible for filling in the questionnaire	Philipp Hasler
Job title	Dr. sc. Techn. Project engineer
Phone	0041 / 1 364 14 12
Fax	0041 / 1 364 14 21
e-mail	verenum@access.ch

1. **Which unit do you prefer for the energy content of a gas and its components?**
(e. g. gross BTU of combustion per standard cubic feet, net MJ of combustion per m³, kcal of formation per mole, net MJ/kg etc.).

MJ/Nm³ (dry gas, LHV)

If you use volume as the basis of the preferred unit, please state the temperature and pressure which defines the standard volume, as this definition sometimes deviates from the more commonly adopted definitions.

0 °C, 1013 mbar

2. **Which components do you take into account when you estimate the heating value of a gas?**

Please give the value and the corresponding unit for the heating value you use for these components. The source of the data, if available, can be entered as a number referring to the source reference list below the tables.

Component	H ₂	CO	CH ₄	C ₂ H ₆	C ₂ H ₄	C ₂ H ₂
HHV						
LHV	10.80	12.60	35.80	63.71	56.03	56.03
Unit	MJ/Nm ³	MJ/Nm ³	MJ/Nm ³	MJ/Nm ³	MJ/Nm ³	MJ/Nm ³
Data source #	1	1	1	1	1	1

Component	C ₃ H ₈	C ₃ H ₆	CH ₃ OH	i-C ₄ H ₈	i-C ₄ H ₁₀	n-C ₄ H ₁₀
HHV						
LHV						
Unit						
Data source #						

Component	C ₆ H ₆	CH ₃ C ₆ H ₅	(CH ₃) ₂ C ₆ H ₄	C ₁₀ H ₈	CH ₃ C ₁₀ H ₇	Other
HHV						
LHV	43.95					
Unit	MJ/kg					
Data source #						

Component	BTX	tar	light tar	heavy tar	black tar	Carbon
HHV						
LHV						34.8
Unit						MJ/kg
Data source #						

Component	NH ₃	HCN	NO	N ₂ O	H ₂ S	COS	CS ₂	S _x
HHV								
LHV								
Unit								
Data source #								

List of references

Data source # 1	I. Barin, Thermochemical Barin, Thermochemical data or pure substances, VCH (1993)
Data source # 2	
Data source # 3	
Data source # 4	
Data source # 5	

3. How do you measure or estimate the tar contents in a gas, as individual components or mixtures of components lumped together as tar, heavy tar etc.?

Sampling:

Absorption at -25°C in Methoxypropanol (previous particle separation at high temperature).

Analysis:

Chemical analysis with GC/MS (from benzene up to US EPA PAH list, incl. Phenolic compounds)

Heavy tars as gravimetric value from evaporation residue of methoxypropanol solution at b.p. of solvent under reduced pressure (80 mbar)

4. Which average molar weight do you use mixtures of components lumped together as tar, heavy tar etc?

For heavy tars: MW app. 150 g/mol

5. How do you measure or estimate combustibles in dust?

Determination of organic carbon in dust (cat. Combustion followed by CO_2 measurement).

Heating value of dust by calorimetric analysis.

A1.7 Deutsche Montan Technologie GmbH

Name of the organisation	Deutsche Montan Technologie GmbH
Street Address	Am Technologiepark 1
ZIP Code	45307
Town	Essen
State	Nordrhein Westfalen
Country	Germany
Person responsible for filling in the questionnaire	Manfred Kaiser
Job title	Dr. Ing.
Phone	+49 / 201 / 172 – 1789
Fax	+49 / 201 / 172 – 1241
e-mail	Ma.Kaiser@DMT.de

1. **Which unit do you prefer for the energy content of a gas and its components?**
(e. g. gross BTU of combustion per standard cubic feet, net MJ of combustion per m³, kcal of formation per mole, net MJ/kg etc.).

KJ / m³ (stp)

If you use volume as the basis of the preferred unit, please state the temperature and pressure which defines the standard volume, as this definition sometimes deviates from the more commonly adopted definitions.

Stp. : 0 °C + 760 mm Hg

2. **Which components do you take into account when you estimate the heating value of a gas?**

Please give the value and the corresponding unit for the heating value you use for these components. The source of the data, if available, can be entered as a number referring to the source reference list below the tables.

Component	H ₂	CO	CH ₄	C ₂ H ₆	C ₂ H ₄	C ₂ H ₂
HHV	3050	3020	9520	16820	15290	14090
LHV	2570	3020	8550	15370	14320	13600
Unit	kcal/m ³ (stp)	kcal/m ³ (stp)	kcal/m ³ (stp)	kcal/m ³ (stp)	kcal/m ³ (stp)	kcal/m ³ (stp)
Data source #	1, 2	1	1, 2	1, 2	1, 2	1, 2

Component	C ₃ H ₈	C ₃ H ₆	CH ₃ OH	i-C ₄ H ₈	i-C ₄ H ₁₀	n-C ₄ H ₁₀
HHV	24320	22540		29110	31530	32010
LHV	22350	21070		27190	29050	29510
Unit	kcal/m ³ (stp)	kcal/m ³ (stp)		kcal/m ³ (stp)	kcal/m ³ (stp)	kcal/m ³ (stp)
Data source #	1, 2	1, 2		1	1, 2	1, 2

