Test of different biomass into the IISc open top co-current gasifier

Project 39772 Contract 80847

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Swiss Federale Office of Energy

Final report, December 2001

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TABLE DES MATIERES

1. Introduction

Through several R&D projects, the Xylowatt team has demonstrated the technical feasibility of the combined heat power production by wood gasification. An industrial plant of 60 kWe is presently installed in a large sawmill in Bulle (CH).

The aim of this project was to test and evaluate other biomass than clean wood into a small gasifier with a biomass consumption of about 1 kg/h of biomass. The system composed by a reactor and a gas treatment system was developed at the Indian Institute of Science (IISc) in Bangalore (India) and adapted by Xylowatt for the test program. The tests were carried out within the scope of a project sponsored by the Swiss Federal Office of Energy (OFEN).

The program test was constituted by seven test of the following biomass (or biofuel):

test 1 - native wood chips,

test 2 - urban waste wood,

test 3 - pecan nuts shells,

test 4 - crushed oak briquettes,

test 5 - wood pellets,

test 6 - coffee hull pellets,

test 7 - chicken litter pellets.

The tests were done in the workshop of Xylowatt at Châtel-St-Denis in two periods during June and September 2001. The fist period was composed by the native wood ships (1), wood pellet (5) and urban waste wood (2) done respectively in June 24th, 25th and 26th. The second period was composed by the coffee hull pellets (6), crushed oak briquettes (4), pecan nuts shells (3) and chiken litter pellets done respectively in September 3rd, 4th, 5th and 6th.

Xylowatt SA has mandated Verenum in Zurich to carry out measurements of particles, tar and some inorganic species present in the raw and clean producer gas of the small open-top downdraft gasifier. For each of the 7 biofuels, measurements for tar and particles were made both in the raw gas and in the clean gas after the gas cleaning system. Beside particles and tar, some inorganic species were measured using both gas phase adsorption (Dräger tubes) and conventional wet chemical absorption methods (impingement in acqeous solutions).

2. Description of the plant

2.1 Open top IISc gasifier

The test plant has been designed and built by the Indian Institute (IISc), the plant is composed by similar items provides in a large plant of gasification.

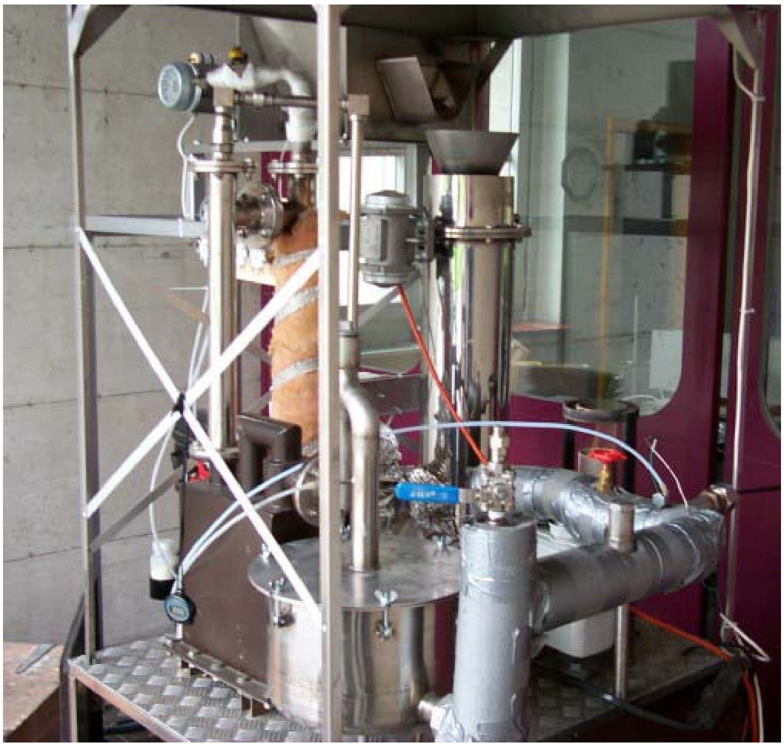


Figure 1: 1 kg/h gasifier and flame into the burner

The production of the gas takes place in the reactor, which is filled with biomass fuel through its top by means of an Archimedes' screw. A mobile grate support the biomass bed into the reactor. The ashes are collected into a container below the reactor. The circulation of air into the reactor as well as the circulation of the produced gas is assured by a blower located at the circuit end of the gas prior to being injected into a burner.

When leaving the reactor the gas is at a high temperature and contains a certain number of pollutants (tar, particles). Large particles are separated into the cyclone, then the gas go trough water scrubber, a droplet separator and a sand bed filter.

Base on the value of the gasmeter, the gas flowrate can be adapted with a manual valve.

The water of the scrubber system works in a closed circuit, a heat exchanger using fresh water maintain its temperature.

