Acceptance Test for Large Biomass Gasifiers

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Summary

For a numbers of years now the interest in the gasification of biomass, as technology to supply our future renewable energy, has been increasing. A numbers of different technologies have been developed over the years, pilot plants and some commercial demonstration plants have been built and are currently under evaluation.

There is still a long road ahead for further development and optimization of the technology to a level that it is reliable, efficient and with an investment cost that matches the commercial supply and demand requirements for power and heat.

In this field of developing technology there should be independent guidelines and codes on how to test these novel power plants as with any power plant or part of a plant (i.e. boiler). In the past these codes have been available (i.e. ANSI PTC16-1974) but these have been withdrawn without replacement. Recently a team was formed to develop a test code for the entire IGCC power plant, including air separation, gasification and gas- and steam turbine (ASME Performance Test Code 47).

Within the IEA Task 20 Gasification of Biomass it had been decided to pay some attention to developing standards in general and in particular developing a test protocol for the acceptance of gasifiers. This work has lead to this (draft) report that describes some aspect of testing and a draft procedure on how one could use the measured values for the calculation of the efficiency, probably the parameter of highest interest.

It should be remembered that this is a draft and a proposal, one of the more important aspects of standard protocols is that they should be widely tested and accepted by suppliers and purchasers of equipment (gasification systems). This requires input of all those parties over a long period of time for matters to get settled.

In this document some aspects of a test protocol will be discussed and a proposal is made to use the maximum amount of available measured parameters in order to increase the accuracy of the calculation.

It is also suggested that the use of a model may be of use for determining the best and most accurate strategy for the determination of efficiency and other parameters. This has been suggested within the team developing the PTC 47 but could equally well be used for only the gasifier.

The draft protocol in annex 2 is not completed yet, it lacks versatility in the sense that no allowance has been made for application to gasification systems other than air blown CFB reactors. In particular a modification should be made for systems like FERCO Sylvagas (formerly Batelle process) and others. It is expected that this will be incorporated in follow-on efforts which will be dependent on continuing sipport.

In the mean time comments that help to improve the protocol, additional technical information (gas properties with reference etc.) or literature on the subject should be directed to Mr. Kees Kwant, NOVEM.

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Literature

Annexes

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Introduction

The IEA Task 20 "Thermal Gasification of Biomass" has decided to start working on the development of test protocols in general (i.e. sampling and testing and analysis of tars, under development). In March 1998 it was decide in Brussels to include the development of a test protocol for the acceptance of both large and small-scale biomass gasifiers. This document describes the efforts undertaken to develop the protocol for large-scale gasifiers. There is, however, similarity between small and large-scale gasifiers and the protocol could probably equally well be used for smaller gasifiers with appropriate modifications.

Since the Brussels meeting the focus has been on the investigation of available standards in the world and a questionnaire was sent out to developers of gasification technology and plant owners in order to find out if any practical and recent experience do exist.

At the Dublin meeting in the fall of 1998 it has been decided to develop a standard parallel to existing standards for steam generators. Meanwhile it appeared that at least one standard, specifically for gas producers, existed. It was then proposed to change the strategy and use a mix of existing (modern) standards for steam generators and (old) standards for gas producers

The *ANSI PTC 16-1974 "Power Test Code for Gas Producers and Continuous Gas Generators"* [1], was the only available code for gasifiers. The code had been withdrawn, however, without replacement and since this was prepared in 1958 with only reaffirmation in 1971, it is considered to be out dated.

In the United Kingdom a British Standard BS 995, *"Test Code for Gas Producer"* [3] has been developed but this standard was also withdrawn without replacement and actually until now no copy could be obtained. Other important documentation that can provide valuable information and guidelines for procedures are acceptance *"DIN 1942, Acceptance Test Code for Steam Generators, 1994"* [4] and *"ASME PTC 4.1, Power Test Code for Steam Generating Units, 1965"* [5]

Recently it was learnt that the ASME Performance Test Code 47 (PTC) for Integrated Gasification Combined Cycle, IGCC plants, was being written. This code will include definitions of the significant overall plant component performance results, input, output and effectiveness. Also codes for the associated subsets will be written to provide owners and users of IGCC power plants guidance and procedures in conducting the performance test and evaluating the deviation of its various units from specified guarantees.

The following codes are being developed in this program:

PTC47	Performance test code needs of an overall IGCC as a single block, thus ignoring the performance related integration between its various units
PTC47.1	Cryogenic air separation
PTC47.2	Gasification unit
PTC47.3	Fuel gas cleaning unit
PTC47.4	IGCC power block unit

The work of the committee was initiated in 1993 and a review draft is expected around 2001.

This raises, however, also the question for the current task, how much effort really is needed to develop a standard in parallel to the PTC47 activity. The PTC47 will be developed mainly for coal fired units but also a wide range of other fuels can be used in the gasifiers and actually these feedstock have not been ruled out from the protocol. The new standard will be quite comprehensive and could probably equally well be used without any modification at all for biomass fuelled gasifiers and associated equipment.

The added value of the current work will in any case at least be (biomass) fuel specific and it has therefore viable reasons to continue. Without doubt, however, the PTC47 work should be followed closely and if the development of a standard is lifted to European or ISO level then the work already done for the PTC47 might well be the starting point.

For further reference on the PTC47 work see [6]-[10].

Objective

The objective of the activity was defined as:

> Development of a standard test protocol for the evaluation of large biomass fuelled gasifiers. The purpose of the protocol is to decrease the level of uncertainty between vendor and purchaser of gasification equipment by providing a standard and widely accepted document on parameters to be tested and procedures to use.

It should be appreciated that normally this procedure, the preparation of International (ISO) or European standards, takes a number of years (see PTC47 schedule) which is too long for the current Task. The formulation of an acceptance test is in fact a "Daunting" task as pointed out by Horazak and Archer [6], complicated by the inherent complexity of the IGCC and the unlikely possibility of conducting actual tests under the specified conditions.

Also there should be ample input from national and international industry and institutes in order to provide a good basis for wide acceptance amongst suppliers and users of the equipment (i.e. mirror committees).

The first phase in the development of a standard could, however, be to develop the technical basis for further use in a future standardization process, this will now be the aim of this work.

The typical stages in the European (CEN) Standardisation process are:

programming
drafting
adoption
transposition

The aim should therefore be limited for the moment on the development of a draft protocol without giving too much attention to the fact that eventually every detail of the testing process should be covered.

In a later stage it can be discussed how to proceed from this result to a stage where, for instance, an ISO Standard for the acceptance test of large gasifiers can be developed.

System definition

The system that will be the subject of the evaluation will comprise of all the components between fuel (wood) feed and cold clean gas, ready for use. The size of the gasifier has been limited arbitrarily downwards to a size corresponding to a fuel input of 10 MW_{th}. The fuel will be biomass exclusively and therefore a definition of biomass is required. A suggestion was made on a recent CEN (European Organization for Standardization) workshop in Stuttgart 1998, was "*All kind of fuels with solid biomass as dominating component*"

One can, however, also question the necessity of developing standards for testing gasifiers exclusively for one type of fuel. From a testing point of view there is little difference between testing a coal or a wood fuelled gasifier. The systems will be different but there is a good resemblance between both the technologies and the type of equipment used.

As far as type of reactor is considered there should not be too much difference between in- and output of various systems and therefore in principle the protocol could be used for any kind of system or with reference to PTC 16-1974:

"*There will be no limitation on equipment to be used for gasification, fixed-, fluidized- and entrained-bed, fuels in all sizes and shapes and gasification at about atmospheric pressure or higher, are included*", (more or less free according to PTC 16-1974).

The draft for the acceptance test should also be flexible enough to cover the current varieties of wood gasifiers in use i.e. bubbling or circulating beds at atmospheric or elevated pressure (up to ~25 bar or higher), the former Batelle process with separated gasification and char combustion but also the larger (> 10 MW_{th}) capacity fixed bed gasifiers.

Gas cleaning and cooling forms an integral part of the gasification system and is therefore part of the acceptance test code. This means that proper attention should be given to a wide variety of gas cleaning equipment ranging from bag house filters for dust removal to ceramic filters, wet (chemical) scrubbers and catalytic ammonia removal.

For a good demarcation it is convenient to include the feed bins for the fuel, top of feed bin is the battery limit.

The purpose of the gasification system is to produce a suitable (cleaned to specification) gas for the purpose intended. The cooling and cleaning equipment therefore should be part of the evaluation. The application of the gas leaving the cleaning equipment can be for direct combustion in a furnace, for use in an IC engine, for use in a gas turbine or maybe even for use in an industrial network with multiple users.

The quality of the gas will depend on the requirements of the downstream equipment. It is appropriate to define as battery limit for the produced gas the exit of the cleaning system. The confirmation of the gas specification demanded by the down stream equipment will be one of the objectives of the test.

A separate acceptance test for the IC-engine or the gas turbine can be conducted according to existing standards, although it should be investigated if additional standardization is required because of the "non-standard" fuel.

The addition and removal of all materials between the indicated main boundaries will be monitored and analyzed on a normalized and standard manner in order to be able to prepare the mass and energy balance for the system.

From these, the parameters that are subject of the test and of the contractual obligations, can be calculated.

Development of a protocol for the testing of Large Biomass Gasifiers

Acceptance tests in general

Usually the contract for the supply of equipment, be it small or large and for whatever purpose, contains a paragraph that specifies the performance of the purchased equipment. For thermal conversion and power generating equipment these can be for instance efficiency, gasifier or boiler output (capacity), power consumption, consumption of chemicals, heating value of the gas, levels of impurities in the gas or flue gas etc.

At the same time that the contract is signed there should be agreement between supplier and purchaser of the equipment on how the contractually agreed performance is being verified. The actual conditions and procedures in the agreement is a matter of concern between purchaser and supplier but in most cases reference is being made to generally accepted standard test protocols.

These protocols have been developed by the National or International Standardization Institutes in consultation of both users, suppliers and experts. This procedure ensures that reasonable procedures are developed with respect to methods of measurement and achievable accuracy.

In absence of an agreement the purchaser and the vendor have to discuss and agree on a reasonable procedure afterwards.