Component	C ₆ H ₆	CH ₃ C ₆ H ₅	(CH ₃) ₂ C ₆ H ₄	C ₁₀ H ₈	CH ₃ C ₁₀ H ₇	Other
HHV	34960	39710				
LHV	33520	37970				
Unit	kcal/m ³ (stp)	kcal/m ³ (stp)				
Data source #	2	2				

Component	BTX	tar	light tar	heavy tar	black tar	Carbon
HHV						
LHV						
Unit						
Data source #						

Component	NH ₃	HCN	H ₂ S to SO ₂	H ₂ S to SO ₃	COS	CS ₂	S _x
HHV	4120		6140	7200			
LHV	3390		5660	6720			
Unit	kcal/m ³ (stp)		kcal/m ³ (stp)	kcal/m ³ (stp)			
Data source #	1		1	1			

List of references

Data source # 1	Messer Griesheim: Gase-Handbuch, 90.1101, 3 rd edition, Frankfurt
Data source # 2	Große, et. Al. : Arbeitsmappe für Mineralöingenieure, VDI-Verlag Düsseldorf, 1962
Data source # 3	
Data source # 4	
Data source # 5	

- 3. How do you measure or estimate the tar contents in a gas, as individual components or mixtures of components lumped together as tar, heavy tar etc.?**

Usually, we determine tar components of gasification process gases by condensing and sampling them as mixture.

- 4. Which average molar weight do you use mixtures of components lumped together as tar, heavy tar etc?**

- 5. How do you measure or estimate combustibles in dust?**

By determination the ultimate analyses of dust samples given as contents of C, H, N, S.

A1.8 Carbona Inc.

Name of the organisation	Carbona Inc.
Street Address	Kaupintie 11
ZIP Code	FIN-00440
Town	Helsinki
State	
Country	Finland
Person responsible for filling in the questionnaire	Andras Horvath
Job title	Director of Technology
Phone	+358-9-5407150
Fax	+358-9-54071540
e-mail	Cb.hki@carbona.fi

1. **Which unit do you prefer for the energy content of a gas and its components?**
(e. g. gross BTU of combustion per standard cubic feet, net MJ of combustion per m³, kcal of formation per mole, net MJ/kg etc.).

KJ/kg

If you use volume as the basis of the preferred unit, please state the temperature and pressure which defines the standard volume, as this definition sometimes deviates from the more commonly adopted definitions.

--

2. **Which components do you take into account when you estimate the heating value of a gas?**

Please give the value and the corresponding unit for the heating value you use for these components. The source of the data, if available, can be entered as a number referring to the source reference list below the tables.

Component	H ₂	CO	CH ₄	C ₂ H ₆	C ₂ H ₄	C ₂ H ₂
HHV	141878	10110	55534	51909	50328	49945
LHV	119494	10110	49915	47413	47150	48214
Unit	kJ/kg	kJ/kg	kJ/kg	kJ/kg	kJ/kg	kJ/kg
Data source #	1	1	1	1	1	1

Component	C ₃ H ₈	C ₃ H ₆	CH ₃ OH	i-C ₄ H ₈	i-C ₄ H ₁₀	n-C ₄ H ₁₀
HHV	50378	48949			49556	
LHV	46290	45736			45679	
Unit	kJ/kg	kJ/kg	kJ/kg	kJ/kg	kJ/kg	kJ/kg
Data source #	1	1			1	

Component	C ₆ H ₆	CH ₃ C ₆ H ₅	(CH ₃) ₂ C ₆ H ₄	C ₁₀ H ₈	CH ₃ C ₁₀ H ₇	C ₆ H ₅ OH
HHV	42293	42875		40826		33256
LHV	40562	40918		39420		31819
Unit	kJ/kg	kJ/kg	kJ/kg	kJ/kg	kJ/kg	kJ/kg
Data source #	1	1		1		1

Component	BTX	tar	light tar	heavy tar	black tar	Carbon
HHV			40826	47194		
LHV			39420	43811		
Unit	kJ/kg	kJ/kg	kJ/kg	kJ/kg	kJ/kg	kJ/kg
Data source #						

Component	NH ₃	HCN	NO	N ₂ O	H ₂ S	COS	CS ₂	S _x
HHV	22497	24680			16524	9142		1389
LHV	18528	23846			15201	9142		771
Unit	kJ/kg	kJ/kg			kJ/kg	kJ/kg		kJ/kg
Data source #	1	1			1	1		1

List of references

Data source # 1	Perry, Green, Maloney: Perry's Chemical Engineers' Handbook 6 th Ed. New York, McGraw-Hill Book Company (1984)
Data source # 2	
Data source # 3	
Data source # 4	
Data source # 5	

3. How do you measure or estimate the tar contents in a gas, as individual components or mixtures of components lumped together as tar, heavy tar etc.?

Light tars (mw 79-200) and benzene are sampled through heated line and quartz fiber filter into dichlormethane wash. This is analysed by gas chromatography. The main light tar compounds determined are the following: pyridine, toluene, m-xylene, styrene, o-xylene, phenol, 4-methylstyrene, indine, naphthalene, isoquinoline, 2-methylnaphthalene, 1-methylnaphthalene, biphenyl, 2-ethylnaphthalene, acenaphthylene, acenaphthalene, dibenzofurane, fluorene, phenanthrene, anthracene, fluoranthene, pyrene.