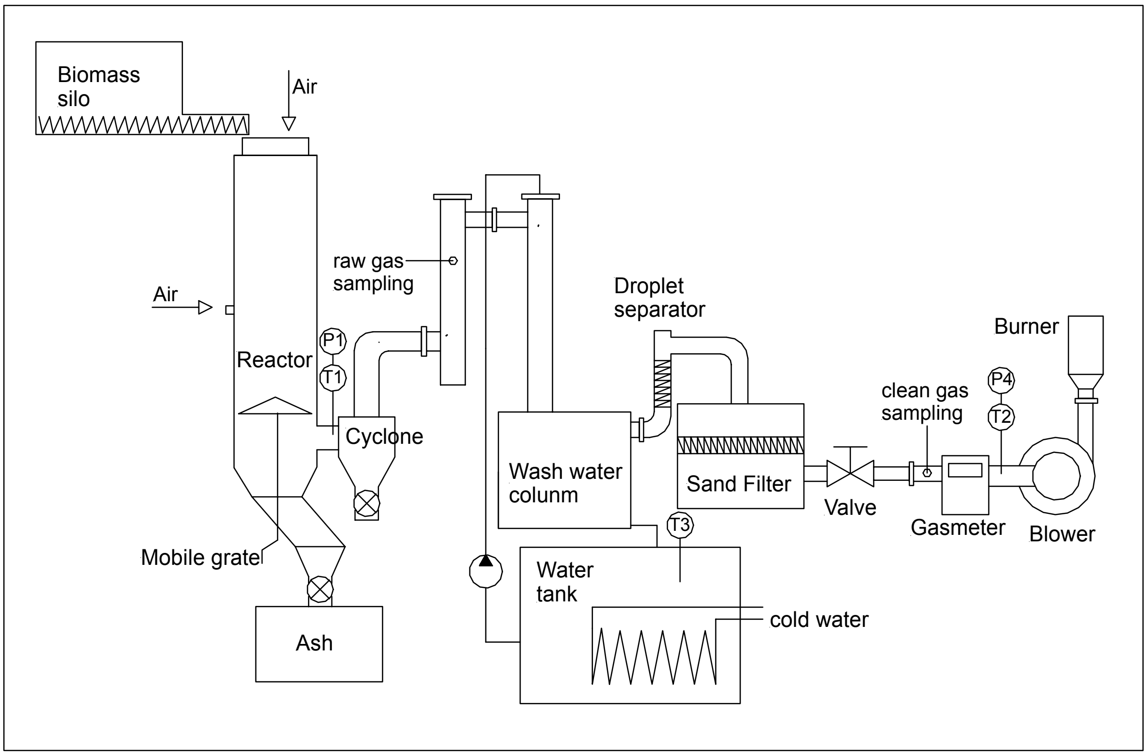


Figure 2: Schematic of the test plant

2.2 Data acquisition system

An inline measurement of the gas composition and some temperatures and pressures of the plant was used during all the tests performed. The data were measured all the minutes using the software LABVIEW.

Figure 3: Gas sampling and data acquisition system

Temperature and pressure

Symbol	Name	Principe	scale
T1	Temperature of the gas at the exit of the reactor	thermocouple K	-200 - 1000°C
T2	Temperature of the gas after the sand bed filter	thermocouple K	-200 - 1000°C
T3	Temperature of the wash water	thermocouple K	-200 - 1000°C
P1	Pressure relative at the exit of the reactor	Ceramic sensor	0 à 50 mbar
P4	Pressure relative before the blower	Ceramic sensor	0 à 50 mbar

Gas composition

Component	Method	Scale	Accuracy
CO_2	NDIR Photometer	0% à 20%	± 2%
CO	NDIR Photometer	0% à 20%	± 2%
CH_4	NDIR Photometer	0% à 5%	± 2%
H_2	HCD thermal	0% à 20%	± 2%
O_2	Electrochemical	0% à 25%	± 2%

2.3 Sampling of the gas

The sampling train used for the sampling of tar and particles (T&P) is identical to the train which is developped and tested within a EC concerted action project entitled “Guideline for Sampling and Analysis of Tar and Particles in Biomass Producer Gases“ [Neeft et al 2001]. The basic concept of the sampling train consists of 4 main modules and a number of submodules. The main modules are gas preconditioning, particle collection, tar collection and volume sampling. The functional description of each modul is given in the table below.

In the preconditioning module (module 1) the process gas is cooled or heated (depending on the process temperature) to a constant temperature of 300°C using a heated probe. The equipment needed in the module comprises of a sampling probe including a nozzle and necessary valves. All valves are heated to constant temperature. Due to the short distances (< 20 cm) and the limited space around the investigated test rig, no heating of the modul 1 was applied.

In the particle collection module (module 2) a heated filter collects solids present in the gas.

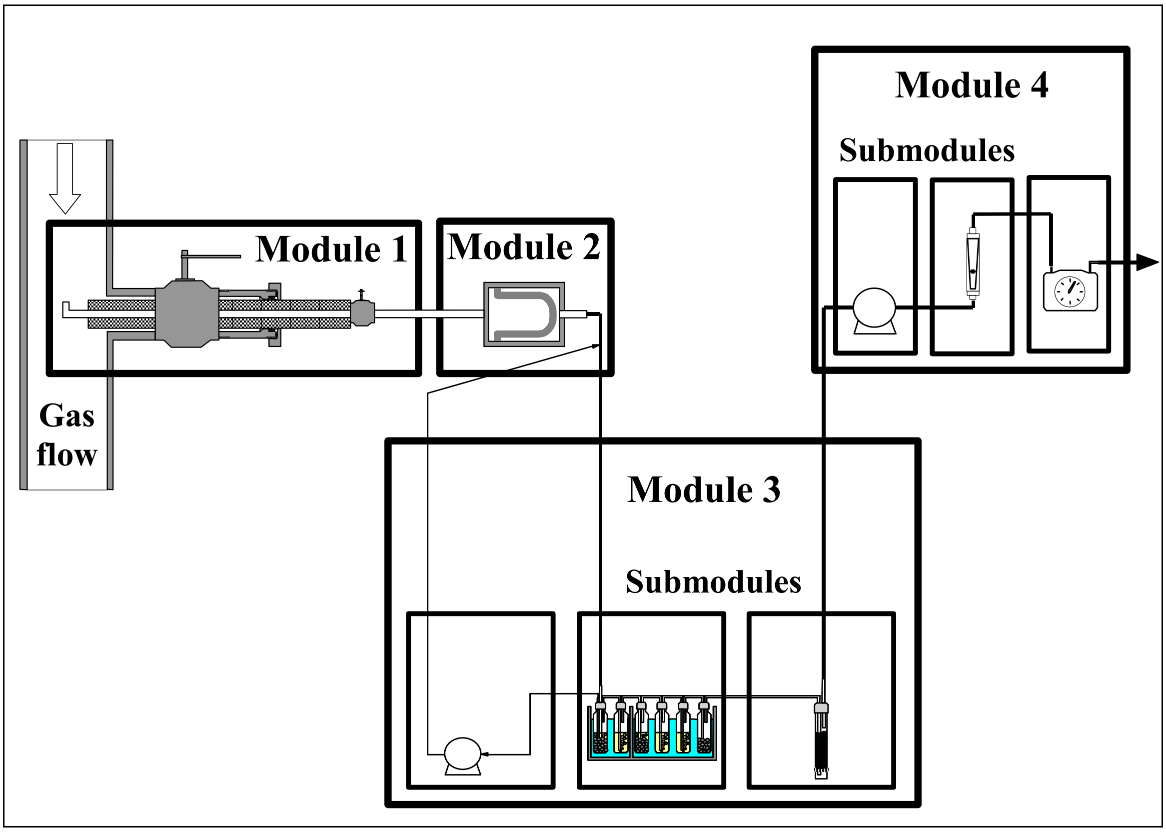


Figure 4: Concept of the modular sampling train [Neeft et al. 2001]
Remarks: The liquid from the optional liquid quench system is injected into the hot gas stream just after the particle filter; The modul 3 of the sampling train used within this report consisted of 1 impinger at 0°C followed by 4 impingers at –20°C (the 3rd impinger has a frit G3), an empty impinger and an activated coke adsorber as backup filter.

