HHV of Syn-Gas

Description

An analysis of syn-gas composition is required before calculating its HHV. The syn-gas is collected from the the gasification system process. Each sampling at the reduction zone must be consistently at the range of 750~850^{o}C.

The sample syn-gas is collected in a gas sample bag and then injected into GC for analysis. Then, each sample syn-gas is injected and analyzed at least five times by the GC and the results should be averaged.. The syn-gas was produced through the GEK gasification system prior to gas analysis.

Below are two multi-step procedures for gas analysis. These include

- Collecting the Syn-Gas
- Analyze the Gas Composition
- Calculating Volume of Syn-Gas
- Data Analysis: Calculation of Energy Conversion Efficiency

Procedure: Collecting the Syn-Gas

Prepare Gasifier

1. Check/drain the filter from the bottom as shown in Figure 1.

Figure 1: Prepare Gasifier

2. Clean the reactor and add some real wood charcoal to the reduction bell (do not use any other pressed

charcoal) as shown in Figure 2.

Figure 2: Prepare Gasifier

3. Add biomass fuel to the drying bucket as shown in Figure 3. The hopper holds up to 10 hours of fuel, this research does not need that much fuel, so rather than the hopper, only the drying bucket was used to hold fuels in this research.

Figure: 3 Prepare Gasifier

4. Turn on the feeding auger and wait until the reactor is filled. The fuel level switch will stop the auger when the reactor is full.
5. Close the drying bucket lid and make sure the whole system is sealed.
6. Connect the air compressor to the ejector venturi and open the flare gas valve as shown in Figure 4.

Figure 4: Prepare Gasifier

7. Make sure all switches on the GCU control panel are in the "reset" position and the engine valve is closed.

Light the Gasifier

1. Adjust the venturi needle valve on the venturi system and keep the reactor pressure (P_reac) lower than 10 because it is easier to ignite the biomass in a slower gas flow condition.
2. Open the ignition port and inject 10 ml of diesel fuel into the reactor as shown in Figure 5.

Figure 5: Light the Gasifier, Step 2

3. Light it with a propane torch one inch away from the ignition port as shown in Figure 6.

Figure 6: Light the Gasifier, Step 3

4. The smoke will come out from the flare during lighting. Stop lighting when there is no smoke coming out from the flare because that usually indicates the biomass fuel has already been ignited. This process might take 1 to 5 minutes (depends on biomass fuel type, moisture content, or the gasifier system flow condition, etc.).

Maintain the gasification process

5. When the T_tred goes up to 200~300 ^{o}C, open the air inlet valve and close the ignition port.
6. The flame will come out from the flare stack after a while (see Figure 18 g). Keep adjusting the pressure (gas flow rate) to maintain the flame. This is a signal to show the reactor inside is producing syn-gas.

Figure 7: : Maintain the Gasifier, Step 2

7. Continue adjusting the pressure valve till the process reaches the target temperature (T_tred, 850~950 ^{o}C

and T_bred, 750~850 ^{o}C). This target is set by All Power Lab from a large number of tests on woodchips. Usually when the gasifier reaches this temperature, the produced syn-gas will be neither too “tarry” nor too “sooty”.

Collect the Syn-Gas

8. Prepare an air sample bag and flush it.
9. Open the gas out valve on the gasification system as shown in Figure 8.

Figure 8: Collect the Syn-Gas, Step 5

10. Connect the hand pump air-in port to the end of gas cooling copper coil as shown in Figure 6. From the gasifier gas out port, and pump out the air inside of the coil. Based on the length of the copper coil and tube inside of the hand pump, 20 or more times of pump are required before the next step.

Figure 9: Collect the Syn-Gas, Step 6

11. Connect the air sample bag to the hand pump air-out port with the coupling as shown in Figure 10.

Figure 10: Collect the Syn-Gas, Step 7

12. Pump appropriate amount of syn-gas into the air sample bag with the hand pump and seal the bag when it is done.

Shut down the gasification system.

13. Close the gas out valve and air inlet valve.
14. Slowly decrease the pressure and close (do not fully close) the flare gas valve.
15. Fully close the flare gas valve and disconnect the air compressor to the ejector venturi after 10 minutes.
16. Wait till the system cools down.