Guidelines and thoughts for the testing of Large Biomass Gasifiers

There are a number of performance characteristics that can be agreed and tested. For an overview see the PTC's for steam boilers [4] and [5] and also PTC 16-1974 for gasifiers [1], but the most important one is probably process efficiency.

In the ASME boiler code PTC 4.1-1964 [5] the efficiency is defined as the ratio of output and input, where output is defined as the "*heat absorbed by the working fluids*" and input is defined as the "*heat in the fuel + heat credits*".

Heat credits are all energy inputs other than in the fuel like heat in entering air and atomizing steam, the sensible heat in the fuel, the primary air fan power, the boiler circulation pump power etc. Which credits should be added depends on the envelope boundary that has been agreed between parties.

Power test codes for steam boilers normally give two options for the procedure to test the efficiency of the boiler:

1. direct method (input/output method) where the energy input and the energy output both are measured directly from a fuel analysis and flue gas analysis.
2. indirect or loss method where the losses are related to the fuel input and only losses are measured, subtracted from 100% this gives the efficiency.

Both methods are fully acceptable but there seems to be a preference for the indirect method because it focuses on the losses. The guideline, however, for a choice between the two should be which method is the most accurate. The advantage of the indirect method is that (for boilers at least) there is no need to actually measure the amount of fuel feed to the boiler, even the measurement of the flue gas flow can be omitted if accurate analysis of fuel and flue gas is available.

For a gasifier there may also be more than one procedure that can be used to determine the efficiency of the system or any other performance characteristic. The direct method is of course the most obvious one and this involves the determination of the input (fuel, air etc.) and the output (LCV gas, steam or heat).

According to PTC 16-1974 [1] the efficiency can be calculated according to 3 definitions namely:

As <u>cold gas efficiency</u> which takes into account only the chemical energy stored in the gas (*"ratio of potential heat [heat of combustion] in cold gas output to total heat of dry input fuel"*, where the output is calculated for <u>dry gas at 60F and 30 in. Hg</u>). The total heat of dry fuel input includes the sensible heat of the dry fuel.

As <u>hot gas efficiency</u> (*"ratio of total heat in hot gas output to total heat of dry input fuel"*). The total heat in hot gas includes potential and sensible heat of dry clean gas, sensible heat of steam in gas, sensible and potential heat in the dust, sensible and potential heat of tar.

And as <u>overall efficiency</u> (*"ratio of the sum of total heat in the gas output to the adjusted heat input"*). The total heat in hot gas is the same as for the hot gas efficiency without the sensible and potential heat in the dust. The adjusted heat input is:

the total of potential and sensible heat in the fuel
sensible heat of moisture in the fuel
sensible heat of dry air
sensible heat of steam to producer
sensible heat of process oxygen (if any)
sensible heat of other feed items
heat of evaporation of steam to producer
and subtract the heat of evaporation of moisture in fuel and other (which gives the efficiency on LHV basis).

This definition comes closest to the definition of efficiency in the boiler test codes (heat in fuel plus credits is defined as heat input). Both the "hot" and "cold" gas efficiencies disregard the heat credits. The hot gas efficiency includes the sensible heat in the dry clean gas.

The PTC 16-1974 [1] follows the direct procedure to calculate efficiency (input/output method), no suggestion for other procedures is being made.

The suggestion now is to use at least the same basis for the heat input in all three definitions, the adjusted heat input. The adjusted heat input is then defined as the potential heat in the fuel plus the heat credits, the definition for "overall" and "hot" gas efficiency are then almost the same, only the "hot" gas efficiency takes into account the sensible and potential heat in the dust.

It is a bit peculiar that the potential heat in the dust (heat of combustion) is counted as a profit instead of a loss, probably one assumes that the residual carbon will burn in the application selected, the condition stated in the standard is "after cleaning".

In any case, after cleaning, the dust load of the gas will be very low and the contribution of the potential heat in the dust will be very small.

The "hot" gas efficiency provides information about the quantity of input energy that is available for the selected application at the "point of sale". The definition can also be used without using gas cleaning, on the condition, however, that the gas is used in this state (i.e. Lahti project). In particular for a pressurized IGCC it is advantageous to characterize the system with the hot gas efficiency. If a dry gas cleaning system is used the temperature at the point of sale can be high and therefore the sensible energy can contribute considerably to the total energy content. The sensible heat in the gas then has the same effect, i.e. increasing flame temperature, as the potential (chemical) energy.

The "cold" gas efficiency provides information about the quantity of input energy that is converted to chemical energy (potential heat), this is a good quality parameter for the gasification process.

Neither of the above take into account that the sensible heat in the gas and, to a lesser extent the solid refuse, can be used in a beneficial way, for air preheat or generating steam for the waste heat boiler in an integrated system. The total efficiency of the process can therefore also be characterized by losses or how much "*heat is absorbed by the working fluids*". In most integrated gasification systems there are at least two working fluids, steam and gas. The definition then becomes similar to that of a CHP plant supplying both electricity and heat.

A perhaps even better definition would take into account the exergy levels within the system. Generating high pressure and temperature steam with the sensible energy would result in higher exergetic efficiency than when only feed water is preheated.

As a last observation one can note that in US mostly the HHV of a fuel is being used to calculate the efficiency (of boilers) and the LHV of the fuel in Europe. It may not be necessary to agree to use one of the two exclusively, but from a standardization point of view it may be required to select one, in this case it is proposed to use the lower heating value of a fuel (wood and gas) as the basis for the calculation.

Summary:

heat input	potential & sensible energy in the fuel (LHV basis) + heat credits
"hot" gas output	sum of the chemical heat (LHV basis) of the gas and the sensible heat of the gas and the dust

"cold" gas output	potential heat of the clean gas (at standard reference condition)
1."hot" gas efficiency	ratio of "hot" gas output and heat input
2. "cold" gas efficiency	ratio of "cold" gas output and heat input
3. total efficiency	ratio of the sum of "hot" gas output and useful heat to heat input
4.exergetic efficiency	ratio of the output exergy to the input exergy

The reference conditions for the calculation of energy flows in the three investigated standards so far are:

[1] PTC 16-1974 (gasifiers)   **60F, 30 in.Hg/14.7 psia, 15.6°C and 1 bar**
[5] PTC 4.1 (boilers)   **68F, 14.7 psia (for density of gaseous fuels), 20°C and 1 bar**
[4] DIN 1942 (boilers)   **25°C … bar**

Also, according to [11]:

"It has been accepted by all concerned that after changing over to the metric system the following units will be used:

...
Standard temperature will be 15°C
Standard pressure will be 1013.25 mbar (760 mmHg at 0°C and standard gravity, 9.8065 m/s^2)
...

...the internationally accepted reference temperature in thermo-chemistry, at which the standard heats of combustion are normally quoted, is 25°C. Calorific value at constant pressure approximates to the negative of the enthalpy of combustion. An equation relating enthalpy of combustion at different temperatures can be used for estimating the change of calorific value with temperature"

(Technical Data on Fuel, 1977 [11] page 130)

It is therefore proposed to use 15°C and 1013.25 mbar as reference for the calculation of heating values and enthalpies. Normally the laboratory results will have to be corrected for the 10°C temperature difference.

Cold gas efficiency

The indirect (loss) method of determination of the cold gas efficiency would require that all losses are determined.

The method normally separates between inputs and losses that are proportional to the fuel flow and those that are not (DIN 1942 [4]).

For (almost) complete combustion in a boiler it is possible to develop relations for the flue gas to fuel and air to fuel values using the analysis of the fuel and flue gas. For the determination of unburnt carbon losses mass balance of the ash in the fuel is used.
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In a gasifier the potential and sensible heat in the gas is the useful heat contained in the working fluid, and the generated steam from cooling the gas is a loss, at least for the cold gas efficiency.

Is it possible to determine the cold efficiency of a gasifier using the loss method, with no analysis of the gas and no determination of the fuel feed? In fact, a similar method is being investigated within the development of PT47 code for IGCC.

Uncertainty calculations are being made to explore energy balance methods for calculating the energy input to various gasifiers. Such methods are important as possible alternatives to direct measurements of the often inconsistent flows and heating value of fuels fed to gasifiers.

Gasification is most frequently proposed to deal with heterogeneous solid and liquid fuels whose flow and composition are difficult to measure accurately. With low uncertainty, and whose heating value may vary significantly throughout a test. The energy balance or heat loss method is described in Fired Steam Generator Code and recommended by the Overall Plant Performance Code for determining the energy input of coal fed to a fired steam generator.

This method makes use of the boiler as a calorimeter whose steam output and heat and stack losses are measured or estimated to calculate the energy input of the coal fuel feed. Committee members of PTC 47 are now performing input calculations to explore whether a gasifier, or perhaps a gasifier and associated heat recovery equipment of the gasification section can similarly be used as a calorimeter to determine the energy input of a fuel feed with less uncertainty than the measurement of fuel flow and heating value to determine energy input (David H. Archer, Ronald L. Bannister and Dennis A. Horazak [8]).

For an overview evaluation of the alternatives consider the following:

The absorbed heat in the gas coolers and the heat rejected to cooling water can be determined directly, but there is no direct proportional relation to the fuel feed. What can be determined once the absorbed heat in the cooler is available is an estimate of the gas flow, at least if the inlet and outlet temperatures of the gas are known. When the enthalpies of the gas are calculated according to the expected composition a rough and inaccurate estimate of the load can be made. More measurements and analysis seems to be necessary for accurate calculation of capacity and efficiency.

The energy loss in the refuse (potential and sensible heat) can be determined directly (mass, temperature and heating value). The loss of potential energy can be linked proportional to the fuel feed with the mass balance of the solid inert material feed to the gasifier. Normally, however, the feed of inert material (sand, dolomite) is large compared to the ash flow and the accuracy of the calculated loss as percentage of fuel feed will be low.

If gas composition analysis is not available there is no clue to the amount of air that is being used in the process.

Therefore, the answer seems to be that it is unlikely that the loss method, proposed for steam boilers, can be used for a gasifiers. Some additional measurements are still required in order to come to acceptable and accurate results. It probably depends on the requested accuracy of the test whether or not it is possible to be able to omit (flow and composition) measurements in the gas.