Heavy tars (mw>200) are sampled through heated line and filter to a condensing system from where it was washed out using dichlormethane. The samples were analysed by gravimetric method as evaporation residue. This method determines only the total amount of heavy tars.

4. Which average molar weight do you use mixtures of components lumped together as tar, heavy tar etc?

Light tars 128 kg/kmol, heavy tars 226 kg/kmol.

5. How do you measure or estimate combustibles in dust?

Isokinetic sampling after filter unit, ash content of the sample is determined according to DIN 51719.

A1.9 Université de Sherbrooke & Enerkem technologies Inc.

Name of the organisation	Université de Sherbrooke & Enerkem technologies Inc.
Street Address	2500 boul. Université
ZIP Code	J1K 2R1
Town	Sherbrooke
State	Québec
Country	Canada
Person responsible for filling in the questionnaire	Nicolas Abatzoglou
Job title	Professor
Phone	819-821 7904
Fax	819-821 7955
e-mail	nicolas.abatzoglou@gcm.usherb.ca

1. **Which unit do you prefer for the energy content of a gas and its components?**
(e. g. gross BTU of combustion per standard cubic feet, net MJ of combustion per m³, kcal of formation per mole, net MJ/kg etc.).

Net MJ of combustion per Nm³

If you use volume as the basis of the preferred unit, please state the temperature and pressure which defines the standard volume, as this definition sometimes deviates from the more commonly adopted definitions.

T = 0°C (273 K)

2. **Which components do you take into account when you estimate the heating value of a gas?**

Please give the value and the corresponding unit for the heating value you use for these components. The source of the data, if available, can be entered as a number referring to the source reference list below the tables.

Component	H ₂	CO	CH ₄	C ₂ H ₆	C ₂ H ₄	C ₂ H ₂
HHV	286	282.8	889	1558	1413	1298.5
LHV						
Unit	MJ/kmol	MJ/kmol	MJ/kmol	MJ/kmol	MJ/kmol	MJ/kmol
Data source #	1	1	1	1	1	1

Component	C ₃ H ₈	C ₃ H ₆	CH ₃ OH	i-C ₄ H ₈	i-C ₄ H ₁₀	n-C ₄ H ₁₀
HHV	2202					
LHV						
Unit	MJ/kmol					
Data source #	2					

Component	C ₆ H ₆	CH ₃ C ₆ H ₅	(CH ₃) ₂ C ₆ H ₄	C ₁₀ H ₈	CH ₃ C ₁₀ H ₇	Other
HHV	3298					
LHV						
Unit	MJ/kmol					
Data source #	2					

Component	BTX	tar	light tar	heavy tar	black tar	Other
HHV		30				
LHV						
Unit						
Data source #		MJ/jg				

Component	NH ₃	HCN	NO	N ₂ O	H ₂ S	COS	CS ₂	S _x
HHV								
LHV								
Unit								
Data source #								

List of references

Data source # 1	Projet BIOSYN; Report IREQ N0 1; Mass & Energy Balances; 1986
Data source # 2	Chemical Engineers's Handbook, Perry & Chilton, 5 th Edition, McGraw-Hill
Data source # 3	
Data source # 4	
Data source # 5	

- 3. How do you measure or estimate the tar contents in a gas, as individual components or mixtures of components lumped together as tar, heavy tar etc.?**

Lumped as tar

- 4. Which average molar weight do you use mixtures of components lumped together as tar, heavy tar etc?**

Average MW: 199.5

- 5. How do you measure or estimate combustibles in dust?**

Measuring inorganic left after an ash test at 550° C. There is a systematic error accounted for lost alkalis.

A1.10 Vattenfall Utveckling AB

Name of the organisation	Vattenfall Utveckling AB
Street Address	Jaemtlandsgatan 99
ZIP Code	162 87
Town	Stockholm
State	
Country	Sweden
Person responsible for filling in the questionnaire	Leif Liinanki
Job title	Manager
Phone	+46-8-739 61 39
Fax	+46-8-739 68 02
e-mail	leif.liinanki@utveckling.vattenfall.se

1. **Which unit do you prefer for the energy content of a gas and its components?**
(e. g. gross BTU of combustion per standard cubic feet, net MJ of combustion per m³, kcal of formation per mole, net MJ/kg etc.).

MJ/m³

If you use volume as the basis of the preferred unit, please state the temperature and pressure which defines the standard volume, as this definition sometimes deviates from the more commonly adopted definitions.

Nm³ at 1 bar and 0°C

2. **Which components do you take into account when you estimate the heating value of a gas?**

Please give the value and the corresponding unit for the heating value you use for these components. The source of the data, if available, can be entered as a number referring to the source reference list below the tables.

Component	H ₂	CO	CH ₄	C ₂ H ₆	C ₂ H ₄	C ₂ H ₂
HHV	68,3174	67,6361	212,798			
LHV	57,7979		191,759			
Unit	kcal/mol		kcal/mol			
Data source #	Perry	Perry	Perry			

Component	C ₃ H ₈	C ₃ H ₆	CH ₃ OH	i-C ₄ H ₈	i-C ₄ H ₁₀	n-C ₄ H ₁₀
HHV						
LHV						
Unit						
Data source #						

Component	C ₆ H ₆	CH ₃ C ₆ H ₅	(CH ₃) ₂ C ₆ H ₄	C ₁₀ H ₈	CH ₃ C ₁₀ H ₇	Other
HHV						
LHV						
Unit						
Data source #						

Component	BTX	tar	light tar	heavy tar	black tar	Other
HHV						
LHV						
Unit						
Data source #						

Component	NH ₃	HCN	NO	N ₂ O	H ₂ S	COS	CS ₂	S _x
HHV								
LHV								
Unit								
Data source #								

List of references

Data source # 1	Perry 's "Chemical Engineers' Handbook " 5 th edition page 3-145
Data source # 2	
Data source # 3	
Data source # 4	
Data source # 5	

- 3. How do you measure or estimate the tar contents in a gas, as individual components or mixtures of components lumped together as tar, heavy tar etc.?**

We measure (estimate) the tar content as a mixture of component as light tars and heavy tars.