Procedure: Analyze the Gas Composition

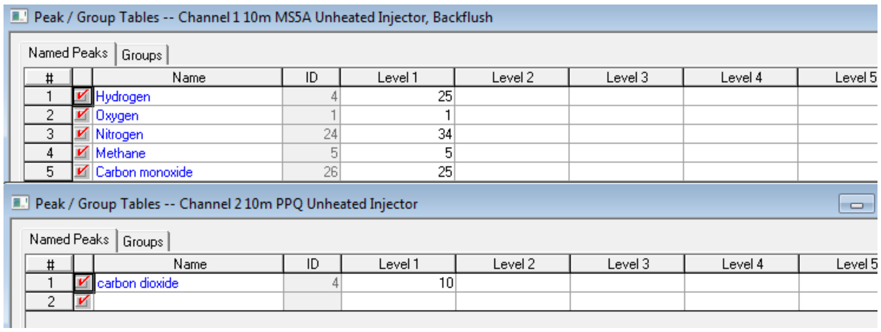
After collecting the syn-gas, the next step is to analyze the gas composition for the sample gas.

Gas Chromatograph (GC) preparation

1. Bake out the GC for at least 8 hours before analyzing.
2. After 8 hours, generate a method for standard syn-gas analysis on GC and name it as "standard_syngas.met".
3. Download the method and wait till the instrument is ready.
4. Use the "standard_syngas.met" to analyze the standard syn-gas that has known concentration for five repetitions (H_2: 25%, CO: 25%, CH_4: 5%, O_2: 1%, CO_2: 10%, N_2: 34%).
5. After the peak results are plotted, define those peaks for both channels with particular sequence: H_2, O_2,

N_2, CH_4, CO for channel one, and CO_2 for channel 2.

6. To calibrate the GC, input the known concentration for each gas components with known percentage at the Peaks/Group Table as shown in Figure 11.


Peak / Group Tables -- Channel 1 10m MS5A Unheated Injector, Backflush

Named Peaks | Groups

#	Name	ID	Level 1	Level 2	Level 3	Level 4	Level 5
1	Hydrogen	4	25				
2	Oxygen	1	1				
3	Nitrogen	24	34				
4	Methane	5	5				
5	Carbon monoxide	26	25				

Peak / Group Tables -- Channel 2 10m PPQ Unheated Injector

Named Peaks | Groups

#	Name	ID	Level 1	Level 2	Level 3	Level 4	Level 5
1	carbon dioxide	4	10				
2							

Figure 11: Calibrate the GC

7. Set the order of single level calibration for level 1 as shown in Figure 12.

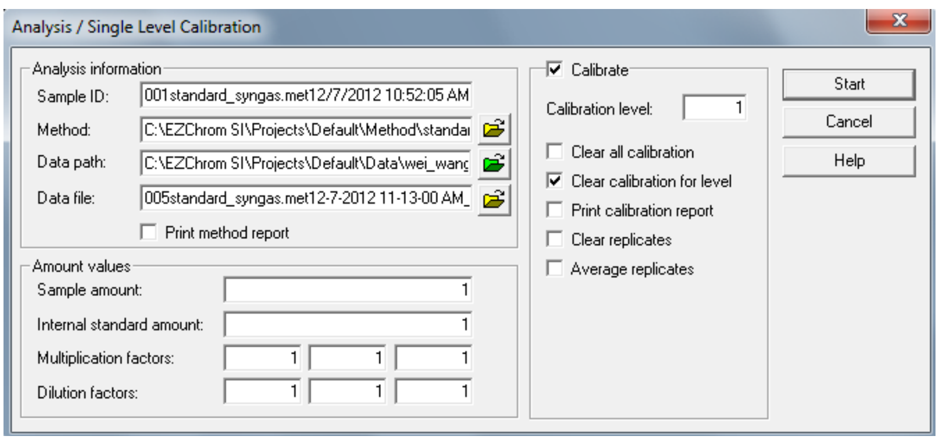


Figure 12: Set Single Calibration Level

8. Check the External Standard Report to make sure all concentrations of gas components are calibrated as shown in Figure 13.