It is required to have as a minimum at least 2 out of 3 measurements for the major mass flows (fuel, air and gas) together with the fuel analysis available for the calculation of the efficiency. This means that it may be possible to complete a successful test without determination by measurement of the fuel feed to the gasifier.

In case the determination of quantity and composition of gas flow is not possible, both the air and fuel feed have to be measured, as well as the heating value of the wood fuel.

The proposed method, deviating from the input/output method, can be denominated as "modified loss" (or input/loss) Method A in contrast to the direct input/output Method B.

Modified loss Method A-1

From the measured fuel feed and air flow rate the gas flow can be calculated taking into account the flow materials to and from the system.

The direct determination of major heat credits (gasification air) and losses (radiation, un-reacted carbon, generated steam, rejected heat to cooling water) is possible.

The output energy can be calculated (= input-losses) as absolute value and relative to the mass flow of the gas. The heating value can be calculated if the sensible heat in the gas is known, for this estimated (design) values for the composition can be used. Both the density and sensible heat can be calculated with reasonable accuracy.

The disadvantage of the method is that the composition of the gas, often subject to guarantees, is not being measured and cannot be calculated. If this is a requirement for the test then the modified heat loss method as described above cannot be applied.

Modified loss Method A-2

The analysis of the composition of the gas can be used to calculate the heating value and the density, still, no measurement of gas flow or analysis of the wood fuel is needed as long as the wood and air mass flow can be determined accurately.

Modified loss Method A-3

If it is not possible to accurately measure the wood feed to the gasifier then either the gas flow (A-3) should be measured or the analysis of the wood (A-4) should be determined. This makes the measurement of the air flow superfluous because the analysis of the gas will reveal the nitrogen content. The only source of nitrogen is the nitrogen in the air. Small corrections can be made for nitrogen in the wood fuel. From this the fuel feed can be calculated (correcting for condensed water) and using a measured LHV for the wood, the heat input can be calculated. Alternatively, as all losses are known as well as the output the input can be calculated.

Modified loss Method A-4

If the analysis of the wood and the composition of the gas are known then it is possible to calculate the cold gas efficiency without measuring the wood fuel and gas mass/volume flow. A carbon and nitrogen balance can be used to calculate the specific gas production (Nm^3/kg) and the specific air consumption (Nm^3/Nm^3). Because normally inert material (sand, dolomite or other) is charged to the system, there is no proportional relation for the ash withdrawn. If the amount of total ash is, however, small compared to the total wood fuel feed, the ratio measured ash (weighed) to design value wood feed may be used in the formula. Normally this will be the case. Other minor carbon losses (tars) or additions (recycle gas, flue gas, dolomite) can be dealt with in the same manner.

The accuracy depends on the amount of inert material (or other material) fed to the gasifier and the carbon content of the bed and filter ash. The advantage is that neither the fuel feed nor the gas flow needs to be measured. Both measurements can be difficult, have low accuracy and/or have higher risk. The last two methods may be useful when it is expected that large amounts of air are leaking into the gasifier in an uncontrolled manner.

In the following table the 4 methods are compared (for the major contributors) with the Direct Method of analysis, B-1.

	Method A-1	Method A-2	Method A-3	Method A-4	Direct B-1
Wood fuel	F, LHV	F, LHV	$(LHV)^{1)}$	LHV, Comp.	F, LHV
Air	F, T	F, T	T	T	$(F)^{3)}$, T
Ash (bed/filter)	F, c (or LHV)	F, c (or LHV)	F, c (or LHV)	F, c	-
Gas	T	T, Comp.	F, T, Comp.	T, Comp.	F, T, Comp.
Radiated heat	Q_{th}	Q_{th}	Q_{th}		-
Recovered heat	Q_{th}	Q_{th}	Q_{th}		-
Rejected heat	Q_{th}	Q_{th}	Q_{th}		-
# measurements$^{2)}$	5	6	6(5)	5	5

input can also be calculated as output + losses
assuming Q_{th} and T are relatively simple except for radiation heat losses
air flow can also be calculated from nitrogen balance

F = mass flow, LHV = lower heating value, T = temperature, c = carbon content, Comp.= composition, Q_{th} = absorbed heat

Without the assessment of the accuracy of each proposed method it is not possible to select the preferable method. It also depends on the local situation in the plant and the accuracy of fixed instrumentation used for normal operation.

If one of the Methods A-4 or B-1 is selected it is advisable to accumulate the information needed to measure the heat loss. This will allow a check on the accuracy of the energy

balance. The same applies to the analysis of the wood, although not needed for Methods A-3 and A-4 it can be used to establish the elemental balance.

If the capacity (load) of the gasifier is subject to testing, for Method A-4 additional measurement of wood fuel mass flow, air flow or gas flow are required.

In stead of making a choice for either one of the methods described above it may also be possible to use a mix of al 3 or 4 of them and thereby increasing the accuracy of the test result. We will therefore assume that the only parameter that cannot be measured directly is the wood fuel feed to the gasifier. All other major parameters can be measured or analyzed, including gas flow and gas analysis. The advantage of this method is that it can be expected that the accuracy of the final result will be higher. In fact, by doing so, the whole set of measured values and analysis can be used and the calculated results should have minimum errors.

It is now possible to trace back the wood fuel feed by using mass-, energy- and carbon balances, this will result in 3 values for the wood fuel feed. A simple arithmetical mean value is probably not accurate enough and an over simplification. If it is possible to assign weighting factors to each calculated wood fuel feed, taking into account the accuracy of the particular procedure then a better balance could be obtained.

Without proof it is assumed that the inverse of the accuracy (error as range) can be used as weighting factor, see the table for an illustration of the proposal.

Method used	Value, kg/s	Error, +/- %	Weighting factor	Contribution
Mass balance	5.87	3.8	13.15	77.19
Energy balance	6.21	5.1	9.80	60.85
Carbon balance	5.52	2.4	20.83	114.98
Direct measurement	5.73	7.8	6.41	36.73
Total:	5.77		50.19	289.75

The numbers have no real meaning and also the accuracy attached to each method is only for illustration. The arithmetical average for the wood fuel flow would be 5.83, a difference of only 1.1%. This is not much but in reality, using real numbers the difference may become larger.

The basic assumptions that have been made for the proposal are:

that multiple calculations will increase the accuracy of the final result
that weighting factors can be determined in a controlled way using fixed procedures, part of the standard
that it is not possible or difficult to select a single method with superior accuracy

If all of these assumptions cannot be proven then it may not be worthwhile to spend this extra effort. For the moment we will, however, assume that this is indeed the case and a procedure will be developed for calculating the efficiency of a large biomass fuelled gasifier using the proposed method.

General comments on parameters and measurements

With respect to the previous suggestions and guidelines the application for the acceptance test protocols can be commented as follows:

Wood fuel

Before a test can start there should be sufficient fuel available for the test period and the quality (species, heating value, moisture content, ash content, chemical analysis and physical properties etc.) should be to the satisfaction of both the supplier of the system and the purchaser or its representatives. This requires, amongst others, agreed procedures on how to sample and analyze the fuels.

The analysis of the wood and the determination, for instance, of the heating value and chemical components are relatively easy and standardized procedures that can be executed "off line" in commercial laboratories. Often these parameters are subject to agreed acceptance criteria which makes it necessary to measure them, either as a condition for the test (LHV within range or size within range) or as a necessary parameter for evaluation of the final result (heating value).

Currently a CEN Workshop has started to develop biomass standards for application in wood fuelled power plants. An inventory has been made of available existing standards in the European Countries and a work program will be initiated in March 2000. The first meeting took place in Stuttgart in March 1999, the second in Stockholm in September 1999.

The CEN Workshop is supported by the FAIR and Thermie programs of the European Commission and on a National level mirror committees have been established which will provide information and assist in the development of standards for testing and characterization of biomass fuels.

For an overview of standards see the Best Practice List [14], IEA participation in this work is within the Task…

Of particular interest is a correct procedure to take samples of the fuel, it is obvious that samples that do not represent the wood fuel feed cannot be used for determination of efficiency. The samples should be taken at regular intervals and as close to the feed point as possible. The weight of the sample is determined by the average size of the fuel, according to one reference (for coal):

Average particle size	10 mm		30 mm		50 mm		80 mm		>80 mm	
Ash content, %	<13	25	<13	25	<11	25	<9	25	<5	25
Total raw sample weight, kg	20	45	40	90	40	150	40	210	40	310
Individual sample weight, kg	0.5		1		1.6		2.5		4	

Actually the influence of ash content will not be very large for wood because this is expected to be below 5%. The total raw sample weight should be reduced to the laboratory sample i.e. by a series of mixing, quartering and again mixing of opposite quarters. If possible use should be made of standards developed for sampling and reduction of the sample size of wood. The weight of the final laboratory sample can be 1-5 kg. This sample should be stored in air tight containers, preferably filled with inert gas, marked with date, time and a

reference to the test or identification number. One can also consider to store an identical fuel sample as a back up and in case of any disputes.

Sometimes it may not be possible to sample directly upstream of the wood fuel feeders, in this case the alternative will be to sample at the inlet of the intermediate storage bins for wood fuel, or even further upstream. Depending on the size of these bins and the expected test period, the sampling may even start before the actual test in order to make sure that the fuel feed from storage during the test can be represented by the samples.

The continuous determination of fuel mass feed to the gasifier is normally less accurate for solid fuels, sometimes on line determination of the mass flow has been omitted for this reason. Measurement by weight is accurate, however, and in case the weight of several batches of fuel can be measured it is not an advantage that determination of fuel feed can be omitted. For smaller systems without instruments for measuring fuel feed (i.e. weighing belts) Methods A-3 and A-4 have an advantage.

Air

The gasification air is usually supplied by one or more compressors providing forced draft or, for smaller gasifiers with induced draft fans located down stream of the gasifier in the cold and clean part of the system. In order to increase the efficiency of the system the air can be preheated with waste heat generated within the system or with external energy. It will depend on the definition of the system and the envelope boundary to be considered. Apparatus is considered to be outside the envelope boundary when it requires an outside source of heat or where the heat exchanged is not returned to the gasification system [7].