- 4. Which average molar weight do you use mixtures of components lumped together as tar, heavy tar etc?**

- 5. How do you measure or estimate combustibles in dust?**

A1.11 NYKOMB SYNERGETICS AB

Name of the organisation	NYKOMB SYNERGETICS AB
Street Address	Floragatan 10B
ZIP Code	114 31
Town	Stockholm
State	
Country	SWEDEN
Person responsible for filling in the questionnaire	Tomas Ekbohm
Job title	Process Design Engineer
Phone	+46 8 440 4059
Fax	+46 8 440 4055
e-mail	Tomas.ekbom@nykomb.se

1. **Which unit do you prefer for the energy content of a gas and its components?**
(e. g. gross BTU of combustion per standard cubic feet, net MJ of combustion per m³, kcal of formation per mole, net MJ/kg etc.).

Net MJ of combustion per m³ or net MJ/kg

If you use volume as the basis of the preferred unit, please state the temperature and pressure which defines the standard volume, as this definition sometimes deviates from the more commonly adopted definitions.

25°C (298.16 K) 1 atmosphere gaseous substances in ideal state.

2. **Which components do you take into account when you estimate the heating value of a gas?**

Please give the value and the corresponding unit for the heating value you use for these components. The source of the data, if available, can be entered as a number referring to the source reference list below the tables.

All values given at 25°C (298.16 K) 1 atmosphere, gaseous substances in ideal state.

Component	H ₂	CO	CH ₄	C ₂ H ₆	C ₂ H ₄	C ₂ H ₂
HHV	286.031	283.179	890.943	1560.923	1411.931	1300.483
LHV	242.056	283.179	802.933	1428.998	1323.981	1256.508
Unit	kJ/mol	kJ/mol	kJ/mol	kJ/mol	kJ/mol	kJ/mol
Data source #	1	1	1	1	1	1

Component	C ₃ H ₈	C ₃ H ₆	CH ₃ OH	i-C ₄ H ₈	i-C ₄ H ₁₀	n-C ₄ H ₁₀
HHV	2221.537	2059.851	764.468	2705.234	2873.577	2880.443
LHV	2045.637	1927.926	676.518	2529.334	2653.702	2660.568
Unit	kJ/mol	kJ/mol	kJ/mol	kJ/mol	kJ/mol	kJ/mol
Data source #	1	1	1	1	1	1

Component	C ₆ H ₆	CH ₃ C ₆ H ₅	(CH ₃) ₂ C ₆ H ₄	C ₁₀ H ₈	CH ₃ C ₁₀ H ₇	C ₃ H ₄
HHV	3303.720	3950.581	4598.321	5156.463		1938.945
LHV	3171.795	3774.681	4378.446	4980.563		1850.995
Unit	kJ/mol	kJ/mol	kJ/mol	kJ/mol		kJ/mol
Data source #	1	1	1	1		1

Component	BTX	tar	light tar	heavy tar	black tar	C ₄ H ₆
HHV						2598.789
LHV						2466.864
Unit						kJ/mol
Data source #						1

Component	NH ₃	HCN	NO	N ₂ O	H ₂ S	COS	CS ₂	S _x
HHV					562.5	553.537	1103.306	314.01
LHV					518.525	553.537	1103.306	314.01
Unit					kJ/mol	kJ/mol	kJ/mol	kJ/mol
Data source #					1	1	1	1

List of references

Data source # 1	Perry, R H, Green, D W, Maloney, J O, Perry's Chemical engineers' handbook, 6 th Ed., 1984.
Data source # 2	Rossini, F D, Selected Values of Physical and Thermodynamic Properties of Hydrocarbons and Related Compounds, Am. Petroleum Inst. Research Proj. 44, Carnegie Institute of Technology (1952)
Data source # 3	(The listed values were taken from a table with references to the above listed 1 & 2.)
Data source # 4	
Data source # 5	

- 3. How do you measure or estimate the tar contents in a gas, as individual components or mixtures of components lumped together as tar, heavy tar etc.?**

We do not. This information is given by our suppliers.

- 4. Which average molar weight do you use mixtures of components lumped together as tar, heavy tar etc?**

No data to provide.

- 5. How do you measure or estimate combustibles in dust?**

We do not. This information is given by our suppliers.

A1.12 TPS Termiska Processer AB

Name of the organisation	TPS Termiska Processer AB
Street Address	Studsvik
ZIP Code	S 611 82
Town	Nyköping
State	
Country	SWEDEN
Person responsible for filling in the questionnaire	Torbjörn Nilsson
Job title	Process Design Engineer
Phone	+46 155 221 371
Fax	+46 155 263 052
e-mail	torbjorn.nilsson@tps.se

- Which unit do you prefer for the energy content of a gas and its components?**
(e. g. gross BTU of combustion per standard cubic feet, net MJ of combustion per m³, kcal of formation per mole, net MJ/kg etc.).