External Standard Report **Page 1 of 1**

Method Name: C:\EZChrom SI\Projects\Default\Method\standard_syngas.met
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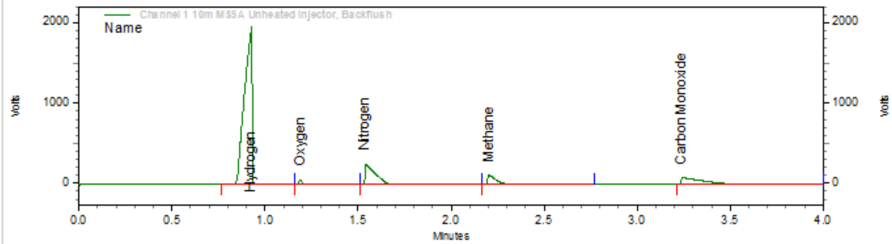
User: System
Acquired: 8/2/2012 2:46:45 PM
Printed: 7/9/2013 3:53:51 PM



Channel 1 10m MS5A Unheated Injector, Backflush Results

Pk #	Name	Retention Time	Area	Concentration
1	Hydrogen	0.929	544762257	**25.000 CAL**
2	Oxygen	1.191	5775678	**1.000 CAL**
3	Nitrogen	1.541	91500759	**34.000 CAL**
4	Methane	2.205	32664773	**5.000 CAL**
5	Carbon Monoxide	3.243	59716634	**25.000 CAL**
Totals			734420101	**90.000 CAL**

Channel 2 10m PPQ Unheated Injector Results

Pk #	Name	Retention Time	Area	Concentration
2	CO2	0.457	184484928	**10.000 CAL**
Totals			184484928	**10.000 CAL**

Figure 13: Concentrations of Gas Components

Procedure: Calculating Volume of Syn-Gas

Analyze Syn-Gas

1. Connect the air sample bag to the GC as shown in Figure 14.

Figure 14: Analyze Syn-Gas, Step 1

2. Stay at the calibrated "standard_syngas.met" and then send the “single run with five repetitions” order to analyze the syn-gas as shown in Figure 15.

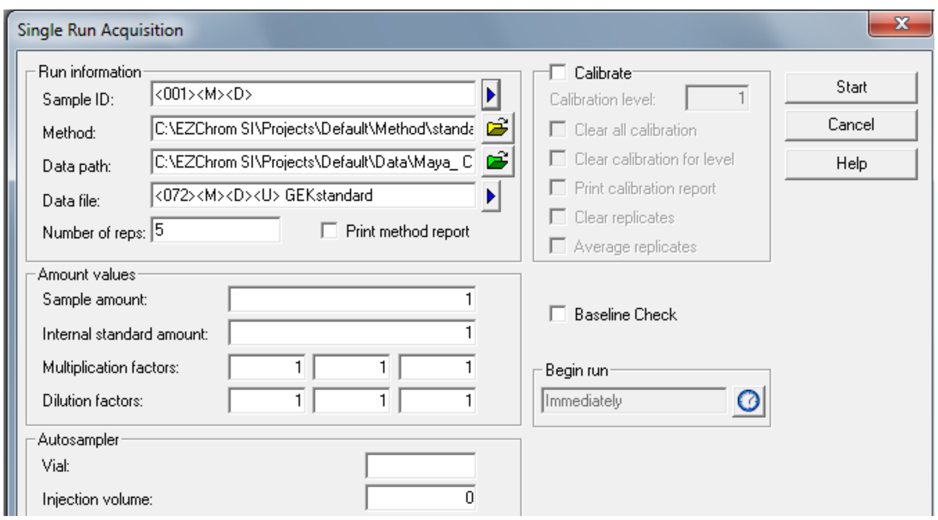


Figure 15: Analyze Syn-Gas, Step 2

3. Slightly push the sample bag to help the injection of syn-gas for the instrument. Wait until five repetitions results are plotted.

