Pyrotech Energy

nettenergy

COFFEE GROUNDS

GASIFICATION

TEST RUN REPORT

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REVISION 1

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1 Executive Summary

Coffee grounds, a major by-product of the coffee industry, is one of the most commonly available lignocellulosic materials that can be converted into different types of fuels and chemical feedstock's through a variety of thermochemical conversion processes.

One of those thermochemical conversion processes is gasification where – different to combustion – a reduced amount of air is added to the process. This results in a syngas which subsequently can be burned in furnaces and gas engines to produce heat and electricity.

Nettenergy has been requested to perform test with coffee grounds in their gasifier with the aim to produce syngas for a gas generator such that electricity production can be quantified.

Nettenergy received the coffee grounds with high moisture content (>60w%). This material had to be dried and pelletized before introducing it in the gasifier.

Gasification of the dried coffee grounds was successful.

The coffee grounds as received yield:

1) a net specific electricity production of 4,85 kg/kW$_{elec.}$
2) a net char production of 4.0%

This implies that 4,85 kg of coffee grounds are required to produce 1 kWh of electricity net.

The net electricity production is calculated based on 25% captive use of electricity for the pre-processing of the coffee grounds.

There is enough waste heat from the gasifier itself to perform the drying.

2 General

2.1 Gasification

Gasification is a process that converts organic- or fossil fuel-based carbonaceous materials into carbon monoxide, hydrogen and carbon dioxide. This is achieved by reacting the material at high temperatures (>700 °C), without combustion, with a controlled amount of oxygen and/or steam. The resulting gas mixture is called syngas (from synthesis gas) or producer gas and is itself a fuel. The power derived from gasification and combustion of the resultant gas is considered to be a source of renewable energy if the gasified compounds were obtained from biomass.

Syngas may be burned directly in gas engines. Gasification of fossil fuels is currently widely used on industrial scales to generate electricity.

Each biomass will yield a different gasifier gas composition and amount of gas produced. The *combination* of the two yields an amount of energy contained in the syngas that can be turned into electricity. This is expressed as kg biomass/kWh_{elec} produced and typical values are shown in table 1.

Table 1: Specific electricity production of biomass

Biomass	Kg/kWh_{elec}
Rice Husk	1,6-1,8
Wood	1,15-1,35
Wood Pellets ENplus A1	0,67-0,8
Coconut Shell	1,26-1,35
Corn Cobs	1,07

Note:
The high value for rice husk is mainly due to its high ash content.

The specific electricity production of biomass is the *gross* production of electricity. The net production is depending on the electricity needed for pre-processing the biomass (Shredding, pelletizing, drying) and the electricity needed by the gasifier itself.

2.2 Power production

The relationship between coffee grounds input and electrical output can be calculated with the following formula:

Electrical Output (kW) = Heat Input (kW) x Gasifier Efficiency(%) x Generator Efficiency(%)

The heat input (kW) = Coffee grounds (kg/h) * LHV (MJ/kg) /3.6
The gasifier efficiency = function of design, operating conditions 60-70% is typical
The generator efficiency = function of design and quality of syngas 25-35% is typical

For some typical values of efficiencies below table shows the power production as function of biomass feed flow.

Table 2: Typical efficiencies Gasifiers and Gas generators

Input	LHV	Gasifier Eff	Genset Eff	Electricity	Sp. Electricity
kg/h	MJ/kg	%	%	kWh_{elec}	kg/kWh_{elec}
20	14	60%	25%	11,7	**1,71**
20	14	65%	25%	12,6	1,58
20	14	70%	25%	13,6	1,47
20	14	60%	30%	14,0	1,43
20	14	65%	30%	15,2	1,32
20	14	70%	30%	16,3	1,22
500	14	60%	25%	291,7	**1,71**
500	14	65%	25%	316,0	1,58
500	14	70%	25%	340,3	1,47
500	14	60%	30%	350,0	1,43
500	14	65%	30%	379,2	1,32
500	14	70%	30%	408,3	1,22

Note: Gas generators running on natural gas or LPG have a higher efficiency then the values shown above. For syngas these efficiencies are less as the syngas contains a high percentage of nitrogen.