	Function	**Equipment**
Module 1 (Gas preconditioning)		
	Gas cooling	Nozzle, valves, sampling lines
Module 2 (Particle collection)		
	Separation and collection of solids	Heated filter (high temperature)
Module 3 (Tar collection)		
SubModule 3.1	Moisture and partial tar condensation	Condenser at 0°C
SubModule 3.2	Tar and VOC collection	Impingers with solvent at T = -20°C
SubModule 3.3	Backup VOC sampler	Adsorber tower (act. carbon)
Module 4 (Volume sampling)		
SubModule 4.1	Gas suction	Pump
SubModule 4.2	Gas volume integration	Gas meter, pressure and temperature indicators
SubModule 4.3	Vent/exhaust gas handling	Outdoor ventilation

The tar collection module (module 3) consists of three submodules. In the submodule 3.1, the gas is cooled to collect moisture and some of the tar in a condenser at a temperature of approximately 0°C. For the clean gas measurements, the condenser is an impinger bottle filled with 150 ml to 250 ml of organic solvent placed in an external ice water bath. For the raw gas measurements, an internal liquid quench system as shown in figure 4 is used. In the submodule 3.2 tar and other organic components are absorbed by a solvent at -20°C in a series of 5 impinger bottles. The 3rd impinger is equipped with a glass frit G3 for the collection of tar aerosols. Four of the five impingers contain approximately 50 ml of an organic solvent for tar collection, the 5th impinger is an empty impinger. As a solvent for the collection of the tar species, 1-methoxy-2-propanol was used. The submodule 3.3 is a backup adsorber collecting residual organic components which may have penetrated the impinger train. The backup VOC adsorber is used as a pump protection unit.

The volume-sampling module (module 4) consists of three submodules. The purpose of submodule 4.1 is the gas displacement from the main duct through the particle filter and the impinger train with a double-head membrane pump. In the submodule 4.2 a gas meter measures the volume of gas. Additionally a flow meter, a pressure indicator and a temperature indicator are needed. The purpose of the submodule 4.3 is vent gas handling.

For the sampling of heavy metals and nitrogen components, a conventional sampling train was used similar to the sampling train shown in figure 4, except that other absorption solutions, temperatures and more impingers were used.
For the sampling of heavy metals, an mixture of an acidic acqueous mixture (1 part of conc. $HCl:HNO_3$ = 3:1 in 9 parts H_2O) was used. The absorption of the heavy metals was done in a serie of three consecutive impingers (the 2nd was equipped with a glass frit G3) at a temperature of 0°C.
For the sampling of ammonia (NH_3), an acqueous mixture of 2.5 wt% HCl was used whereas for the collection of hydrogen cyanide (HCN), 5 wt% acqueous NaOH was applied.
For both the heavy metal and nitrogen compound sampling, a series of impingers filled with 1-methoxy-2-propanol was used after the acqeous sampling train to avoid tar penetration to the pump and gas metering device.
Beside conventional wet chemical sampling and analysis, the solid phase adsorption (SPA) technique developped at the KTH Stockholm [Brage et al. 1997] was used to determine the breakthrough of organic tar components through the sampling train.
Furthermore, Dräger tubes were used after the particle filters for semiquantitative determination of hydrogen sulphide (H_2S), ammonia (NH_3), hydrogen cyanide (HCN) and hydrochloric acid (HCl).

After the tar sampling, the particle filters were placed in a Soxhlet extraction apparatus for the extraction of condensed tar components. For the Soxhlet extraction, 1-methoxy-2-propanol was used at its boiling point temperature (120°C). Generally, the solution from the Soxhlet extraction was combined with the impingement solution for later chemical analysis.
The analysis of the solutions derived from the tar sampling tests was made using both gravimetric and gas chromatographic (GC) methods. The determination of the gravimetric tar concentration was made by evaporation of the sampling solutions at 105°C and ambient pressure in an oven for a total of 16 hours. This method is <u>not</u> in accordance with the reference guideline for tar sampling according to [Neeft et al. 2001]. As no reference method for the gravimetric tar has been approved yet for the reference guideline, the chosen approach has also been used by other workers in this field [Kurkela et al. 1995].

3. Results

3.1 Reminder of the data obtained with a larger gasifier

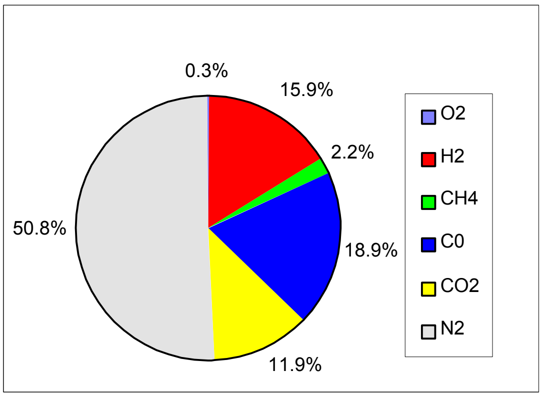
Through three R&D projects between 1996 and 2000 done with the support of Swiss Federal Office of Energy (OFEN), the Xylowatt team (former CCC) has demonstrated the technical feasibility of the combined heat power production from wood by the gasification with a 50 kWe plant.

The plant composed by a Open top downdraft gasifier developed by the Indian Institute of Science (IISc) and a gas treatment system with items similar of those used into the this project (Scrubber and sand filter) has been operated with native wood chips as fuel during about 2'000 hours. The gas produced has been used during 1'200 hours into a standard spark ignition gas engine coupled to a generator connected to the electrical grid.