Heat credits are defined as those amounts of heat added to the envelope of the system other than the chemical heat in the fuel. In case the air pre-heater is an integral part of the system the actual energy supplied to the air need not to be considered, only the enthalpy of the air entering the air pre-heater and the added energy from power conversion in the compressor.

The air flow to the gasifier can be measured without too much problems, temperature is low even with air pre-heat, the composition is exactly known and various standardized and accurate measurement devices and procedures are available. The only reason where it would be advantageous that not to measure the air flow is when it can be expected that some air can enter the system in an uncontrolled manner.

This may happen when cooling air is applied to start-up burners or sealing air to fuel feed systems or of the gasifier is operated with a pressure lower than the ambient. When these quantities of (unmeasured) air are expected to be small then the design value for the additional "parasitic" air may be used.

There should be, however, proof that this is the case, i.e. by measuring a pressure difference and using graphs for air leakage.

Ash

The ash comprises of several components:

ash as an integral part of the fuel
inert materials (sand) collected simultaneously with the fuel

bed material (sand)
chemicals (dolomite, limestone) used in certain applications i.e. for cracking of tars or absorption of trace components like chlorides
unreacted carbon

The ash is probably collected at different locations in the system, as coarse bottom ash in the gasifier and as fine dust in the gas cleaning section (ceramic, bag house or other type of filter). The filter ash can contain a high percentage of carbon and this should be treated as a loss, unless some type of recycling is used i.e. returning the ash to the gasifier or incinerate the ash and return the heat to the system. In particular the flyash with its high carbon content and small particles is considered to ignite and oxidize easily. Samples should be stored immediately in gas tight containers filled with nitrogen.

The determination of total weight during the test can be accomplished by collecting and weighing all the ash removed during the test or part of the test. Normally there are no measurement devices that give an actual value for the mass flow of ash generated within and removed from the system.

The accumulation of any kind of solids in the system should be prevented, this requires a careful and accurate determination of starting and stopping conditions (i.e. pressure drop in fluid bed). Handling of containers in inaccessible areas may be difficult but not impossible.

Determination of the heating value and/or carbon contents is relatively easy, although one should consider that hydrogen may still be present in the ash. Sometimes, in case of very low carbon content one could consider to add material with known heating value to the ash sample and calculate the heating value of the mixture. As for the wood fuel, sampling is an important condition for the final accuracy of the result. Samples should be taken at regular intervals and the weight reduced in size i.e. by quartering several times until a laboratory sample of 1-5 kg is left. In particular for the fine filter ash it is imperative to store the sample in containers filled with nitrogen in order to avoid oxidation.

 For calculation of the sensible heat loss it can be assumed that the ash has the temperature of the gas at the location where it is removed. This will be more accurate than measuring exit temperatures and determination of any loss by cooling the ash to air or water.

Gas

The composition (with calculated LHV) of the gas is the major deliverable of the gasifier and probably subject to agreed acceptance criteria in the contract. Not needing to know the composition (A-1) is therefore normally not an advantage. The gas flow is more difficult to measure than air (unusual composition, toxic gas and explosion risk) but nevertheless it is possible and larger systems will use a measurement device which allows a continuous registration of the gas flow. In case these devices are used for the determination of the flow during the test, they should be calibrated and certificates should be available as part of the report.

Probably smaller systems can benefit from procedures not needing to measure the gas flow.

For sampling and analysis of gases and trace components widely accepted standards should be used. Gas can be sampled and analyzed after the gas cleaning but if evidence of the

performance of the gas cleaning system should be collected as well, also sampling upstream of the gas cleaning system is required. This may become necessary when the removal efficiency has been limited to a range of inlet concentrations of certain species like ammonia, chlorides, tars etc.

The upstream reconstruction of gas composition from downstream sampling and analysis is troublesome, inaccurate and should be avoided. If evidence is needed of the quality of the gas at certain locations in the system, all efforts should be made to take direct measurements. In case of extreme conditions i.e. high gas temperature upstream of a ceramic particle filter this may not always be technically possible or safe. In these circumstances alternatives should be proposed and agreed between the supplier and purchaser of the equipment or his representative.

When the heating values of the gas is not measured directly, tables with heating values of the various components should be used to calculate the heating value. These tables should be from reliable source and agreed to by all parties. Particular care should be given to the use of proper reference conditions in the table (pressure and temperature) with respect to the actual pressure and temperature at the point of gas sampling. When necessary, corrections should be made.

Radiation heat loss

For the testing of steam boilers the heat loss by radiation is not measured but instead standard graphs are used. For gasifiers these graphs are not available and calculation of total (relevant) outside surface, outside temperature of the vessel(s) and the ambient temperature as well as the atmospheric conditions (i.e. wind velocity) are required. It represents a certain effort but this can be done and one would probably be interested in estimating heat loss by radiation anyway.

A measurement protocol for the total outside surface of the gasification system within the system boundary envelope should be part of the final report. The whole system should be divided into a number of logical subsections i.e. according to size and expected temperature of the outside surface. At the start of a test, in the middle and at the end it is advised to record the surface temperatures of the various sections with suitable means i.e. thermographic methods or optical pyrometers. The procedure and formulae used for the calculation of the heat loss should follow standard technical practices.

Recovered heat

In modern large biomass gasifiers i.e. circulating fluid bed gasifiers, the gas is produced at a relatively high temperature. In most cases, the gas has to be cooled down to a temperature level where it can be used in the downstream equipment. When gasifiers are used for electric power production, the sensible heat in the gas can be used in the thermal system as a useful byproduct.

When inlet and outlet enthalpies of the water, steam or air as well as the mass flow are known the calculation is not difficult. When the flow of water or air is not measured during normal operation, temporary instruments are required.

Rejected heat

This requires the determination of cooling water flow and its inlet and outlet temperatures. Normally it should not be a problem to measure although not always the mass flow of cooling water is measured so periodic measurement instruments are needed. On the other hand, the thermal loss from cooling water will not be extremely large and errors made in the determination are unlikely to have a large effect on the outcome of the test.

Accuracy

The calculation of the efficiency should be accurate. The protocol for the acceptance test should contain clear procedures on how to calculate the error in the outcome of the calculation based on the accuracy of the instruments used and the calculation procedure followed and illustrated with examples

Summary of Gas Properties

Component		MW kg/kmol	MV Nm^3/kmol	Density [2] kg/m^3	Density [1] kg/Nm^3	LHV[3] MJ/Nm^3	LHV[4] MJ/m^3
Methane	CH_4	16.043	22.3600	0.6785	0.717	35.882	33.95
Ethane	C_2H_6	30.070	22.1875	1.272	1.355	64.353	60.43
Ethene	C_2H_4	28.054	22.2431	1.195	1.261	59.476	55.96
Propane	C_3H_8	44.097	21.9297	1.865	2.011	93.207	86.42
Propene	C_3H_6	42.080	21.9895	1.814	1.914	87.607	81.45
Carbon dioxide	CO_2	44.010	22.2461	1.861	1.977	-.-	-.-
Carbon monoxide	CO	28.011	22.3991	1.185	1.250	12.634	11.97
Hydrogen	H_2	2.016	22.4354	0.083	0.090	10.779	10.22
Nitrogen	N_2	28.013	22.4037	1.185	1.250	-.-	-.-
Oxygen	O_2	31.998	22.3919	1.353	1.429	-.-	-.-
Water vapour	H_2O	18.015	21.629	0.762	0.833	-.-	-.-
Carbonylsulfide	COS	60.070	22.0884	2.581	2.723	24.844	
Hydrogen sulphide	H_2S	34.076	22.1881	1.456	1.536	23.377	21.82
Hydrogen cyanide[5]	HCN	27.026	22.062	1.161	1.225	29.080	
Ammonia[5]	NH_3	17.032	22.091	0.738	0.771	14.404	
Benzene	C_6H_6	78.115	20.5	3.304	3.810	154.608	134.05
Toluene	C_7H_8	92.142	20.5	3.897	4.495	183.994	159.54
Xylene	C_8H_{10}	106.167	20.5		5.179	213.474	

at 101.325 kPa and 273.15 K (0°C)
at 101.325 kPa and 2883.15 K (15°C)
starting and final conditions 25°C and 101.325 kPa, Handbook Natural Gases, Nederlandse Gasunie NV, 1980 [12]
starting and final conditions 15°C and 101.325 kPa, Technical Data on Fuels, 7TH edition, 1977 [11]
Dubbels Tachenbuch der Machinenbau 1987 [13]

The numerical values for lower heating value in the table are at constant pressure, although the actual determination takes place at constant volume. The difference in the last two columns is because of a different reference temperature (for the m^3) and a different reference temperature for the determination of the heating value.

For example:

	15°, MJ/m^3	15°, MJ/Nm^3	25°, MJ/Nm^3	25°, MJ/Nm^3
	Techn. Data on Fuel [11]	Calculation m^3 -> Nm^3	Calculation 15°C -> 25°C	Gasunie [12]
Methane	33.95	35.816	35.86	35.882

For every kMol methane one kMol carbon dioxide is formed and two kMols of water vapour. In other words, combustion in oxygen of 22.36 Nm^3 methane results in 22.2461 Nm^3 carbon dioxide (1.656 kJ/Nm^3K) and 43.258 Nm^3 water vapour (1.495 kJ/Nm^3K).

The correction for the 10°C difference in temperature is therefore: 368.4 kJ for CO_2 and 646.7 kJ for H_2O and for 22.36 Nm^3 methane. Per Nm^3 methane the correction is therefore 45.4 kJ, the LHV at 25°C should be lower than at 15°C so the final value is 35.816+0.0454=35.861 MJ/Nm^3, the difference is only 0.06% when compared to the reported value at a different reference temperature.

The zero pressure specific enthalpy of the gases forming the majority of fuel gas produced by biomass gasifiers can be taken by interpolation from the following table (ref [11]).