With larger installations these efficiencies are typically better.

2.3 Coffee grounds Preprocessing

2.3.1 Australia Source

The coffee grounds obtained from Australia have been tested on moisture content upon arrival. Two samples were taken.

The coffee grounds were stored in an air-tight vessel of 200L. From this vessel another sample was taken to measure the moisture by an outside lab (See appendix A). Also the chemical composition has been measured.

	w% moisture
Top sample	53,5
Bottom sample	60,4
Lab sample	67,6

The moisture content was too high to be processed directly in the gasifier. Values below 30w% moisture are preferred.

The material was first pelletized and then dried using electrical heated air.

Pelletzing the wet coffee grounds

Dryer of coffee ground pellets

The chemical composition of the coffee ground is shown in the table below. (Appendix A)

Date sampled	**29 nov-2019**	**[Lit.1]**
Moisture Content w%	67.6	
Ultimate analysis w%	Dry	Dry
C w%	53,5	54,22
H w%	7,4	6,74
O w%	34,8	35,25
N w%	2,9	1,88
S w%	<0,1	0,14
Ash w%	1,3	1,78
Low Heating Value MJ/kg		21,31
High Heating Value MJ/kg		22,79
Volatile w%		82,66
Fixed Carbon w%		15,56

The ultimate analysis matches well with values found in literature [1].

Table 1 : Chemical composition Coffee Grounds

Chemical components	Composition (g/100 g dry material)	
	Spent coffee grounds	Coffee silverskin
Cellulose (Glucose)	12.40±0.79	23.77±0.09
Hemicellulose	39.10±1.94	16.68±1.30
Arabinose	3.60±0.52	3.54±0.29
Mannose	19.07±0.85	1.77±0.06
Galactose	16.43±1.66	3.76±1.27
Xylose	nd	7.61±0.02
Lignin	23.90±1.70	28.58±0.46
Insoluble	17.59±1.56	20.97±0.43
Soluble	6.31±0.37	7.61±0.16
Fat	2.29±0.30	3.78±0.40
Ashes	1.30±0.10	5.36±0.20
Protein	17.44±0.10	18.69±0.10
Nitrogen	2.79±0.10	2.99±0.10
Carbon/nitrogen (C/N ratio)	16.91±0.10	14.41±0.10
Total dietary fiber	60.46±2.19	54.11±0.10
Insoluble	50.78±1.58	45.98±0.18
Soluble	9.68±2.70	8.16±0.90

The chemical composition reveals a high protein content [Lit.2]

2.3.2 Nettenergy Source

The coffee grounds obtained from Australia were not enough to complete the testing. Nettenergy used another source of coffee grounds. This source of coffee grounds supplied ultra-dry coffee grounds with only 6w% moisture.

This material was pelletized with a Mandoka pellet mill (www.mandoka.com) using a 4 mm mold. Water needed to be added to the coffee grounds to form stable pellets @ 22.9 w% moisture. Pelletizing went easy with half the power typically required for wood pellets.

Figure 1 : Pellet mill used

The pellets produced were fragile so to avoid pulverization conveyor belts are preferred over screw conveyors when feeding the gasifier.

2.3.3 Moisture content

The moisture content has a serious impact on the calorific value of the coffee grounds as can be seen from below figure.

The coffee grounds received from Australia with 67.6 w% moisture has a lower heating value of only 5 MJ/kg.