During May 1998, a long duration test of 150 hours were performed with the plant [P. Giordano & al, 1998], five gas sampling were realised (four in the raw gas and one in the clean gas). The data collected during this test is summarised below:

Native wood gasification and gas production:

Wood moisture	18%	Atro
Low heating value of the wood	15.33	MJ/kg
Gas production	2,4	Nm3/kg of wood
Gas density	1.14	Kg/Nm3
Low heating value of the gas	4.9	MJ/Nm3
Gasification efficiency	75,6 %	
Electrical production efficiency	22.5%	
Ash production	1.4%	of wood use
Mineral content in the ash	25%	
Average gas composition (see graph below)		



Tar and particles in the gas:

Minimum and maximum values measured in the raw gas

			Measurement in the raw gas	
			Min	max
1.	Particle	mg/Nm3	207	260
2.	Heavy tar	mg/Nm3	277	594
3.	Phenols	mg/Nm3	62	175
4.	PAH[1]	mg/Nm3	373	595

Values measured in parallel in the raw and clean gas and the reduction efficiency

			Raw gas	Clean gas	reduction
1.	Particle	mg/Nm3	245	60	75%
2.	Heavy tar	mg/Nm3	423	49	88%
3.	Phenols	mg/Nm3	160	5	97%
4.	PAH[1]	mg/Nm3	433	258	40%

Concentration of pollutant into the water used to treat the gas:

pH	Hydrocarbon total	cyanides	DCO	N-Kjeldahl	phenols	chrome	Iron	lead	zinc
8.4	0.50 mg/kg	0.02 mg/kg	3'822 mg/kg	258 mg/kg	0.07 mg/kg	0.004 mg/kg	0.038 mg/kg	0.021 mg/kg	0.326 mg/kg

In the large system, the water is continuously treated with flocculent. The analyse of the pollutant has been done on a sample of water after treatment.

[1] PAH is the sum of the following polyaromatic hydrocarbon components: Naphthalene, 2-Methylnaphthalene, 1-Methylnaphthalene,2-Ethylnaphthalene, Biphenyl, Acenaphthylene, Acenaphthene, Dibenzofurane, Fluorene, Phenanthrene, Anthracene, 4H-Cyclopenta[def]phenanthrene, Benz[e]acenaphthylene, Fluoranthene, Pyrene

3.2 Gasification of the different bio-fuel

Test 1 – Native wood Chips

	Flow	Mineral content	Density	moisture
Fuel	1.2 kg/h	1%	220 kg/m3	25% atro
	Flow	Mineral content	kg ash / kg biomass	
Ash	8.4 g/h	45%	0.68%	
	Flow	Density	m3 gas / kg biomass	
Gas	3 m3/h	1.19 kg/Nm3	2.5	

Test 2 – Urban waste wood

	Flow	Mineral content	Density	moisture
Fuel	1.1 kg/h			14% atro
	Flow	Mineral content	kg ash / kg biomass	
Ash	30.6 g/h	40%	2.8%	
	Flow	Density	m3 gas / kg biomass	
Gas	3.2 m3/h	1.18 kg/Nm3	2.9	

Test 3 – Pecan nuts shells

	Flow	Mineral content	Density	moisture
Fuel	1.2 kg/h	4.3		11% atro
	Flow	Mineral content	kg ash / kg biomass	
Ash	63.2 g/h	29%	5.1%	
	Flow	Density	m3 gas / kg biomass	
Gas	3.1 m3/h	1.19 kg/Nm3	2.5	

Test 4 – crushed oak briquettes

	Flow	Mineral content	Density	moisture
Fuel	1.2 kg/h			10% atro
	Flow	Mineral content	kg ash / kg biomass	
Ash	49.5 g/h	27.2%	3.52%	
	Flow	Density	m3 gas / kg biomass	
Gas	3.5 m3/h	1.16 kg/Nm3	2.5	

Test 5 – Wood pellets

	Flow	Mineral content	Density	moisture
Fuel	1.5 kg/h	0.4%		9.5% atro
	Flow	Mineral content	kg ash / kg biomass	
Ash	12.4 g/h	19.7%	0. 8%	
	Flow	Density	m3 gas / kg biomass	
Gas	3.2 m3/h	1.16 kg/Nm3	2.51	

Test 6 – Coffee hull pellets

	Flow	Mineral content	Density	moisture
Fuel	1.6 kg/h	6.9		9.5% atro
	Flow	Mineral content	kg ash / kg biomass	
Ash	110 g/h	49.6%	6.7%	
	Flow	Density	m3 gas / kg biomass	
Gas	3.0 m3/h	1.19 kg/Nm3	1.8	

Remarks: the coffee hull pellets used contain a percentage of oil (in a unknown percentage)

Test 7 – Chicken litter pellets

	Flow	Mineral content	Density	moisture
Fuel	1.5 kg/h	15%	340 kg/m3	10% atro
	Flow	Mineral content	kg ash / kg biomass	
Ash	202 g/h	88.9%	13.5%	
	Flow	Density	m3 gas / kg biomass	
Gas	3 m3/h	1.19 kg/Nm3	2	

Comments:

All the bio-fuels have been tested during a continuous run of 10 hours. They all have generate a constant gas able to burn itself in the burner.

In annexe, for all the bio-fuels, are given the evolution during the time of the bio-fuel consumption, gas production, gas temperature, gas pressure and gas composition.

The ratio gas production per bio-fuel consumption is comparable between the small gasifier (2.5 Nm3/kg with native wood) and the large system (2.4 Nm3/kg).

For the bio-fuel containing a high percentage of mineral content like the Chicken litter pellets (15%) and the coffee hull pellets (6.9%) the grate of the reactor was operated all the 15 minutes to evacuate the ash.