	298.15	300	400	500	600	700	800	900	1000	1100	1200
O_2	271.2	273.0	365.8	461.4	560.3	661.9	766.2	872.6	980.8	1190.5	1201.4
N_2	309.5	311.4	415.5	520.5	627.0	735.6	846.6	959.9	1075.7	1193.4	1312.8
Air	298.6	300.5	401.3	503.4	607.4	713.7	822.4	933.4	1046.5	1161.5	1278.2
CO	309.6	311.5	415.8	521.3	628.8	738.8	851.4	966.5	1083.9	1203.3	1324.5
H_2	4200	4227	5668	7118	8571	10028	11493	12969	14459	15967	17493
CO_2	212.8	214.3	303.8	401.5	506.1	616.2	731.0	849.7	971.7	1096.4	1223.4
H_2O	549.6	553.1	741.2	933.9	1132.3	1337.0	1548.3	1766.5	1901.7	2224.0	1263.2
CH_4	624.5	628.6	865.7	1137.0	1445.6	1790.8	2170.3	2581.6	3021.9	3488.3	3978.4
C_2H_4	374.8	377.6	548.7	754.7	992.1	1256.7	1544.7	1853.1	2179.6	2521.6	2877.4
C_2H_6	394.9	398.2	594.4	833.3	1111.8	1425.5	1770.3	2142.5	2539.3	2957.1	3393.7
C_3H_8	333.2	336.4	527.2	762.9	1037.1	1346.4	1685.1	2049.5	2435.7	2841.8	3265.9

Temperatures in Kelvin
Enthalpy h in kJ/kg rounded to 1 decimal and with datum h=0 at 0 deg K

The effect of pressure on the enthalpy is not very large, according to [13] page D26 the effect for the gases considered is between 0 (Hydrogen) and 0.028 kJ/Nm^3 (C_2H_2 at 0°C) per bar increase of the pressure. The increase becomes less for higher temperatures.

For the major constituents, increase of specific heat capacity in kJ/Nm^3 per bar:

Components

Temperature	Nitrogen	Carbon Monoxide	Carbon Dioxide	Methane
0°C	0.003	0.003	0.022	0.007
100°C	0.002	0.002	0.013	0.006
200°C	0.001	0.001	0.008	0.000

For Nitrogen at 200°C this is about 0.08 % increase per bar and for Carbon Dioxide 0.4 % increase per bar. For system pressures normally applied for pressurized gasification, ~20 bar, the increase can be 0.13% assuming nitrogen content 45% and CO_2 content 15% and assuming the rest to increase as CO.

More accurate data is required in case the test protocol is used for a pressurized gasifier. Although, the pressure effect may be discarded as concluded from this example.

Literature

[1]   ANSI PTC 16-1974 Power Test Code for Gas Producers and Continuous Gas Generators, 1958 and revised in 1974

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[3]   B.S. 995, Test Code for Gas Producers

[4]   DIN 1942, Acceptance Test Code for Steam Generators, 1994

[5]   ASME PTC 4.1, Power Test Code for Steam Generating Units, 1965

[6]   Performance Modeling as an Aid in the Preparation of a Test Code for IGCC Plants, PTC 47, ASME Turbo Expo Land, Sea & Air, Indianapolis, Indiana June 7-10 1999; Dennis A. Horazak and David H Archer

[7]   ASME PTC47.4, IGCC Performance Testing Issues for the Power Block, PWR-Vol. 34, 1999 joint Power Generation Conference, Volume 2 ASME 1999; Ashok K. Anand and Jeff Parmar

[8]   ASME PTC47, Gasification Combined Cycle Performance, Uncertainty, 1998 International Joint Power Conference & Exposition, Baltimore, Maryland, August 24026, 1998; David H. Archer, Ronald L. Banister and Dennis A Horazak

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[11]   Technical Data on Fuel, edited by J.W. Rose and J.R. Cooper, seventh Edition 1977 ISBN 0 7073 0129 7

[12]   Handbook Natural Gases, Nederlandse Gasunie NV, 1980

[13]   Dubbels Taschenbuch der Machinenbau 1987

[14]   VDI Wärmeatlas 4^e Auflage 1984

Annexes

Generic performance, mass- and energy balance of a typical 20 MW$_e$ gasification unit.

Proposal for revised text of test protocol using ANSI PTC 16 as basis

ANNEX 1

Generic performance of typical 20 MW$_e$ gasification unit

The information and performance provided in the following tables is for comparison only and has only a mild relationship with some existing gasification process.

The numbers can be used to judge the effect of measurement strategy. Following advise given by Horazak and Archer elsewhere [6] it should be considered to develop a standard and more detailed computerized system performance model for the gasification process that can emulate the effects of measurement strategy and thereby improve the overall accuracy of the test.

Horazak and Archer [6] list applications of such model for the PTC47 committee:

Illustration of calculations of variously defined performance factors (input, output and effectiveness) for the overall plant and for its component systems from measured or measurable conditions
Calculation of uncertainty associated with each of these performance factors based on methods recommended in other related standards (i.e. PTC19.1) and on data for systematic uncertainty for each of the measured quantities involved
Evaluation of the sensitivity of plant performance parameters to each input
Recommendation of practical measurement methods for each input and output variable
Assessment of the energy balance method for calculating the heat input to the plant based on balances around the fuel gasifier, including perhaps components of heat recovery equipment. Direct measurements of the flow and heat of combustion of gasifier fuel may be difficult and uncertain. Measuring the fuel gas product and energy output and losses from the gasifier may provide a more accurate estimate of the heat input to the gasifier and thus to the plant.

Input of mass and energy:

INPUT:	Kg/s	% of total	KWth	% of total
Wood fuel, 10% m.c. (1)	3.35	43.3	54,015	97.4
Air	3.93	50.8	963	1.7
Sand (1)	0.14	1.8	1.8	0.0
Inert gas (3)	0.04	0.5	0.8	0.0
Syngas to filter	0.08	1.0	497	0.9
Solid additions (4)	0.2	2.6	2.4	0.0
Total mass flow in	7.74	100	55,480	100

1.   **Lower heating value wood fuel:**   **18.2 MJ/kg (dry)**
2.   **Air preheated to:**   **250 °C**
3.   **Inert gas is for used for purging of the filters**
4.   **Materials at ambient temperature**

Output of mass and energy:

OUTPUT:	Kg/s	% of total	KWth	% of total
Fuelgas exit cleaning	6.8	84.7	41,592	74.4

Bottom ash	0.18	2.2	130.7	0.2
Filter ash	0.16	2.0	2,706	4.8
Condensed water	0.89	11.1	2,309	4.1
Total mass flow out:	8.03	100		
Evaporator			6,483	11.6
Coolers			1,454	2.6
Heat loss			980	1.8
Sensible heat in gas			250	0.5
Total energy flow out			55,904	100

NB: Evaporators are assumed to supply dry saturated steam

Inert solids to gasifier:

			Percentage of total
Actual ash in wood	kg/s	0.05	13.1
Sand in, total	kg/s	0.14	36.2
Solid additions in, total	kg/s	0.19	50.7
Total inert material	kg/s	0.38	

Inert material discharged from gasifier:

			Percentage of total
Total solids discharged	kg/s	0.34	100

The carbon content in the ash is roughly 20-30 %.

Composition of the fuelgas:

Component	Vol % after cleaning	Component	Vol % after cleaning
CO	21.0	H_2O	3.4
H_2	13.6	N_2	41.8
CH_4	4.9	NH_3	0.03
C_2H_6	1.8	H_2S	0.03
CO_2	13.4	HCl	0.03

Minor components:	BTX & tar 1-2 g/Nm^3	
Density:	1.151	kg/Nm^3
LHV:	7.04	MJ/Nm^3
Carbon content:	0.179	kg/Nm^3
Nitrogen content:	0.522	kg/Nm^3

Carbon balance:

Input

Wood	3.35	kg/s		43.4 % carbon	1.31	kg/s
Fuelgas		0.08	kg/s		0.01	kg/s
Total in:					1.32	kg/s

Output

Fuelgas		5.91	Nm³/s	0.179 kg/Nm³		1.06	kg/s
Residues	0.35	kg/s		25 %	0.09	kg/s	
Total out:					1.15	kg/s	
Unaccounted for:					0.17	kg/s	

The 0.17 kg/s is roughly 13% of the input, partly the missing carbon will be in the tars.

Nitrogen balance:

Input

Wood	3.35	kg/s		0.07 % Nitrogen	0.002	kg/s	
Fuelgas		0.08	Nm³/s	0.522 kg/Nm³		0.05	kg/s
Air	3.12	Nm³/s		79 %	3.08		
Total in:					3.132	kg/s	

Output

Syngas	5.91	Nm³/s	0.522 kg/Nm³	3.09	kg/s
Ammonia in gas	PM	kg/s		PM	kg/s
Ammonia removed	?	kg/s		?	kg/s
Total out:				3.09	kg/s
Unaccounted for:				-0.04	kg/s

Wood input with 10% moisture, nitrogen content based on dry material.

Energy balance:

An overview energy balance can now be used to close the circle and calculate a rough estimate of the electrical efficiency. The calculation is made for illustration purpose only and actually is beyond the scope of the work.

Energy available in syngas:	41,592	kWth
Assumed gross electrical efficiency gas turbine:	27	%
Electricity generated by gas turbine	11,230	kWe
Energy available for steam plant	37,388	kWth
Assumed gross electrical efficiency steam plant	37	%
Electricity generated by steam plant	13,834	kWe
Internal plant power consumption	4,750	kWe
Nett power generated	20,314	kWe
Heat input by fuel	50,752	kWth
Net electrical plant efficiency	40.0	%

For the calculation of the energy input by the fuel it has been assumed that the wood arrives at the plant with a moisture content of 35% and that this moisture can be removed to a final 10% by using waste heat from the plant in a dryer. The mass flow of wood to the plant with 35% moisture is therefore 4.64 kg/s with lower heating value 10.94 kJ/kg

At this point one should appreciate that the actual heat input in the gasifier is higher, 54 MWth because of the use of low grade waste heat to dry the wood. If this energy is not available then it should be supplied from an external source with associated reduction in overall efficiency.