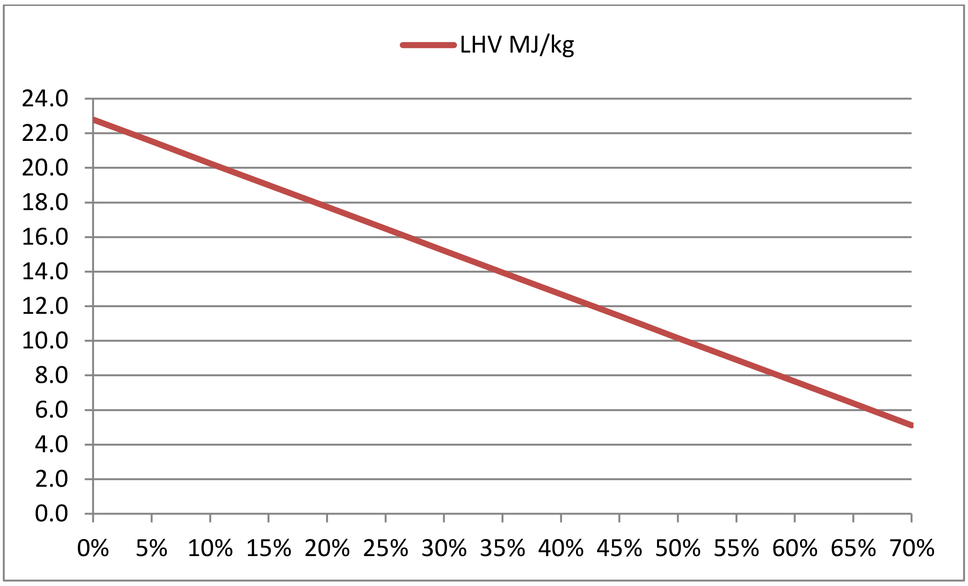

Figure 2: Heating value as function of moisture content

Nettenergy's coffee grounds with 22,9 w% moisture has a lower heating value (LHV) of 17,0 MJ/kg. This value is used to determine the efficiency of the gasifier.

3 Gasification Tests

3.1 Technology

Nettenergy's gasifier is based on its proprietary PyroGasifier technology.

Key aspects of this technology are:

a) Gasification agent is air
b) Downdraft gasifier – the biomass and the air enter the reactor from the top and flow downwards.
c) Wet cleaning of syngas to remove tars, impurities from the syngas.
d) Co-production of char and hot air.
e) The reactor operates below atmospheric pressure.

3.2 Installation

The test runs were performed with the pilot installation of Nettenergy. A schematic of the reactor is shown in below picture.

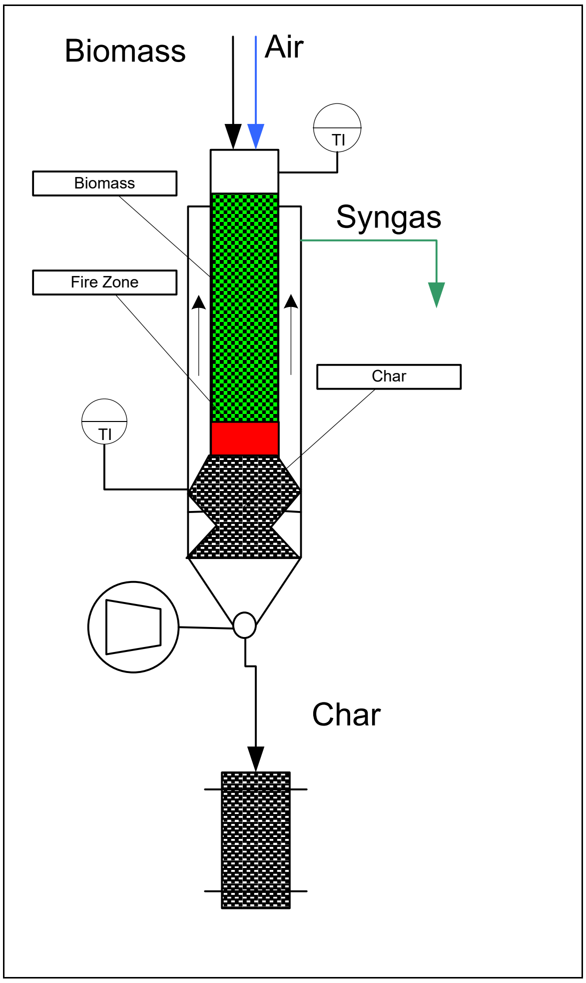

Figure 1 : Reactor Setup

The reactor is 2 meter tall and 0.3 meter in diameter.