Net MJ of combustion per normal m³

If you use volume as the basis of the preferred unit, please state the temperature and pressure which defines the standard volume, as this definition sometimes deviates from the more commonly adopted definitions.

0°C (298.16 K) 1 atmosphere for volume. Heating values at 25°C.

2. **Which components do you take into account when you estimate the heating value of a gas?**

Please give the value and the corresponding unit for the heating value you use for these components. The source of the data, if available, can be entered as a number referring to the source reference list below the tables.

Component	H ₂	CO	CH ₄	C ₂ H ₆	C ₂ H ₄	C ₂ H ₂
HHV						
LHV	10.79682	12.63496	35.821	63.74855	59.067547	
Unit	MJ/Nm ³	MJ/Nm ³	MJ/Nm ³	MJ/Nm ³	MJ/Nm ³	
Data source #	1	1	1	1	1	

Component	C ₃ H ₈	C ₃ H ₆	CH ₃ OH	i-C ₄ H ₈	i-C ₄ H ₁₀	n-C ₄ H ₁₀
HHV						
LHV						
Unit						
Data source #						

Component	C ₆ H ₆	CH ₃ C ₆ H ₅	(CH ₃) ₂ C ₆ H ₄	C ₁₀ H ₈	CH ₃ C ₁₀ H ₇	Other
HHV						
LHV						
Unit						
Data source #						

Component	BTX	tar	light tar	heavy tar	black tar	C (loss of ignition)
HHV	-	-	-	-	-	
LHV	146.37414	240.18738				35
Unit	MJ/Nm ³	MJ/Nm ³				MJ/kg
Data source #						3

Component	NH ₃	HCN	NO	N ₂ O	H ₂ S	COS	CS ₂	S _x
HHV	-	-	-	-				
LHV	14.13224	28.79443	4.034754		23.15179			
Unit	MJ/Nm ³	MJ/Nm ³	MJ/Nm ³		MJ/Nm ³			
Data source #	2	2	2		2			

List of references

Data source # 1	Reid, Sherwood, Praunzitz, "Properties of Gases and Liquids"
Data source # 2	Hougen, Watson, Ragatz, "Chemical Process Principles" Part 1 . 2 nd Ed. Wiley I E. (1966)
Data source # 3	DIN 1942
Data source # 4	
Data source # 5	

3. How do you measure or estimate the tar contents in a gas, as individual components or mixtures of components lumped together as tar, heavy tar etc.?

Tar and BTX are mixtures of components with boiling point above 80°C excluding H₂O. BTX is C₆H₆ + CH₃C₆H₅ + (CH₃)₂C₆H₄ and tar all other components.

4. Which average molar weight do you use mixtures of components lumped together as tar, heavy tar etc?

BTX 78.112 tar 128.174

5. How do you measure or estimate combustibles in dust?

Combustibles are sum of C, H, N measured with LECO-CHN1000, S and Cl measured by other methods and O by difference from loss of ignition.

The net calorific value is estimated as 35 MJ/kg of loss of ignition.

A1.13 Bioelettrica S.p.A.

Name of the organisation	BIOELETTICA S.p.A.
Street Address	Via Cesare Battisti, 47
ZIP Code	56125
Town	PISA
State	PI
Country	ITALY
Person responsible for filling in the questionnaire	H.J. de Lange
Job title	Technical Manager
Phone	+39 050 535479
Fax	+39 050 535477
e-mail	delange@bioelettrica.it

1. **Which unit do you prefer for the energy content of a gas and its components?**
(e. g. gross BTU of combustion per standard cubic feet, net MJ of combustion per m³, kcal of formation per mole, net MJ/kg etc.).

We prefer gross kJ/kg, but most of our data is based on net J/kmol.

If you use volume as the basis of the preferred unit, please state the temperature and pressure which defines the standard volume, as this definition sometimes deviates from the more commonly adopted definitions.

If volume is used, we prefer per Nm³ (0°C, 1 bara), but usually data appears to be available at 25°C and 1 atm.

2. **Which components do you take into account when you estimate the heating value of a gas?**

Please give the value and the corresponding unit for the heating value you use for these components. The source of the data, if available, can be entered as a number referring to the source reference list below the tables.

Component	H ₂	CO	CH ₄	C ₂ H ₆	C ₂ H ₄	C ₂ H ₂
HHV						
LHV	119952.376	10105.338	50029.297	47510.093	47159.723	48275.968
Unit	kJ/kg	kJ/kg	kJ/kg	kJ/kg	kJ/kg	kJ/kg
Data source #	[1]	[1]	[1]	[1]	[1]	[1]

Component	C ₃ H ₈	C ₃ H ₆	CH ₃ OH	i-C ₄ H ₈	i-C ₄ H ₁₀	n-C ₄ H ₁₀
HHV						
LHV	46332.791	45762.398	19917.608	45284.741	45370.878	45718.562
Unit	kJ/kg	kJ/kg	kJ/kg	kJ/kg	kJ/kg	kJ/kg
Data source #	[1]	[1]	[1]	[1]	[1]	[1]