3.3 Gas production

		Biomass LHV*	Producer gas LHV	efficiency	CO	CO2	H2	CH4	N2
		MJ/kg	MJ/Nm3	%	%	%	%	%	%
Test 1	Native Wood chips	14.30	4.15	63.4	15.4	15.6	13.9	1.9	53.3
Test 2	Urban waste wood	16.59	4.52	61.9	14.5	18.4	13.6	2.0	51.6
Test 3	Pecan nuts shells	16.77	4.64	64.9	11.0	21.0	10.7	2.3	55.1
Test 4	Crushed oak briquettes	16.59	5.16	67.3	14.3	20.2	15.3	2.7	47.8
Test 5	Wood pellets	16.68	5.06	63.0	13.7	20.1	14.6	2.6	49.2
Test 6	Coffee hull pellets	16.70	3.79	40.6	14.4	12.9	13.4	2.0	57.4
Test 7	Chicken litter pellets	12.60	3.98	60.8	13.6	15.3	12.5	2.0	56.9

*LHV: lower heating value

Comments:

Except with the coffee hull pellets, the efficiency to transform the energy contained in the bio-fuels in an energetic gas are in the range of 61 to 67%. This result is very appreciable with the chicken litter pellets that is a bio-fuel with high mineral content (15%) and with a lower calorific value than the other bio-fuel tested (12% to 24% less rich).

For the comparison with the larger gasifier, we have to notice that the moisture content of the native wood chips is of 25% for the test in the small gasifier against 18% for the larger. Using the results obtained during other tests with comparable moisture content of the native wood chips in the large gasifier [P. Giordano, 1996] the lower heating value (LHV) of the gas is 4.64 MJ/Nm3.

The reduction of efficiency is about 10% with the small gasifier. This de-rating is perfectly understandable because first of the lighter insulation of the small gasifier (no ceramic) that create larger thermal lost and reduce the temperature inside the reactor. An other possible reason is the effect of using a biomass with the same dimension in a reactor with a smaller diameter (10 cm against 40 cm for the large system).

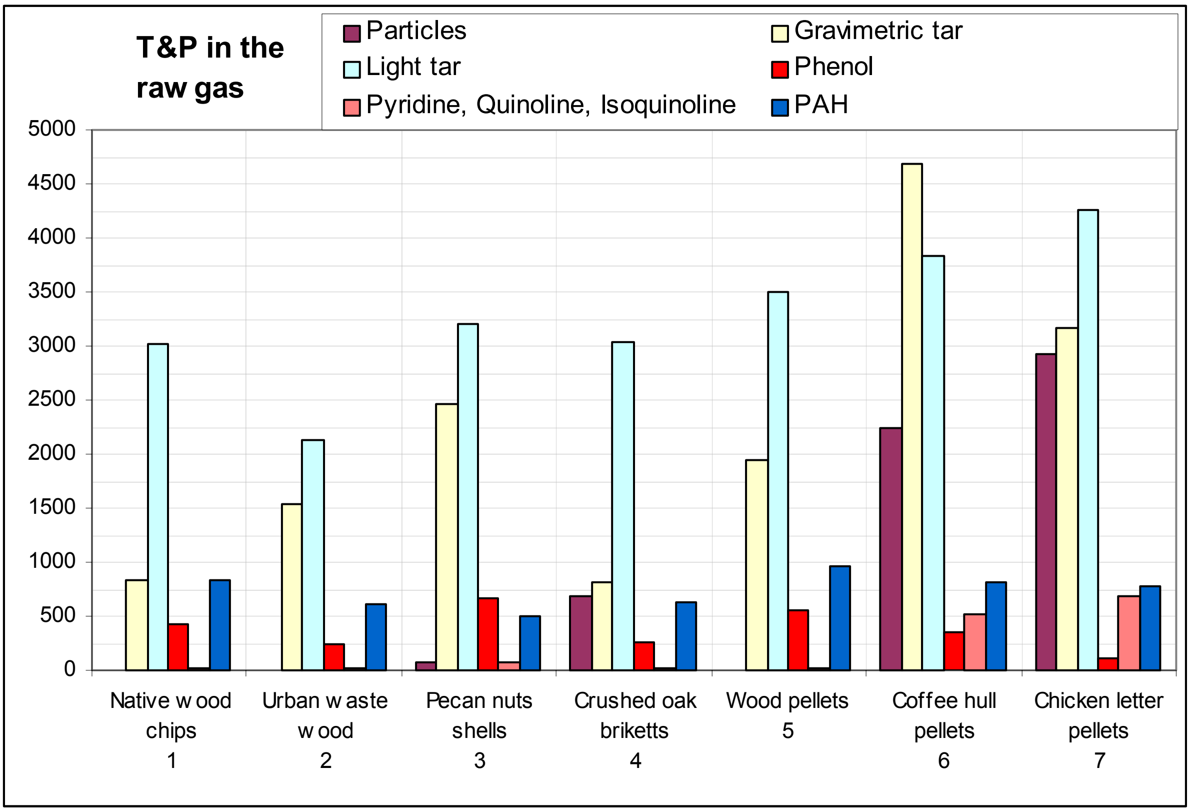
3.4 Tar and Particle in the gas

3.4.1 Tar and Particle in Raw gas

		Particles	Gravimetric tar	Light Tar*	Phenol	Pyridine, Quinoline, Isoquinoline	PAH**
		[mg/mn3]	[mg/mn3]	[mg/mn3]	[mg/mn3]	[mg/mn3]	[mg/mn3]
Test 1	Native Wood chips	n.d.	832	3'018	427	15	842
Test 2	Urban waste wood	n.d.	1'543	2'127	239	26	616
Test 3	Pecan nuts shells	69	2'469	3'209	671	73	498
Test 4	Crushed oak briquettes	691	812	3'036	258	12	631
Test 5	Wood pellets	n.d.	1'939	3'502	558	27	957
Test 6	Coffee hull pellets	2'234	4'682	3'833	347	511	813
Test 7	Chicken litter pellets	2'931	3'175	4'260	108	685	769

*Light tar Benzene, Toluene, Ethynylbenzene, m-Xylene, o-Xylene, Styrene, 4-Methylstyrene, Indene

**PAH Naphthalene, 2-Methylnaphthalene, 1-Methylnaphthalene, 2-Ethylnaphthalene, Biphenyl, Acenaphthylene, Acenaphthene, Dibenzofurane, Fluorene, Phenanthrene, Anthracene, 4H-Cyclopenta[def]phenanthrene, Benz[e]acenaphthylene, Fluoranthene, Pyrene



Comments:

The concentrations of particles could not be determined for test runs in July 2001 (test 1,2 and 5) both for the raw and the clean gas due to an inappropriate pre and post sampling conditioning procedure for the thimble filters.

The gravimetric tar concentration are the remaining weight after evaporation of the solutions derived from the tar sampling tests (see chapter 2.3) at 105°C and ambient pressure in an oven for a total of 16 hours.