The efficiency of the gasifier can be calculated according to the various definitions:

Heat input by fuel (LHV)	54,015	kWth
Heat credits	1,465	kWth
Heat input	55,480	kWth
Heat in fuelgas (LHV)	41,592	kWth
Sensible heat in gas	250	kWth
Useful heat in steam/water	7,937	kWth
Cold gas efficiency, η_{cold}	74.97	%
Hot gas efficiency, η_{hot}	75.42	%
Overall efficiency, $\eta_{overall}$	89.72	%

Draft test protocol using parts of ASME ANSI PTC 16 - 1974

SECTION 0, INTRODUCTION

This code for conducting tests of Large Biomass Fuelled Gasifiers is intended primarily for tests of those gasifiers whose gas is to be used for power, heating or chemical purposes . A Large Biomass Fuelled Gasifier is here defined as any unit which generates primarily CO or H_2 continuously from biomass fuels. Units such as the fixed-bed, fluid-bed, entrained or pulverised types, all operating at about atmospheric pressure or higher, are included.

0.1   The term "fuel," as herein used, includes only biomass defined as fuel consisting for a large part of woody and herbaceous material.

0.2   In testing a Large Biomass Fuelled Gasifiers the auxiliary apparatus must be included in many cases, as being essential parts of the unit. If a complete test of the Large Biomass Fuelled Gasifiers is desired, separate records should be made of the amounts of fuel, water, power, and labour required to operate the producer and each of its auxiliaries.

SECTION 1, OBJECT AND SCOPE

1.1   The purpose of this code is to establish rules for conducting tests to determine the operating characteristics of Large Biomass Fuelled Gasifiers. All continuous types of Large Biomass Fuelled Gasifiers are to be included with a fuel capacity larger than 10 MWth, such as those using fluidized beds, pulverised fuels, fixed beds and those using oxygen and/or recycled CO_2

1.2   Possible objectives for which a test may be carried out may he one or more of the following

The maximum capacity of the Large Biomass Fuelled Gasifier and each of its auxiliaries
The efficiency of the Gasifier in making gas and the performance of each of its components
The ability of the Gasifier to use a specific fuel
The ability of the Gasifier to respond to varying loads
The quantity, quality, and cleanliness of the gas
The results obtained by using different kinds and sizes of fuels and using them in different ways
The amounts and costs of labour and power required to operate the the Gasifier and its auxiliaries
The reliability of the Gasifier and of its component parts
The causes of faulty operation of the producer or its auxiliaries
The efficiency of recovery of by-products, such as NH_3.

1.3   Analysis of performance of auxiliaries is not usually contemplated, although their consumption of fuel, utilities, labour and such items as contribute to the cost of their operation will be accounted for. It should be clearly stated in the objectives of the test which producers and what auxiliary equipment are to be included. In some cases only performance data on the producer itself may be desired.

SECTION 2, DESCRIPTION AND DEFINITION OF TERMS

Description and Definition of Terms. The following table defines the units and terms which are used.

TO BE COMPLETED LATER INCLUDING DIAGRAM WITH BOUNDARY ENVELOPE

SECTION 3, GUIDING PRINCIPLES and TEST CONDITIONS

3.1   Before the test, the parties concerned shall reach a definite agreement on the following items:

Object of test
Source and selection of fuel
Selection of instruments
Method of calibration of instruments
Limits of permissible error
Intent of contract or specifications if ambiguities or omissions appear evident
Adjustment of equipment for continuous commercial operation and method of operating equipment under test, including that of any auxiliary equipment, the performance of which may influence the test result
Methods of maintaining constant operating conditions as closely as possible to those specified
Organisation of personnel, including designation of engineer in responsible charge of test
Number of copies of original data required
Method of determining duration of operation under test conditions before test readings are started
Duration of test runs
Frequency of observations
Values of corrections for deviations of test conditions from those specified and provision for rejecting inconsistent readings
Methods of computing results (Section 5 of this code)
Preparation of final report
Cost of tests

Agreement in writing must be made regarding allowable deviations that may occur during testing, owing to unforeseen circumstances.

Should serious inconsistencies in the observed data be detected during a run, or during the computation of results, the run shall be rejected in whole or in part. A run that has been rejected shall be repeated, if necessary, to attain the objectives of the test.

Preparation for Tests.

The dimensions of the Gasification system and of each of its components individual pieces of equipment, and auxiliaries together with the physical condition of each, should be carefully determined and recorded. The testing appliances should then be installed and the preparations for making the test completed, including the provision of an adequate number of suitably prepared log books and other supplies which may be needed for the different pieces of components, equipment, and auxiliaries. Tests should be made for leaks. Leaks should be stopped, but if this is impracticable, agreement should be reached on their

importance and suitable allowances should be made for them in the final results. The use of photographs of the assembled equipment is recommended.

Starting and Stopping. The conditions regarding the temperature of the Gasifier and its contents, and the quantity and quality of the latter, should be as nearly as possible the same throughout the test, and particularly so at the beginning and at the end. As far as may be reasonably possible, there should be no clinker on the walls or in the Gasifier at the beginning and the end of the test. To secure the desired equality of conditions, the starting and stopping should occur at the conclusion of the times of regular cleaning, and they should be in operation for a period of not less than eight hours by the same regular working conditions as are intended to characterise the test as a whole. Unless the conditions of the fuel bed at the beginning and end of a test can be so accurately determined, and possible differences in level allowed for, that the error in determining the net weight of fuel used during the test shall not exceed two per cent, the tests should be abandoned as valueless, unless a larger allowable error has been previously agreed upon.

Requirements as to Adjustment of Equipment and Methods of Operation. For acceptance tests, the equipment manufacturer or supplier shall have reasonable opportunity to examine the equipment, to correct defects, and to render the equipment suitable, in his/her judgement, to undergo test. He/she may make such reasonable preliminary test runs as deemed necessary for this purpose. The manufacturer, however, is not thereby empowered to alter or adjust equipment or conditions in such a way that contract or other stipulations are altered or voided. The manufacturer may not make adjustments to the equipment for test purposes that may prevent immediate continuous and reliable operation at all capacities or outputs and under all specified operating conditions. Observations during preliminary test runs should be carried through to the calculation of results as an overall check of procedure, layout and organisation. If mutually agreed, a preliminary test may be considered an acceptance test, provided it has complied with all the necessary requirements of this code. Preliminary test runs with log records serve to determine if the equipment is in a satisfactory condition to undergo test, to check instruments and methods of measurement, and to train personnel.

Requirements for Duration of Tests.

Full-Time and Complete Tests: The duration, both of efficiency and capacity full-time tests of a gasifier, is a matter upon which there should he prior agreement between the parties concerned.

Short-Time or Spot Tests: The use of short-time tests or spot tests is sometimes required in order to determine the capacity of the producer, the quality of the gas, and certain other specific items. The data generally required in such a test depend to some extent on the purpose of the test, but the usual procedure is to collect gas and fuel samples over a suitable period of time. An analysis of the gas sample and an ultimate analysis of the fuel provide sufficient information to enable the calculation to be made of the amounts of air and steam needed to gasify the biomass, and also the quantity of gas produced per kg of biomass. Generally this procedure neglects the carbon losses in the ash, soot and tar, but, if desired, these factors can be accounted for. However, since they are difficult to obtain they probably would not be determined in short-time tests. For more complete tests, such items of measurement as may be appropriate for the purpose required may be selected, by agreement, from Sections 5 and 6.

SECTION 4, INSTRUMENTS AND METHODS OF MEASUREMENT

The necessary instruments and rules for making measurements are prescribed herein. References will be made to Test Codes, Supplements on Instruments and Apparatus (hereinafter referred to as I & A), and to other publications describing methods and apparatus which can be used in testing gas producers under this code.

The following check list, not necessarily complete, is provided to indicate the instruments and measurements that will most generally be required. An exact list for any given test will depend upon the specific objectives for which the test is being made.

Input quantity measurement: Fuel weighing devices, flow meters, etc
Output quantity measurements: Scales, weigh tanks, flow meters, etc
Temperature measurements: Gas, steam, air, liquids, and solids. Thermometers, thermocouples, pyrometers, etc
Pressure measurements: Gas, air, and liquids. Manometers, pressure gages, etc
Gas and vapour analysis and quality determinations: For flue gases, feed gases, steam quality
Calorimeters: Both sampling and continuous
Apparatus for dust, tar, and soot determinations
Instruments for power measurements

SECTION 5, COMPUTATION OF RESULTS

The filled in tables will become an integral part of the report as well as additional sheets needed to calculate intermediate results i.e. heating value and density of the gas.

Wood fuel

No.	Description	Unit	Value
5.1	Moisture content as received	%	
5.2	Ah content on dry basis	%	
5.3	Carbon content on dry basis	%	
5.4	Hydrogen content on dry basis	%	
5.5	Oxygen content on dry basis	%	
5.6	Nitrogen content on dry basis	%	
5.7	Chloride content on dry basis	%	
5.8	Sulphur content on dry basis	%	
5.9	Temperature of the wood as charged	°C	
5.10	Lower heating value of the wood as received	kJ/kg	
5.11	Screen analysis		
5.12	Bulk density of the wood	kg/m^3	
5.13	Fusion temperature of the ash in reducing conditions: • Initial deformation • Softening point • Fluid point	°C	

General:

Sampling, preparation of the laboratory sample and analysis should take place according to widely accepted standards for biomass.

5.9   When the fuel is at atmospheric temperature it will suffice to use this temperature. Otherwise the fuel temperature should be measured by suitable thermometry. This will depend to a large extent on the method of feeding the fuel.