The gas flow can be controlled with the suction pump downstream of the reactor. This pump provides for an under pressure at the bottom of the reactor. It is controlled by an inverter.

Initial tests have been performed to "learn" this biomass – how does it perform. The reason to use also pelletized material is the low bulk density of coffee grounds. The reactor is not stirred and uses gravity to transport the biomass in the reactor.

Note that the reactor bottom temperature is measured below the fire-zone.

3.3 Test procedure

The aim of the tests is to determine the potential of the coffee grounds in producing electricity. For this the syngas composition and input/output flows need to be determined.

With the syngas composition genset manufacturers can be approached to obtain their generator efficiency.

The testing of the coffee grounds followed the following procedure.

1) The gasifier was initially heated by using wood particles to reach steady state. In this way the limited amount of coffee ground pellets was used for testing during steady state.

2) The gasifier was manually fed from the top with a basket containing circa 2 kg.

3) Feed was added to the reactor when the fire zone became visible by the infrared sensor. In the graphs of temperatures shows a sharp increases in top temperature and an immediate drop when the coffee grounds were fed.

Figure 3: Reactor dosing

Figure 4: Top view reactor

4) The syngas produced was measured with a venturi meter and flared

Figure 5; Flared syngas

5) The produced char was continuously removed from the reactor

Figure 6: Charred coffee ground pellets versus fresh pellets

3.4 Coffee Ground

Date	30 October 2019
Objective	Gasification of Coffee grounds - initial test Verify that coffee grounds produce syngas Verify carbonization of pellets

Setup:
Dried coffee ground pellets from Australia were used.
Preheating with 8 mm woodchips.

Results:
1) Flammable gases were produced = syngas
2) Full carbonization of the pellets was achieved
3) No yields were measured during this test nor were analysis taken.

	
Char produced	Fully carbonized

3.5 Coffee grounds gasification - Testrun

Date	Dec 4 2019
Objective	Gasification of coffee grounds pellets – final testrun with sample taking

Setup:
Coffee ground pellets (4 mm) from Nettenergy were used.
Preheating with 8 mm woodchips

During this test run the reactor bottom temperature was kept at 450C to maintain stable operation. Samples were taken from the gas after the washer and from the barrel with char and send to the lab the same day.

Results:
1) Feed dosing was manual on average 23,4 kg/h @ 22.9 w% moisture
2) The suction pump was kept at 35 Hz speed
3) Syngas flow measured was 35 M3/h – see graph.
4) Syngas composition was measured by KIWA as per table below. (See Appendix B).

	Mol%
Helium - He	0
Argon - Ar	0,65
Hydrogen - H2	8,16
Oxygen - O2	0,70
Nitrogen _ N2	55,97
Carbondioxide - CO2	17,74
Carbon monoxide - CO	11,62
Methane - CH4	2,07
C2+	3,09
Sum	100.00
LHV MJ/m3	6,30
HHV MJ/m3	6,78
Wobbe Index inf. MJ/m3	6,26
Wobbe Index sup. MJ/m3	6,74
Density versus air	1,01
Specific mass kg/m3	1,31

5) The reactor top temperature shows the saw tooth behavior as explained earlier. The hot air produced reached a temperature of 90C