The Light tar, phenols, pyridine, quinoline, isoquinoline and PAH are determined into the solutions derived from the tar sampling tests using gas chromatographic (GC) method. A certain amount of those components contribute in the quantity of gravimetric tar but in a small proportion (about 10%).

The gravimetric tar components are found in significantly higher concentrations depending on the fuel gasified. The higher value is obtained with chicken litter and coffee hull pellets. Both are bio-fuel containing some additives (oil for the coffee hull) that may be responsible of the high values. It has to be notice that the particle contents follow the tendency of the gravimetric tar.

Chicken litter and coffee hull pellets which both contain significant higher levels of fuel nitrogen, produce one order of magnitude higher levels of organic nitrogen compounds (pyridine, quinoline and isoquinoline).

In comparison with the results obtained with the large gasifier, the values are two to three time higher for all the different tars (except light tar where no data are available with the large system).

3.4.2 Tar and Particle in the clean gas

		Particles		**Gravimetric tar**		**Light tar**		**Phenol**		**Pyridine, Quinoline, Isoquinolin**		**PAH**	
		mg/ Nm3	Red-uction	mg/ Nm3	Red-uction	mg/ Nm3	Red	mg/ Nm3	Red-uction	mg/ Nm3	Red-uction	mg/ Nm3	Red-uction
Test 1	Native Wood chips	n.d.		463	44%	2'969	2%	3	99%	10	34%	390	54%
Test 2	Urban waste wood	n.d.		760	51%	2'174	-2%	3	99%	7	74%	387	37%
Test 3	Pecan nuts shells	55	20%	1'083	56%	3'330	-4%	13	98%	17	77%	340	32%
Test 4	Crushed oak briquettes	28	96%	518	36%	3'105	-2%	9	96%	25		285	55%
Test 5	Wood pellets	n.d.		691	64%	3'228	8%	4	99%	3	89%	394	59%
Test 6	Coffee hull pellets	574	74%	1'121	76%	4'171	-9%	19	94%	65	87%	367	55%
Test 7	Chicken litter pellets	964	67%	3'965	-25%	3'584	16%	13	88%	30	96%	251	67%

Comments:

The experience with the large gasifier has show that the deposit collected in the piping after the gas treatment items are composed only by particle and gravimetric tar. An other important information is also the high reduction of the PAH (> 98%) burning into the gas engine.

As it was notice with the large gasifier, the evolution of the tars and particles through the gas treatment system, is the following:

- There is no reduction of the light tar, they will increase the low heating value of the gas.
- The phenols, pyridine, quinoline and isoquinoline are largely remove from the gas.
- Gravimetric tar and PAH are reduce with a comparable efficiency that noticed with the large gasifier.

Gravimetric tar measured into the clean gas produced with chicken litter pellets are upper to the value measured into the raw gas; the authors of this report think that it is an errors in the gas sampling or in the analyse in the laboratory. It has to be notice than the PAH for the chicken litre are reduced by the treatment.

3.5 Other pollutant in the producer gas

Besides tar and particles, a number of gaseous inorganic impurities were sampled using Dräger tubes. The impurities determined are: ammonia (NH_3), hydrogen cyanide (HCN) and hydrogen sulphide (H_2S). For each of this impurity, selective Dräger tubes[2] were purchased. The gas volume for the tubes is taken manually using a Dräger pump (model accuro 21/31; 100 ml sample volume per strike). The results are summarized in the table below.

		Ammonia (NH_3)			**Hydrogen cyanide (HCN)**			**Hydrogen sulphide (H_2S)**		
		Raw gas	Clean gas	Reduc-tion	Raw gas	Clean gas	Reduc-tion	Raw gas	Clean gas	Reduc-tion
		mg/Nm3	mg/Nm3		mg/Nm3	mg/Nm3		mg/Nm3	mg/Nm3	
Test 1	Native Wood chips	n.d.	n.d.		n.d.	n.d.		n.d.	n.d.	
Test 2	Urban waste wood	456	2	99.6%	54	3	94.4%	146	77	47.3%
Test 3	Pecan nuts shells	0	n.d.		61	n.d.		34	n.d.	
Test 4	Crushed oak briquettes	n.d.	n.d.		n.d.	n.d.		28	18	35.7%
Test 5	Wood pellets	5	0	100 %	17	3	82.4%	85	66	22.4%
Test 6	Coffee hull pellets	1'965	18	99.1%	140	6	95.7%	1	n.d.	
Test 7	Chicken litter pellets	950	n.d.		n.d.	n.d.		> 285	n.d.	

During two test runs, a conventional sampling train for ammonia and hydrogen cyanide was used in parallel with the Dräger measurement. The results from these tests are shown below.

[2] Dräger tubes are available for more than 100 individual compounds and for various concentration ranges. The measurement technique is designed for air and emission measurements.

			Dräger mg/Nm^3	Gas sampling mg/Nm^3
Test 3	Pecan nuts shells	HCN	61	< 1.8
Test 7	Chicken litter pellets	NH3	950	15'022

The results from the wet chemical sampling method deviate significantly from the values of the Dräger tube measurements. The determined NH_3 concentration is more than 1 order of magnitude higher from the conventional sampling train than from the Dräger tube measurement. The situation is reversed for the HCN where the Dräger tube measurements leads to concentrations which are more than 1 order of magnitude higher than those from the wet absorption train. Based on the current knowlegde, no final assessment of the used methods can be made and further testing would be required.

At least, the Dräger tube measurements both in the raw and clean gas lead to concentration levels which seem not unreasonable and to separation efficiencies that comply with earlier measurements [Giordano 1996].

The tendency is that Ammonia (NH3) and Hydrogen cyanide (HCN) contents into the gas are largely reduced (> 90%) but for the Hydrogen sulphide (H2S) the reduction is only arround 30%.