Dry (free from droplets) and clean fuel gas

No.	Description	Unit	Value
5.14	Pressure at sample point	bar.a	
5.15	Temperature at sample point	°C	
5.16	Measured flow (at actual conditions)	m^3/s	
5.17	Measured flow (at 0°C and 1013.25 mbar)	Nm^3/s	
5.18	Flow recycled to the gasifier (at actual conditions)	m^3/s	
5.19	Flow recycled to the gasifier (at 0°C and 1013.25 mbar)	Nm^3/s	
5.20	Net flow of fuel gas (at actual conditions) =5.16-5.18	m^3/s	
5.21	Net flow of fuel gas (at 0°C and 1013.25 mbar) =5.17-5.19	Nm^3/s	
5.22	Net flow corrected to standard conditions (15°C and 1013.25 mbar)	m^3/s	
5.23	Carbon Monoxide: CO	%	
5.24	Hydrogen: H_2	%	
5.25	Methane: CH_4	%	
5.26	Ethane: C_2H_6	%	
5.27	Carbon Dioxide: CO_2	%	
5.28	Water vapour: H_2O	%	
5.29	Nitrogen: N_2	%	
5.30	Ammonia: NH_3	%	
5.31	Hydrogen Cyanide: HCN	%	
5.32	Hydrogen Sulphide: H_2S	%	
5.33	Carbonyl Sulphide: COS	%	
5.34	Benzene: C_6H_6	mg/m^3	
5.35	Toluene: C_7H_8	mg/m^3	
5.36	Xylene: C_8H_{10}	mg/m^3	
5.37	Tars in mg per m^3 at 15°C and 1013.25 mbar	mg/m^3	
5.38	Lower heating value of tars	mJ/kg	
5.39	Carbon content of tars	kg/kg	
5.40	Hydrogen content of tars	kg/kg	
5.41	Particulate content of the gas in mg per m^3 at 15°C and 1013.25 mbar	mg/m^3	
5.42	Carbon content of particulates	kg/kg	
5.43	Calculated density of fuel gas (at 15°C and 1013.25 mbar)	kg/m^3	
5.44	Calculated Lower Heating Value, LHV (at 15°C and 1013.25 mbar)	mJ/m^3	
5.45	Calculated Lower Heating Value, LHV (at 0°C and 1013.25 mbar)	mJ/Nm^3	
5.46	Calculated Molecular weight	kg/kmol	

Carbon content of dry and clean syngas

No.	Description	Unit	Value
5.47	Carbon Monoxide: CO =(5.23/22.40)x12/100	kg/Nm^3	
5.48	Methane: CH$_4$ =(5.25/22.36)x12/100	kg/Nm^3	
5.49	Ethane: C$_2$H$_6$ =(5.26/22.19)x24/100	kg/Nm^3	
5.50	Carbon Dioxide: CO$_2$ =(5.27/22.25)x12/100	kg/Nm^3	
5.51	Hydrogen Cyanide: HCN =(5.31/22.34)x12/100	kg/Nm^3	
5.52	Carbonyl Sulphide: COS =(5.33/22.064)x12/100	kg/Nm^3	
5.53	Benzene: C$_6$H$_6$ =(5.34/20.5)x72/100	kg/Nm^3	
5.54	Toluene: C$_7$H$_8$ =(5.35/20.5)x84/100	kg/Nm^3	
5.55	Xylene: C$_8$H$_{10}$ =(5.36/20.5)x96/100	kg/Nm^3	
5.56	Tars =(5.37x5.37)/1,000,000	kg/m^3	
5.57	Particulates =(5.41x5.40)/1,000,000	kg/m^3	
5.58	Total carbon in the syngas =Sum(5.47 – 5.55)x0.948+5.56+5.57	kg/m^3	
5.59	Mass flow carbon in net flow of syngas =5.55x5.22	kg/s	

Nitrogen content of dry and clean syngas

No.	Description	Unit	Value
5.60	Nitrogen: N$_2$ =(5.29/22.4)x28/100	kg/Nm^3	
5.61	Ammonia: NH$_3$ =(5.30/22.1)x14/100	kg/Nm^3	
5.62	Hydrogen Cyanide: HCN =(5.31/22.6)x14/100	kg/Nm^3	
5.63	Total nitrogen in fuel gas =Sum(5.60 – 5.62)	kg/Nm^3	
5.64	Mass flow nitrogen in fuel gas =5.63x5.22x0.948	kg/s	

Gases to gasifier

No.	Description	Unit	Value
5.65	Volume flow nitrogen in fuel gas =(5.60x5.22x0.948/1.2504)	Nm^3/s	
5.66	Nitrogen input as inert gas	Nm^3/s	
5.67	Nitrogen input by air =(5.65 – 6.66)	Nm^3/s	
5.68	Dry air flow =(5.67/0.79)	Nm^3/s	
5.69	Mass flow dry air =(5.66x1.293)	kg/s	
5.70	Temperature dry air	°C	
5.71	Pressure dry air	bara	
5.72	Enthalpy dry air above 15°C	kJ/kg	
5.73	Temperature nitrogen	°C	
5.74	Pressure nitrogen	bara	
5.75	Enthalpy of nitrogen above 15°C	kJ/kg	
5.76	Recycled syngas	m3/s	
5.77	Temperature recycled fuel gas	°C	
5.78	Pressure recycled fuel gas	bara	
5.79	Enthalpy recycled fuel gas above 15°C	kJ/kg	
5.80	Steam to gasifier	kg/s	
5.81	Temperature steam	°C	
5.82	Pressure steam	bara	
5.83	Enthalpy steam above 15°C	kJ/kg	
5.84	Carbon Dioxide to gasifier	kg/s	
5.85	Temperature carbon dioxide	°C	
5.86	Pressure carbon dioxide	bara	
5.87	Enthalpy carbon dioxide above 15°C	kJ/kg	

5.10   It is assumed that the fuel bound nitrogen will not be converted to gaseous nitrogen

The gaseous materials, other than steam, which are fed to the gasifier may enter the reaction zone separately or combined, but each flow must be measured separately. Standard orifice or displacement flow meters are recommended. It is most important to totalize accurately the flow data for the whole run, if this is not achieved by the instrument. Obtain the temperature, pressure, and humidity of the gas at the point of measurement to enable later calculation to standard, dry basis. Temperatures are to be taken at the point of entry into the gasifier or boundary envelope. If flows have been combined, the temperature of the combined flow will suffice. In the analyses, all constituents amounting to more than 1 per cent by volume should be noted. The analysis of air by volume is taken as 79% N_2 and 21 per cent O_2 except in the case of contamination or dilution. The "humidity" is the moisture content of the gases at the point of entry. Humidities taken upstream from this point might be invalid because of condensation of moisture due to cooling or compression. No moisture should be added to the steam flow (such as water for desuperheating) beyond the point of flow measurement. If there is any possibility of condensation in the lines between the point of flow measurement and the producer, a trap-out device should be provided at the producer to measure the condensate.

Inert solids to gasifier

No.	Description	Unit	Value
5.88	Sand	kg/s	
5.89	Temperature	°C	
5.90	Solid additions calcined raw material	kg/s	
5.91	Temperature	°C	

Gas cleaning

No.	Description	Unit	Value
5.92	Dry and clean fuel gas (at 0°C and 1013.25 mbar) =5.17	Nm^3/s	
5.93	Density (at 0°C and 1013.25 mbar) =(5.43x1.0549)	kg/Nm^3	
5.94	Mass flow dry and clean fuel gas =(5.92x5.93)	kg/s	
5.95	NaOH addition to scrubber	kg/s	
5.96	H$_2$SO$_4$ addition to scrubber	kg/s	
5.97	Make up water to scrubber	kg/s	
5.98	Pressure of make up water	bar	
5.99	Temperature of make up water	°C	
5.100	Enthalpy of make up water above 15°C	kJ/kg	
5.101	Discharged water from scrubber	kg/s	
5.102	Pressure of discharged water	bar	
5.103	Temperature of discharged water	°C	
5.104	Enthalpy of discharged water above 15°C	kJ/kg	
5.105	Tar content of discharged water	kg/kg	
5.106	Carbon content of tars	kg/kg	
5.107	Carbon loss in discharged water =(5.101x5.105x5.106)	kg/s	
5.108	Ammonia content in discharged water	kg/kg	
5.109	Nitrogen loss in discharged water =(5.101x5.108x0.822)	kg/s	
5.110	Additional chemicals to scrubber =(5.95+5.96)	kg/s	
5.111	Nett water removed from scrubber =(5.101-5.97)	kg/s	
5.112	Additional water in raw gas inlet scrubber =(5.111-5.110)	kg/s	
5.113	Mass flow raw gas inlet scrubber =(5.94+5.112)	kg/s	
5.114	Cooling water flow	kg/s	
5.115	Inlet pressure cooling water	bar	
5.116	Inlet temperature cooling water	°C	
5.117	Inlet enthalpy cooling water	kJ/kg	
5.118	Outlet pressure cooling water	bar	
5.119	Outlet temperature cooling water	°C	
5.120	Outlet enthalpy cooling water	kJ/kg	
5.121	Energy removed by cooling water =(5.120-5.117)x5.114	kW	

Gas filtration

No.	Description	Unit	Value
5.122	Outlet mass flow fuel gas =5.113	kg/s	
5.123	Outlet temperature fuel gas	°C	
	Outlet pressure fuel gas	bar	
5.124	Removed particles	kg/s	
5.125	Inlet mass flow fuel gas + particles =(5.122+5.124)	kg/s	
5.126	Outlet temperature fuel gas	°C	
5.127	Outlet pressure fuel gas	bar	
5.128	Carbon content removed ash	%	
5.129	Lower heating value of the removed ash	kJ/kg	

5.124   The ash withdrawn may be of a very heterogeneous nature and care must be taken to obtain a representative sample. It will be assumed that only carbon (no volatiles) is present in the refuse in addition to inorganic matter. The carbon can be analysed by standard combustion procedure. For the bulk density determination, dry 1 kg of a thoroughly mixed and representative sample of the ash. (Do not grind or crush any of the material.) Then load into a calibrated volumetric container, and shake down or tamp gently. Note volume and express the dry bulk density as kg per cubic meter. "Moisture" in ash is difficult to obtain and liable to be misleading. It is the nature of this material to lose moisture rapidly when exposed to the atmosphere. Thus material sampled at the plant might lose appreciable quantities of moisture in handling prior to the actual analysis. Thus, wet weights of ash and moisture analyses are not to be used to compute the dry weight.