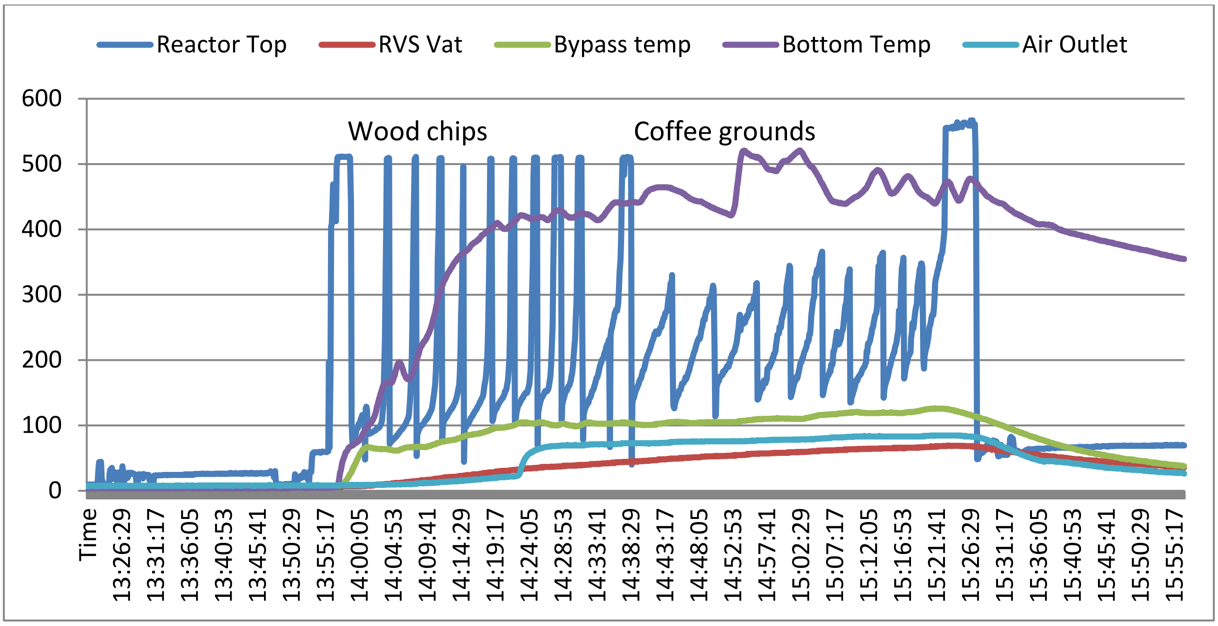

Figure 7: Temperature profiles testrun

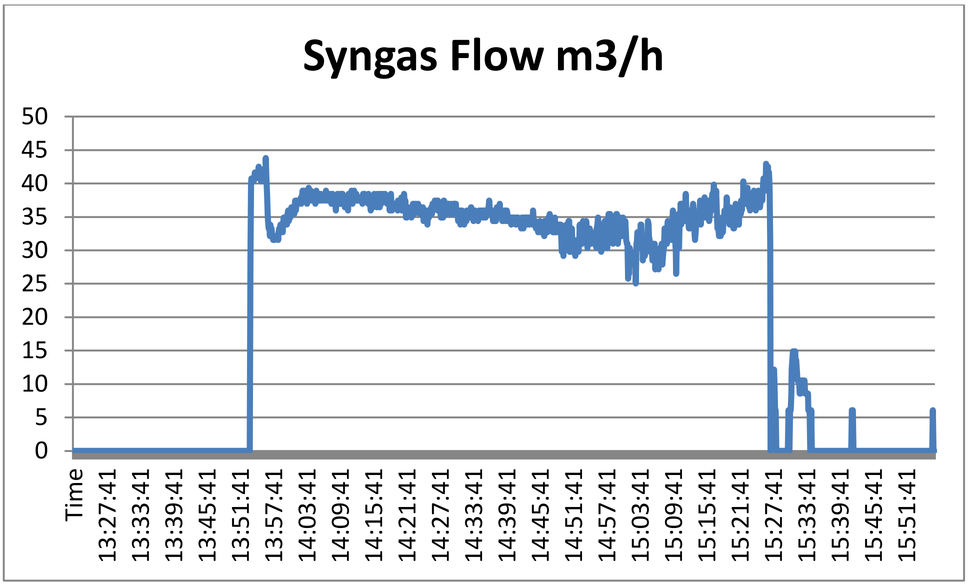

Figure 8: Syngas flow testrun

6) 4) The char flow was 2,23 kg/h resulting in a 9,5 w% yield. The analysis can be found in Appendix C.