Record Results

4. Open the External Standard Report for the last three repetitions. The first two results are neglected

because they are affected by the air contained in the coupling and connecting tubes as shown in Figure 16.

External Standard Report **Page 1 of 1**

Method Name: C:\EZChrom SI\Projects\Default\Method\standard_syngas.met
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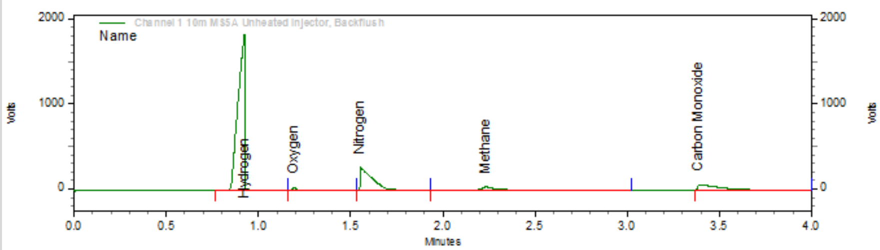
User: System
Acquired: 12/7/2012 11:13:18 AM
Printed: 7/9/2013 4:12:40 PM



Channel 1 10m MS5A Unheated Injector, Backflush Results

Pk #	Name	Retention Time	Area	Concentration
1	Hydrogen	0.924	458793817	**21.022**
2	Oxygen	1.195	2997539	**0.488**
3	Nitrogen	1.554	112488103	**41.609**
4	Methane	2.235	13720366	**2.114**
5	Carbon Monoxide	3.391	43665671	**18.436**
Totals			631665496	**83.669**

Channel 2 10m PPQ Unheated Injector Results

Pk #	Name	Retention Time	Area	Concentration
2	CO2	0.452	134676468	**6.703**
Totals			134676468	**6.703**

Figure 16: Record Results

5. Average the results from three repetitions and record them as gas concentration results for one gasification run.

Procedure: Data Analysis: Calculation of Energy Conversion Efficiency

With the collected data of fuel HHV and syn-gas composition, the thermal conversion efficiency of gasification could be calculated based on the following known factors:

1. Assume 1kg of biomass can be converted to 2m^3 of syn-gas ("Modeling Gasifier Mass," 2010).
2. Standard HHV (Waldheim & Nilsson, 2001) for: H_2 = 12.76MJ/m^3; CO = 12.63MJ/m^3; CH_4 =

39.76MJ/m^3.

3. Syn-gas composition: H_2, O_2, N_2, CH_4, CO, CO_2. The total percentage of all these gases is 100%.
4. HHV of biomass fuels.

Since only H_2, CO and CH_4 are combustible, the HHV of syn-gas is the calorific value of these three gases: ΔH (2m^3 syn-gas) = (12.76MJ/m^3 × 2m^3 × H_2%) + (12.63MJ/m^3 × 2m^3 × CO%) + (39.76MJ/m^3 × 2m^3×CH_4%) = 2(12.76 × H_2% + 12.63 × CO% + 39.76 × CH_4%)MJ/m^3

The thermal conversion efficiency equation is (Rajvanshi, 1986):

$$\eta = \frac{Calorific\ value\ of\ gas\ per\ kg\ of\ fuel}{Calorific\ value\ of\ 1kg\ fuel} \qquad (4)$$

Thus, gasifying 1kg of biomass has the thermal conversion efficiency of:

$$\eta = \frac{\Delta H_{gas}(\frac{kJ}{m^3}) \times 2(m^3)}{\Delta H_{biomass}(\frac{kJ}{kg}) \times 1(kg)} \times 100\% \qquad (5)$$

Among which kJ/Nm^3 is the unit of gas calorific value – kilo Joule per cubic meter; kJ/kg is the unit of biomass calorific value – kilo Joule per kilogram.

The percentage of H_2, CH_4 and CO (H_2%, CH_4%, CO%) could be obtained from syn-gas analysis and the HHV of biomass ($\Delta H_{biomass}$) could be tested by bomb calorimeter. Therefore, the thermal conversion efficiency η could be calculated for both of biomass fuels.