3.6 Water use to treat the gas

3.6.1 pollutant contained in the water

		pH	Hydrocarbon total	cyanides	DCO**	Phenols	N-NH3***
			mg/kg*	mg/kg*	mg/kg*	mg/kg*	mg/kg*
Test 1	Native Wood chips	7.19	14.8	1.3	5'092	925	577
Test 2	Urban waste wood	7.86	45.1	3.1	11'049	1'493	1'115
Test 3	Pecan nuts shells	7.58	20.6	1.8	12'682	1'583	1'823
Test 4	Crushed oak briquettes	7.89	10.4	6.1	8'073	975	3'055
Test 5	Wood pellets	7.29	12.8	0.2	10'974	1'392	882
Test 6	Coffee hull pellets	8.69	50.0	8.7	17'627	978	10'507
Test 7	Chicken litter pellets	9.05	37.0	37.7	12'821	398	18'340

* mg of pollutant contained in the water per kilo of biomass used
** Chemical Demand in Oxygen
*** Ammoniacal nitrogen

<u>Comments:</u>

For each tests, a new volume of fresh water (about 50 litres) was used during the test period. At the end of the test, all the water was collected in a tank and homogenised. Two sample of this water were taken (about 1 litres each), the first one was send to the laboratory and the second treated with a flocculent.

The concentrations of pollutants in the water are in the same order of magnitude for each bio-fuel except for the Ammoniacal nitrogen where the coffee hull and chicken litter show very higher values. This point is in accordance with the presence in the gas of a high quantity of tar components with nitrogen (Pyridine, Quinoline, Isoquinoline).

The water used to treat the gas produced with chicken litter pellets has a higher amount of cyanide and a lower amount of the phenols. The second value is in accordance with the presence in the gas of a lower quantity of phenols.

The comparison with the large gasifier is difficult because only data for the treated water are available.

3.6.2 Treatment of the water with flocculent

		Hydrocarbon total		**cyanides**	
		mg/kg	Reduction	mg/kg	Reduction
Test 1	Native Wood chips	< 7.2	> 51%	0.6	49%
Test 2	Urban waste wood	< 9.1	> 80%	0.5	84%
Test 3	Pecan nuts shells	< 8.6	> 58%	0.4	79%
Test 4	Crushed oak briquettes	< 6.5	> 38%	3.5	43%
Test 5	Wood pellets	< 5.7	> 56%	< 0.03	> 86%
Test 6	Coffee hull pellets	< 6.3	> 87%	1.9	78%
Test 7	Chicken litter pellets	< 7.0	> 81%	11.1	71%

Reduction of heavy metal content by treatment with flocculent:

	Chromium	**Copper**	**Iron**	**Lead**	**Zinc**
	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
Raw	< 0.11	1.68	6.51	< 0.68	0.77
Treated	< 0.11	< 1.55	< 0.36	< 0.68	< 0.18
reduction	-	< 8%	< 94%	-	< 76%

Comments:

The limit of detection for the total hydrocarbon depend of the quantity of water supply, unfortunately a too small amount was transmit to the laboratory.

The use of flocculent which allow to remove the small particles in suspension in the water, can reduce significantly the pollutant contained into the water. The flocculent used is compose of bentonit, it is conform to the swiss normes.

3.7 Balance of heavy metal in the gasification of urban waste wood

The table show the total quantity of three heavy metal (lead, chromium and zinc) found into the different part of the gasification system during the 10 hours test:

Values in mg	Wood	Ash	Raw gas	Water	Sand	Clean gas
Lead (Pb)	*600**	→	414	→	→	328
		203		0	31	
Chromium (Cr)	*24**	→	0.6	→	→	0.3
		22		1.2	0.6	
Zinc (Zn)	*1100**	→	275	→	→	235
		828		8.3	4.1	

** values estimated*

<u>Comments:</u>

Concerning the values for the raw and clean gas, the concentrations of the heavy metals in the impingement solutions could not be measured accurately due to the presence of a large amount of organic solvent. During the sampling, heavy foam formation occurred in the acqeous impingers leading to a carryover of acqeous solution into the tar collection train which contained organic solvent. Hence both the acqeous and the content of the first impinger with organic solvent were combined for the later analysis. In the laboratory, the organic solvent turned out to create severe difficulties which did not allow a quantitative determination of the heavy metals.

Base on the value measured we can estimate the repartition of the heavy metal into the different part of the gasification system:

gasifier		Wood	Ash	Water	Sand	Clean gas	
Lead (Pb)		*63 mg/kg**	30 - 40%	0 - 5 %	2 - 6 %	50 - 60 %	10.6 mg/Nm3
Chromium (Cr)		*2.5 mg/kg**	85 - 90%	2 -10%	1 - 5 %	1 - 5 %	0.01 mg/Nm3
Zinc (Zn)		*116 mg/kg**	70 - 80%	0 – 5 %	2 – 6 %	20 –25%	7.6 mg/Nm3
	Total	*182 mg/kg*					18.2 mg/Nm3

** values estimated*

For comparison, the table below show the repartition of the same heavy metal obtained with wood boiler [OFEFP 1996]:

Wood boiler	Ash	cyclone	Exhaust gas
Lead (Pb)	60 %	10 %	30 %
Chromium (Cr)	90 %	10 %	0 %
Zinc (Zn)	50 %	10 %	40 %

4. Conclusion

The program test performed with the small gasifier has permit to give precious informations about other bio-fuel than native wood chips. This knowledge in gasification different bio-fuel would not have been financially possible into a large system.

The values obtained with native wood chips are slightly different than the values obtained with a large gasifier:

- about 10% lower calorific values,
- higher tar production (about two time more),

but this difference is understandable and the values obtained with other bio-fuels can be adjusted in the same range.

The wood in the form of chips, pellets or briquettes are bio-fuels that can be use to produce a clean and energetic gas for the production of electricity. The same is applicable to the pecan nuts shell and let estimate that probably other biomass shell or pit (as apricot pit) are interesting bio-fuel.

The gasification of urban waste wood is possible but the problematic of heavy metal present in the gas after its treatment. However, complementary tests should be done using a better scrubber which would probably increase the particle (containing heavy metal) separation.

The gasification of Chicken litter is possible however, the gas treatment is not sufficient to allow to use it into a gas engine.

Finally, the coffee hull pellets (which in this were containing oil) is not an interesting bio-fuel both because the gasification efficiency is low and because the tar and particle content in the gas is very high.

Base on inquiries received from different contact person, further test should be done on the small gasifier with other bio-fuel among them: olive and apricot pits, dry sludge coming from water treatment plant, animal residues or plastic residue coming from recycling industries (Ebanite). This tests would be also an opportunity to test complementary gas treatment devices more adapted for more contaminated gas.