Component	C ₆ H ₆	CH ₃ C ₆ H ₅	(CH ₃) ₂ C ₆ H ₄	C ₁₀ H ₈	CH ₃ C ₁₀ H ₇	Other
HHV					n/a	n/a
LHV	45762.398	40525.200	40926.088	38860.698		
Unit	kJ/kg	kJ/kg	kJ/kg	kJ/kg		
Data source #						

Component	i-C ₇ H ₁₄	C ₁₄ H ₁₀		HCl	Sx	H ₂ S
HHV		40189.011			n/a	
LHV	44291.744			784.402		15201.404
Unit	kJ/kg	kJ/kg		kJ/kg		kJ/kg
Data source #	[1]	[2]		[1]		[1]

Component	BTX	tar	light tar	heavy tar	black tar	Other
HHV	n/a	n/a	n/a	n/a	n/a	n/a
LHV						
Unit						
Data source #						

Component	NH ₃	HCN	NO	N ₂ O	COS	CS ₂
HHV			3006.055	n/a	9089.535	14145.355
LHV	18602.029	23063.318				
Unit	kJ/kg	kJ/kg	kJ/kg		kJ/kg	kJ/kg
Data source #	[1]	[1]	[1]		[2]	[1]

List of references

Data source # 1	Perry's Chemical Engineers' Handbook 7 th ed.
Data source # 2	Hanbook of Chemistry & Physics, 66 th Ed., 1985-1986
Data source # 3	
Data source # 4	
Data source # 5	

- 3. How do you measure or estimate the tar contents in a gas, as individual components or mixtures of components lumped together as tar, heavy tar etc.?**

As individual components.

- 4. Which average molar weight do you use mixtures of components lumped together as tar, heavy tar etc?**

N/A

- 5. How do you measure or estimate combustibles in dust?**

N/A

Appendix 2
Returned comments

A2.1 NYKOMB SYNERGETICS AB

Från: Tomas Ekbohm [tomas@nykomb.se]
Skickat: den 24 maj 2000 10:45
Till: Lars Waldheim
Kopia: Nykomb Synergetics
Ämne: Re: IEA Task Group on Biomass Gasification: Survey of Heating Value Data

Hej Lars,

då vi fungerar som konsulter gäller ej några av dina frågor för oss, bland annat mätning. Vi förlitar oss istället på andras uppgifter, men i våra interna räkningar använder (åtminstone) jag dessa värden. Högre kolväten förekommer i princip aldrig i våra sammanhang därför behöver vi ej det över C₆H₆, men jag listar ändå mina tabellvärden. Sedan vore vi väldigt tacksamma att ta del av era resultat när arbetet är klart.

Med vänlig hälsning,

Tomas Ekbohm

--

Hej Lars,

glömde säga att mina värden är ursprungligen givna i kcal/mol och där jag räknat om dem med 1 kcal = 4.1868 kJ vilket kan inverka på decimalerna.

Som jämförelse, värden i Lars Westers "Tabeller och Diagram" som jag också använder är hämtade från Sydgas "Naturgashandboken" och överlag ligger runt 0.05% lägre än de värden jag listade.

Mvh Tomas

--

Tomas Ekbohm, M.Sc. Chemical Engineering

Nykomb Synergetics AB Tel: +46 8 440 4059
Floragatan 10B FAX: +46 8 440 4055
SE-114 31 Stockholm E-mail: tomas.ekbohm@nykomb.se
SWEDEN Internet: <http://www.nykomb.se>

A2.2 Combustion and Material Research, Abo Akademi University

Från: Rainer Backman [Rainer.Backman@abo.fi]
Skickat: den 23 maj 2000 07:01
Till: Lars Waldheim
Ämne: Re: ÅBOIEA Task Group on Biomass Gasification: Survey of Heating Value Data

Dear Lars,

I appreciate the work you do with a survey of heating values for combustible gases. It certainly is a topic where this type of work has to be done.

In our laboratory at Åbo Akademi University, we do not do combustion or gasification experiments in pilot scale, but in small laboratory scale usually with synthetic gases. Thus, we have no experience/need of experimental heating values in the same way as you are in your projects.

However, dealing rather much with gasification and combustion processes of solid fuels, we often use the heating value of different combustible gases in calculations to estimate e.g. maximum temperatures in processes. In some cases we use this kind of estimation to provide a temperature for a kinetic reaction or to determine a maximum temperature for e.g. corrosion. We use a total energy balance method to estimate the adiabatic temperature. This method has been developed by us for black liquor gasification/combustion processes and is based on the experimental HHV of the black liquor. Usually the composition of gas from a gasifier is estimated or calculated based on equilibrium assumptions.

On the pure gas side there is no problem with the heating value. Thermodynamic data for all significant gas species are available and should not vary much between different sources. We have used the following databases and found no significant differences in the values: SGTE (Scientific Group Thermodata Europe), HSC (Thermodynamics for Windows), FACT (Database from Ecolé Polytechnique in Montreal). The conversion between HHV and LHV is straight forward.

We have not been working with the estimation of heating values for tar components, but I know fairly good experimental data on the heating value (enthalpy of formation) are available for many components. I assume that the problem is more analytical than thermodynamical, i.e. the lack of a good analysis of amounts and compositions makes an estimation of the heating value very difficult.

I do not fill in your form, because our work is a little different from what it is designed for. But I hope you will find my comments useful to some extent. I look forward to hearing about the results from questionnaire and am ready to answer further questions if you have.