However, the assumption that 1kg of biomass can produce 2m^3 syn-gas was merely an approximate estimation for woodchips gasification. For comparison between different types of biomass fuels, in practice, the amount of syn-gas produced through gasifying1kg biomass varies. Therefore, instead of simply using 2m^3 syn-gas production, a more specific method to calculate the real volume of syn-gas produced by gasifying 1kg biomass fuels is required.

$$\eta = \frac{\Delta H_{gas}(\frac{kJ}{m^3}) \times V(m^3)}{\Delta H_{biomass}(\frac{kJ}{kg}) \times 1(kg)} \times 100\% \qquad (6)$$

Where V is the volume of syngas produced from 1 kg of actual biomass gasification, which can be calculated from the equivalence ratio method.

Calculate Using the Equivalence Ratio Method.

Equivalence ratio (ER) is the ratio of actual air-fuel ratio to the stoichiometric air-fuel ratio. Usually, the ER range for gasification lies between 0.19-0.43 theoretically, but 0.25 is identified to be the optimum (Zainal et. al, 2002). ER is directly related to the pressure, and thus affects the performance of the gasification process ("Modeling Gasifier Mass," 2010; Gunarathne, 2012). In this research, the equivalence ratio is proportional to the pressure of the reactor in this gasification system (P_reac). Based upon the stoichiometric ratio calculation, in a complete combustion, the stoichiometric ratio of biomass (CH_2O) to air is roughly 1:4.58 in mass. In other words, 1 kg of biomass needs 4.58 kg of air for complete combustion. The ER of wood gasification is 0.25. That is, the amount needed for an ideal gasification is approximately 25% of what is needed for a complete combustion. Under these assumptions, with the data of P_reac for gasifying Arundo donax and the mixture, their ER could be calculated. Therefore, the amount of syn-gas produced from gasifying 1kg different fuels can be calculated.

Calculating the Volume of Syn-Gas

The following describes the detailed steps of calculating volume of syn-gas generated from the gasification process:

5. The air needed for a complete combustion of biomass is 4.58 kg of air per kg of biomass.
6. The ER for each biomass gasification is proportional to the pressure of the gasifier reactor; ER = C × P_reac (where P_reac is the pressure of gasifier reactor in the unit of inch water, and C is an experimental constant depending upon the specific gasifier).
7. The baseline ER for woodchips gasification is 0.25 (Zainal et. al, 2002). In other words, $ER_{wood} = C \times P_{rw} = 0.25$ (where P_{rw} is the reactor pressure for woodchip gasification).

   Thus, $C = 0.25 / P_{rw}$.

8. The following can be used to calculate the ER for other biomass:

   $ER_{biomass} = C \times P_{rb} = 0.25 \times P_{rb} / P_{rw}$ (where P_{rb} is the reactor pressure for other biomass gasification).

9. Once the ER determined, the amount of air supplied to the gasification process can be calculated as follows:

   $M_{air} = ER \times 4.58$ (where M_{air} is the mass of air).

10. Total mass of syn-gas produced from a gasification process equal to the sum of biomass and air

    $M_{syn\text{-}gas} = M_{biomass} + M_{air}$

11. The density of syn-gas is determined by the volume percentage of each gas component and its corresponding gas density. Assuming the syn-gas is composed of H_2, O_2, N_2, CH_4, CO, CO_2 and other gases. Additionally, based upon the experimental observation, other gases are mainly water vapor (H_2O).

Thus,

$$\rho_{syn\text{-}gas} = \rho(H_2) \times H_2\% + \rho(O_2) \times O_2\% + \rho(N_2) \times N_2\% + \rho(CH_4) \times CH_4\% + \rho(CO) \times CO\% + \rho(CO_2) \times CO_2\% + \rho(H_2O) \times H_2O\ \%$$

12. Once the density syn-gas is determined, the volume of syn-gas generated from 1 kg of biomass can be calculated:

$$V_{syn\text{-}gas} = M_{syn\text{-}gas} / \rho_{syn\text{-}gas}$$

Note: Plugging the result of $V_{syn\text{-}gas}$ into equation (6), the thermal efficiency of biomass gasification can be calculated.