Heat recovery

Boiler

No.	Description	Unit	Value
5.130	Inlet mass flow fuel gas	kg/s	
5.131	Inlet temperature fuel gas	°C	
5.132	Inlet pressure fuel gas	bar	
5.133	Inlet enthalpy fuel gas	kJ/kg	
5.134	Outlet temperature fuel gas	°C	
5.135	Outlet pressure fuel gas	bar	
5.136	Outlet enthalpy fuel gas	kJ/kg	
5.137	Inlet mass flow feed water	kg/s	
5.138	Inlet temperature feed water	°C	
5.139	Inlet pressure feed water	bar	
5.140	Inlet enthalpy feed water	kJ/kg	
5.141	Outlet temperature steam	°C	
5.142	Outlet pressure steam	bar	
5.143	Outlet enthalpy steam	kJ/kg	
5.144	Energy absorbed in steam	kW	

Cooler 1

No.	Description	Unit	Value
5.145	Inlet mass flow fuel gas	kg/s	
5.146	Inlet temperature fuel gas	°C	
5.147	Inlet pressure fuel gas	bar	
5.148	Inlet enthalpy fuel gas	kJ/kg	
5.149	Outlet temperature fuel gas	°C	
5.150	Outlet pressure fuel gas	bar	
5.151	Outlet enthalpy fuel gas	kJ/kg	
5.152	Inlet mass flow feed water	kg/s	
5.153	Inlet temperature feed water	°C	
5.154	Inlet pressure feed water	bar	
5.155	Inlet enthalpy feed water	kJ/kg	
5.156	Outlet temperature steam/water	°C	
5.157	Outlet pressure steam/water	bar	
5.158	Outlet enthalpy steam/water	kJ/kg	
5.159	Energy absorbed in steam/water	kW	

Cooler 2

No.	Description	Unit	Value
5.160	Inlet mass flow fuel gas	kg/s	
5.161	Inlet temperature fuel gas	°C	
5.162	Inlet pressure fuel gas	bar	
5.163	Inlet enthalpy fuel gas	kJ/kg	
5.164	Outlet temperature fuel gas	°C	
5.165	Outlet pressure fuel gas	bar	
5.166	Outlet enthalpy fuel gas	kJ/kg	
5.167	Inlet mass flow feed water	kg/s	
5.168	Inlet temperature feed water	°C	
5.169	Inlet pressure feed water	bar	
5.170	Inlet enthalpy feed water	kJ/kg	
5.171	Outlet temperature steam/water	°C	
5.172	Outlet pressure steam/water	bar	
5.173	Outlet enthalpy steam/water	kJ/kg	
5.174	Energy absorbed in steam/water	kW	

Heat loss to the environment by convection & radiation

No.	Description	Unit	Value
5.175	Average external air temperature	°C	
5.176	Surface area section 1	m^2	
5.177	Average temperature surface area 1	°C	
5.178	Heat transfer coefficient, convection & radiation	W/m^{2}K	
5.179	Heat loss surface section 1 =(5.177-5.175)x5.176x5.178	kW	
5.180	Surface area section 2	m^2	
5.181	Average temperature surface area 2	°C	
5.182	Heat transfer coefficient, convection & radiation	W/m^{2}K	
5.183	Heat loss surface section 2 =(5.181-5.175)x5.180x5.182	kW	
5.184	Surface area section 3	m^2	
5.185	Average temperature surface area 3	°C	
5.186	Heat transfer coefficient, convection & radiation	W/m^{2}K	
5.187	Heat loss surface section 3 =(5.185-5.175)x5.184x5.186	kW	
5.188	Surface area section 4	m^2	
5.189	Average temperature surface area 4	°C	
5.190	Heat transfer coefficient, convection & radiation	W/m^{2}K	
5.191	Heat loss surface section 4 =(5.189-5.175)x5.188x5.190	kW	
5.192	Total heat loss by convection and radiation =(5.179+5.183+5.187+5.191)	kW	

Mass balance

No.	Description	Unit	Value
5.193	Gases to gasifier =(5.69+5.66x1.2504+5.76x5.43+5.80+5.84)	kg/s	
5.194	Inert solids to gasifier =(5.88+5.90)	kg/s	
5.195	Filter ash removal =5.124	kg/s	
5.196	Bottom ash removal	kg/s	
5.197	Discharged water from scrubber =5.101	kg/s	
5.198	Dry and clean fuel gas after scrubber (upstream of take of recycling gas) =(5.17x5.43)x1.0549	kg/s	
5.199	Calculated wood fuel flow (wet) =(5.198+5.195+5.196+5.197-5.193-5.194)	kg/s	

Energy balance for 15°C reference temperature

No.	Description	Unit	Value
5.200	**Sensible heat in gases to gasifier** $=(5.72 \times 5.69 + 5.75 \times 5.66 \times 1.2504 + 5.79 \times 5.76 \times 5.43 + 5.83 \times 5.80 + 5.87 \times 5.84)$	kW	
5.201	**Chemical heat in recycled fuel gas** $=(5.79 \times 5.44)$	kW	
5.202	**Sensible heat in inerts feed to gasifier** $=(5.88 \times (5.89-15) \times C_{psand} + 5.90 \times (5.91-15) \times C_{add})$	kW	
5.203	**Heat input by air preheater**	kW	
5.204	**Heat input by make up scrubber water** $=(5.97 \times 5.100)$	kW	
5.205	**Heat input by air compressor**	kW	
5.206	**Total heat input besides wood fuel** $=(5.200+5.201+5.202+5.203+5.204+5.205)$	kW	
5.207	**Chemical heat in dry and clean fuel gas**	kW	
5.208	**Sensible heat in dry and clean fuel gas**	kW	
5.209	**Sensible heat loss in discharged water from scrubber** $=(5.101 \times 5.104)$	kW	
5.210	**Chemical heat loss by tars in discharged water** $=(5.105 \times 5.101 \times 5.38)$	kW	
5.211	**Energy removed by cooling water in scrubber** $=5.121$	kW	
5.212	**Sensible heat in filter ash** $=(5.125 \times (5.126-15) \times C_{pash})$	kW	
5.213	**Chemical energy in filterash** $=(5.125 \times 5.129)$	kW	
5.214	**Sensible heat in bottom ash** $=(5.196 \times (850-15) \times C_{pash})$	kW	
5.215	**Chemical energy in bottom ash**	kW	
5.216	**Useful energy in water/steam** $=(5.144+5.159+5.174)$	kW	
5.217	**Total heat loss by radiation & convection** $=5.192$	kW	
5.218	**Total heat output** $=(5.207+5.208+5.209+5.210+5.211+5.212+5.213+5.214+5.215+5.216+2.217)$	kW	
5.219	**Heat input by wood fuel** $=(5.218-5.206)$	kW	
5.220	**Calculated wet wood fuel feed** $=(5.219/5.10)$	kg/s	

5.202   For the heat capacity of sand C_{psand} is equal to 0.84 kJ/kg°C and the heat capacity of the solid additions C_{add} is equal to 0.97 kJ/kg°C and for calcined solid additions 0.84 kJ/kg°C (approximate values) for temperatures below 200°C.

5.204 The energy input by the air compressor can be determined by measuring the power consumption and using the efficiency corrections supplied with the electric motor. If the temperature can be measured accurately downstream of the compressor and air pre-heater it is possible to calculate directly the heat absorbed which can be used to replace the sum of 201 and 204.

5.212   The heat capacity of the filter ash C_{pash} is equal to 0.84 kJ/kg°C for temperatures below 200°C

Carbon balance

No.	Description	Unit	Value
5.221	Carbon in fuel gas =5.59	kg/s	
5.222	Carbon in discharged water =5.107	kg/s	
5.223	Carbon in filter ash =(5.124x5.128)/100	kg/s	
5.224	Carbon in bottom ash =(5.196x...)/100	kg/s	
5.225	Total carbon flow out =(5.221+5.222+5.223+5.224)	kg/s	
5.226	Carbon in recycled fuel gas =(5.58x5.22)	kg/s	
5.227	Carbon in added CO_2 =(5.84/44)x12	kg/s	
5.228	Carbon in solid additions (CO_2) =(5.90x0.48)	kg/s	
5.229	Carbon in besides wood fuel =(5.226+5.227+5.228)	kg/s	
5.230	Carbon in wood fuel =(5.225-5.229)	kg/s	
5.231	Calculated dry wood fuel feed =(5.230x100)/5.3	kg/s	
5.232	Calculated wet wood fuel feed =(100x5.231)/(100-5.1)	kg/s	

Calculation of weighed mass flow wood fuel feed

No.	Description	Unit	Value
5.233	Mass flow wood according to mass balance	kg/s	
5.234	Weighing factor mass balance	-	
5.235	Mass flow wood according to energy balance	kg/s	
5.236	Weighing factor energy balance	-	
5.237	Mass flow wood according to carbon balance	kg/s	
5.238	Weighing factor carbon balance	-	
5.239	Mass flow wood according to direct measurement	kg/s	
5.240	Weighing factor direct measurement	-	
5.241	Sum(mass flow)xweighting factor =(5.233x5.234+5.235x5.236+5.237x5.238+ 5.239x5.240)	kg/s	
5.242	Sum(weighting factor) =(5.234+5.236+5.238+5.240)	-	
5.243	Weighted average for mass flow =(5.241/5.242)	kg/s	

Efficiency

No.	Description	Unit	Value
5.244	Potential heat input wood fuel =(5.243x5.10)	kWth	
5.245	Sensible heat input wood fuel =(5.243x(5.9-15)x0.2.72	kWth	
5.246	Heat credits =5.206	kWth	
5.247	Heat input =(5.244+5.245+5.246)	kWth	
5.248	Potential heat output fuel gas =5.207	kWth	
5.249	Sensible heat output fuel gas =5.208	kWth	
5.250	Useful heat in steam/water =(5.144+5.159+5.174)	kWth	
5.251	Cold gas efficiency =(5.248/5.257)	%	
5.252	Hot gas efficiency =(5.248+5.249)/5.257	%	
5.252	Overall efficiency =(5.248+5.249+5.250)/5.257	%	

Accuracy

SECTION 6, REPORT OF TEST RESULTS

General information

Period of test:

Start:	Month Day Year Time	
End	Month Day Year Time	

Location:

Type and size of the gasifier

Dates of completion of of installation:

Name and address:

Owner	Name Address Street and number City Post Code Country Telephone Telefax	
Builder	Name Address Street and number City Post Code Country Telephone Telefax	

B.   Summary of data