Best regards,

Rainer Backman

*** Rainer Backman ***
 *** Associate Professor (Docent) ***
 *** Process Chemistry Group, Combustion and Material Research ***
 *** Abo Akademi University tel. +358-2-2154455 ***
 *** DataCity fax. +358-2-2154780 ***
 *** FI-20520 ÅBO e-mail: rainer.backman@abo.fi ***
 *** internet: <http://www.abo.fi/fak/ktf/ccrg/> ***
 *** Home: Sophus Lies gate 6B tel: +47-22431066 ***
 *** NO-0264 OSLO fax: +47-22436126 ***

A2.3 AEA Technology plc

Från: Peter Sage [peter.sage@aeat.co.uk]
Skickat: den 23 maj 2000 09:29
Till: lars.waldheim@tps.se
Kopia: Nick Barker
Ämne: CRERe: IEA Task Group on Biomass Gasification: Survey of Heating Value Data

Dear Lars,

When your original request was received I discussed with my colleague Nick Barker and we agreed that he would respond on behalf of AEA Technology.

I trust all is well with yourself and with TPS. Please pass my best wishes on to Niklas Berge.

Yours sincerely

Peter Sage

From Nick Barker [nick.barker@aeat.co.uk]

Lars

We don't have a method ourselves as we don't have a gasification process but I have passed your message on to a number of UK companies who I hope will reply directly.

MVH

Nick

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Registered in England and Wales, number 3095862.

A2.4 Bioelettrica S.p.A.

from :Henk de Lange [delange@bioelettrica.it]

Dear Lars,

It has been some time that we have been in contact and it is good to hear from you via this survey.

I would have a suggestion for the accompanying letter with the request of information. I think that it would be useful to stress that the collected data will be made available in some manner to be agreed upon to all participants to the survey so that everybody can learn possibly something from it. Furthermore, it should be considered how the collected data and related experiences can be made available to the general public. I believe that in this manner, you might find more subjects available for releasing their data, which will thus improve the reach of the survey.

(P.S. This does not apply to us. We will fill out the form anyway!!)
Let me know what your thoughts are please.

Best regards,

Henk

Henk de Lange
Technical Manager
Bioelettrica S.p.A.
Via Cesare Battisti, 47
56125 PISA
ITALY
Tel. +39-050-535479
Fax +39-050-535477
e-mail: delange@bioelettrica.it

A2.5 NREL

Från: Bain, Richard [SMTP:BainR@tcplink.nrel.gov]
 Skickat: den 31 mars 1998 21:48
 Till: babu@igt.org; erek.rensfelt@tps.se; lotta.kronlund@tps.se; vlotta.kronlund@tps.se
 Ämne: Standard Conditions

Thanks in advance -Please forward this message to Lars Waldeim

Lars - As a start to the fuel gas heating value discussion, I am sending you a summary of my understanding of standard conditions and ASTM tests.

March 26, 1998

Standard Measuring Conditions for Gases

Unit	Where Used	Standard Conditions Reference Pressure	Temperature	
scm/scf	EPA Method Dry gas	760 mm Hg = 1 atm	68°F = 20°C	(1)
scf	American Gas Association	762 mmHg = 30 in. Hg Dry gas	60°F = 15.5/9°C	(2)
scf	Compressed Gas Institute	760 mm Hg = 1 atm = 29.92 in. Hg	68°F = 20°C	
Nm ³	NTP = STP	760 mm Hg = 1 atm	0°C = 32°F	
Nm ³	Standards Council of Canada	1 atm, dry gas	15°C	(3,4)
ft ³	Environment Canada Air Pollution Control Directorate	29.92 in. Hg = 1 atm	537°R = 78°F	(5)
scf	ANSI Standard Z132.1 For gas calorific value	14.73 psia = 1 atm	60°F Saturated with water	(6)
Molecular weight standard conditions		29.92 in Hg = 101.325 kPa	0°C = 32°F	(7)

- (1) Environmental Protection Agency, "Determination of Particulate Emissions from Stationary Sources," Codified Federal Register 40, Pt. 60, Appendix A, Method 5.
- (2) Parker, S.P., ed (1989). *McGraw-Hill Dictionary of Scientific and Technical Terms, 4th Ed.* McGraw-Hill, New York, New York, ISBN 0-07-045270-9.
- (3) International Standards Organization, *Measurement Conditions for Gaseous Fuels, ISO STD 5024-TC28, 1979.*
- (4) ENFOR Project C172, DDS File No. 41SS, KL229-1-4117, 1979.
- (5) Environment Canada Air Pollution Directorate, EPS 1 AP.74-1, 1974.
- (6) *Calorific Value of Gases in Natural Gas Range by Continuous Recording Calorimeter, ASTM D 1826, 1977.*
- (7) *Determining the Properties of Fine Particulate Matter, ASME PTC-28, 1965.*

Methods and Units for Fuel Characterization

Methods and Units*

	Biomass	Coal
Bulk Density, lb/cfm kg/m ³	<u>E873</u>	
Fuel Size	<u>E323</u>	
Calorific Value, Btu/lb, MJ/kg	<u>D2015, E711</u>	D2015
Proximate Composition		D3172
Moisture	<u>E871</u>	D2013,D3173
Ash	<u>D1102, E830</u>	D3174
Volatiles	<u>E872, E897</u>	D3175
Fixed Carbon	By difference	By difference
Ultimate Analysis		D3176
C,H	<u>E777</u>	D3178
N	<u>E778</u>	D3179
S	<u>E775</u>	D4239, D3177
Cl	<u>E776</u>	D2361,AOAC969.10

* Note: ASTM methods underlined are preferred.