Date sampled	**4 Dec 2019**
Moisture Content w%	0.0
Ultimate analysis w%	Dry
C w%	63,9
H w%	3,6
O w%	21,4
N w%	2,4
S w%	<0,1
Ash w%	8,3
High Heating Value MJ/kg	27,6
Low Heating Value MJ/kg	25,7

The char flow removes 2,23*25,7 = 57,3 MJ/h of heat which is 15% of the incoming heat.

When the char production is compared with the as received coffee grounds the yield is 4.0%

3.6 Energy Balance

The gasifier efficiency can be calculated from the heat input to the gasifier from the coffee grounds and the heat output of the syngas. The calorific heat is taken for this.

Input	LHV	Heat Input	Syngas	Syngas LHV	Heat Output	Gasifier Eff
kg/h	MJ/kg	MJ/h	M3/h	MJ/m3	MJ/h	%
23,4	17,0	372,06	35	6,3	220,5	55,54

Assuming a gas generator efficiency of 25% one can calculate the specific electricity produced as per paragraph 2.2.

The gasifier in combination with a genset @ 25% efficiency produces 15,3 $kW_{elec.}$

Part of this electricity is for captive use: conveyor belts, mechanical and thermal dryer, pelletizer. This captive use is estimated to be 25% of the electricity production.

The gross and net specific power production for the "as received –a.r." coffee grounds with 67.6 w% moisture is much higher as is shown in below table.

Coffee grounds	Moisture w%	Sp. Elec kg/kW_{elec} -Gross	Sp. Elec kg/kW_{elec} -Nett
Test run	22,9	1,53	2,04
As received	67,6	3,64	4,85

Drying the coffee grounds is required to have a proper functioning gasifier. This drying can be performed with the waste heat of the gasifier and the genset.

For proper drying of the coffee grounds a mechanical drying as first step is recommended. Vincent corporation USA (https://vincentcorp.com/) supplies mechanical drying equipment that can dry the material from 72w% to 54w% moisture.

For the input during the test run the heat required for drying has been calculated as shown in below table.

		a.r.	Mechanical	Thermal
CG dry	kg/h	18,04	18,04	18,04
Moisture	w%	67,6%	54,0%	22,9%
Water	kg/h	37,64	21,18	5,36
Total	kg/h	55,68	39,22	23,40
Water removed	kg/h		16,46	15,82
Heat required	MJ/h			35,75

The heat required of 35.75 MJ/h can be supplied by the hot air of 90^0C from the gasifier. This hot air represents circa 10% of the heat input (37,2 MJ/h). Additional heat can be obtained from cooling the char and the exhaust gas of the genset if needed.

3.7 Summary

Gasification of coffee grounds was successful. The coffee grounds require drying and pelletizing before entering the gasifier.

Nettenergy' s pilot scale gasifier has an efficiency of 55,54 % with coffee grounds pellets. The lower efficiency is typical for small units. Efficiency increases with capacity of the installation for both the gasifier and the gas generator.

The specific electricity production (gross and net) is:

Coffee grounds	Moisture w%	Sp. Elec kg/kW$_{elec}$ -Gross	Sp. Elec kg/kW$_{elec}$ -Nett
Test run	22,9	1,53	2,04
As received	67,6	3,64	4,85

The specific char production is:

Coffee grounds	Moisture w%	Kg/kg %
Test run	22,9	9,5
As received	67,6	4,0

The coffee grounds after mechanical drying can be further dried with the waste heat of the gasifier.

4 Literature List

1) https://phyllis.nl/Browse/Standard/ECN-Phyllis#coffee (#3592)

2) Chemical, Functional, and Structural Properties of Spent Coffee Grounds and Coffee Silverskin, Lina F. Ballesteros & José A. Teixeira & Solange I. Mussatto, Food Bioprocess Technol (2014) 7:3493–3503

APPENDIX A

GBA Coffee Grounds analysis report

APPENDIX B

KIWA Gas analysis report

APPENDIX C

GBA Char analysis report