Water Soluble alkali

K, Na, Ca: Soak overnight in H₂O at 90°C, analyze by AA.

Residual or Ash Composition

Special precautions must be taken to prepare ash fuel samples for elemental analysis so that some of the constituents will not be volatilized. Microwave digestion or wet ashing methods are preferred. ASTM D4278, AOAC 14.7, US Bureau of Mines Method

Ash Preparation (600°C)		D1102
Ash Elemental (Si, Al, Ti, Fe, Ca, Mg, Na, K, P)		D3682, D2795
Optional: Ash sinter test	Heat sample in muffle furnace at 100°C intervals from 550° to 950°C or higher and inspect for sintering.	
Ash fusion temperatures		D1857

Dirty fuels such as bark, urban wood waste, stump grindings, etc. should be screened to determine ash and alkali content of the fines; screen sample with Tyler No. 8 sieve, record percent of total; analyze both < 8mm and > 8mm

ASTM - American Society of Testing and Materials, Philadelphia, PA.
 AOAC - Association of Official Analytical Chemists, Washington, D.C.

Appendix 3

Letter sent to addressees

Dear Colleague

Re. **Heating value of gases from biomass gasification**

Dear Sirs,

On behalf of the International Energy Agency Bioenergy Agreement subcommittee on Thermal Gasification of Biomass, you are kindly asked to participate in an enquiry of what methods and standards are used in your organisation for the heating values of the components forming the gases produced in gasification and similar processes. You are respectfully requested to contribute to this survey by providing such data as specified in the attached questionnaire.

I kindly ask you to return the filled in survey to either of the address below before June 1, 2000.

Your contribution is highly appreciated.

Sincerely Yours

Lars Waldheim

TPS Termiska Processer AB
611 82 Nyköping
Phone: +46 155 22 1382
Fax: +46 155 26 30 52
e-mail: lars.waldheim@tps.se

Appendix 4

Mailing list

Från: Lars Waldheim
Skickat: den 29 mars 2000 18:40
Till: Huub E. Stassen (E-post 2);
'knoeff@btg.ct.utwente.nl';
'k.kwaant@novem.nl';
Kai Sippilä (E-postl)
'Kyriakos.MANIATIS@BXL.DG17.cec.eu.int';
'A.A.C.M.Beenackers@chem.rug.nl';
'babu@igt.org';
'BainR@tcplink.nrel.gov';
'barnesi@cregroup.co.uk';
'bridgwav@pcmail.aston.ac.uk';
'delange@bioelettrica.it';
'Deutchs@tcplink.nrel.gov';
'Don.Stevens@pnl.gov';
'Dr_Johannes_Albrecht@lurgi.de';
'dvy@vyncke.be';
'ehogan@nrcan.gc.ca';
'envitec@compulink.gr';
'Esa.Kurkela@vtt.fi';
'galej@cregroup.co.uk';
'gert.huisman@sec.schelde.com';
'jdruyck@vub.ac.be';
'JORma_nieminen@fwfin.fwc.com';
'kai.sipila@vtt.fi';
'knoef.btg@ct.utwente.nl';
'Kristen.stahl@sydkraft.se';
'Kristen@chemtech.kth.se';
'Nick.Barker@aeat.co.uk';
'nicolas@coupal.gcm.usherb.ca';
'ppanouts@cres.gr';
'RALPH.overend@nrel.gov';
'rbuehler@mus.ch';
'richard_bain@nrel.gov';
's.vanloo@mep.tno.nl';
'sbabu@igt.org';
'stassen.btg@ct.utwente.nl';
'verenum@access.ch';
André PC Faaij (E-postl);
Frank Sowa (E-postl);
Joachim Wolff (E-postl);
José Corella (E-postl);
; Kai Sippilä (E-postl);
Magnus Neergaard (E-postl);
Nicolas Abatzoglou (E-postl);
Peter Sage (E-postl);
Rainer Backman (E-postl);
Thomas Koch (E-postl);
Ton Konings (E-postl);
'hfc@ens.dk';
'hhofba@mail.zserv.tuwien.ac.at';
'nicolas@coupal.gcm.usherb.ca';
'verenum@access.ch';
'uh@et.dtu.dk';

'kwant@novem.nl';
'scoditti@casaccia.enea.it';
'nsyokaic@ipt.br';
'peter.gogolek@nrcan.gc.ca';
'leif.liinanki@utveckling.vattenfall.se';
Joachim Wolff (E-postl);
Torbjörn Nilsson
; 'tomas@nykomb.se'
Carbona Helsinki;
Åke Brandberg;
Clas Ekström;
Dennis Brown;
Dirk Drost;
Foppe de Walle;
Ingemar Bjerle;
John Griffiths;
Juergen Karg;
Jukka Konttinen;
Lamar Davis;
Lars Andersson;
Mats Johansson;
Michael Antal;
Peter Tijm;
Rainer Zeller;
Randall E. Rush;
Terry Dixon;
Viktoria Martin;
Johann Penninger

Ämne: IEA Task Group on Biomass Gasification: Survey of Heating Value Data