5. Bibliography

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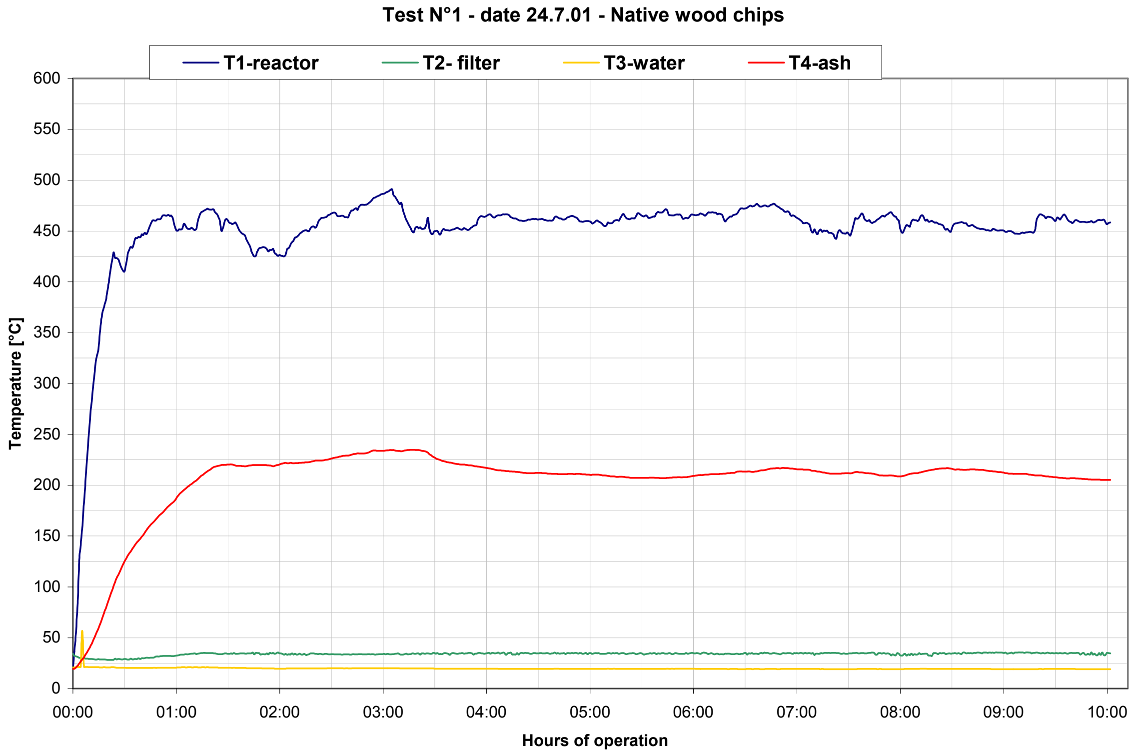
Neeft, J.P.A.; Knoef, H.A.M.; Zielke, U.; Sjöström, K.; Hasler, P.; Simell, P.A.; Dorrington, M.A.; Abatzoglou, N.; Deutch, S.; Greil, C.; Buffinga, G.J.; Brage, C.; Suomalainen, M.: Guideline for Sampling and Analysis of Tar and Particulates in Biomass Producer Gases, draft version 2.1 (20. February 2001; not yet public)

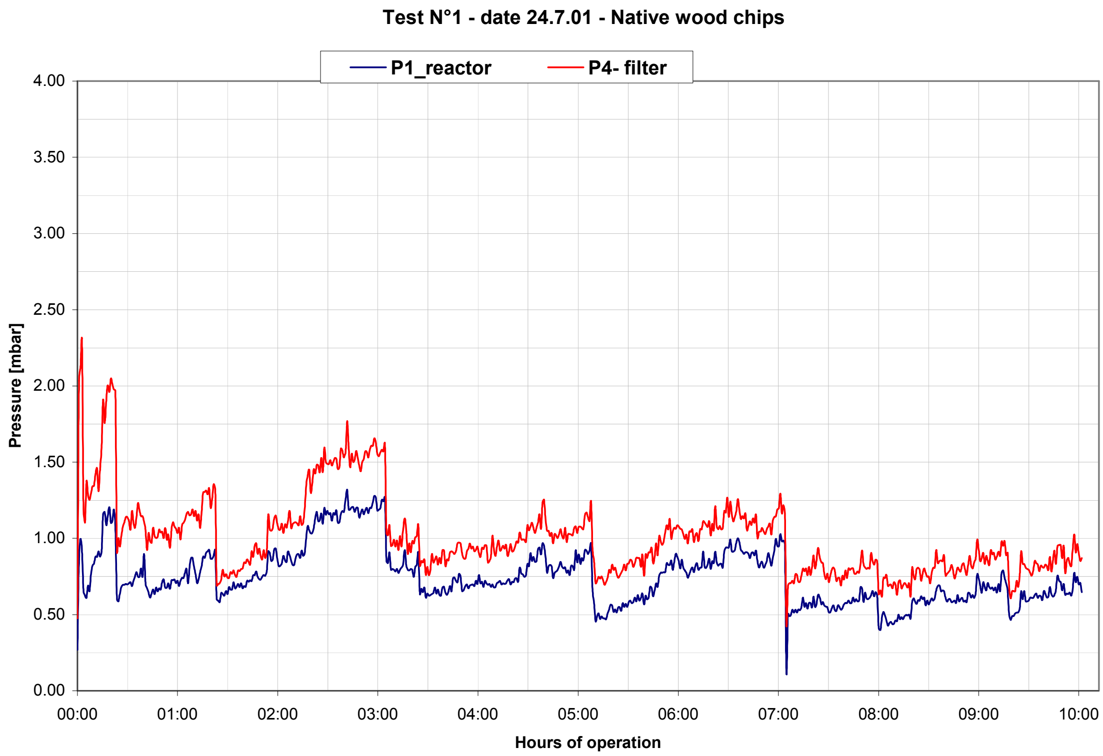
Kurkela, E.; Lappi, M.; Pitkänen, P.; Stahlberg, P.; Leppämäki, E.: Strategies for sampling and analysis of contaminants from biomass gasifiers, draft report from VTT prepared for the IEA biomass gasification activity, March 1995

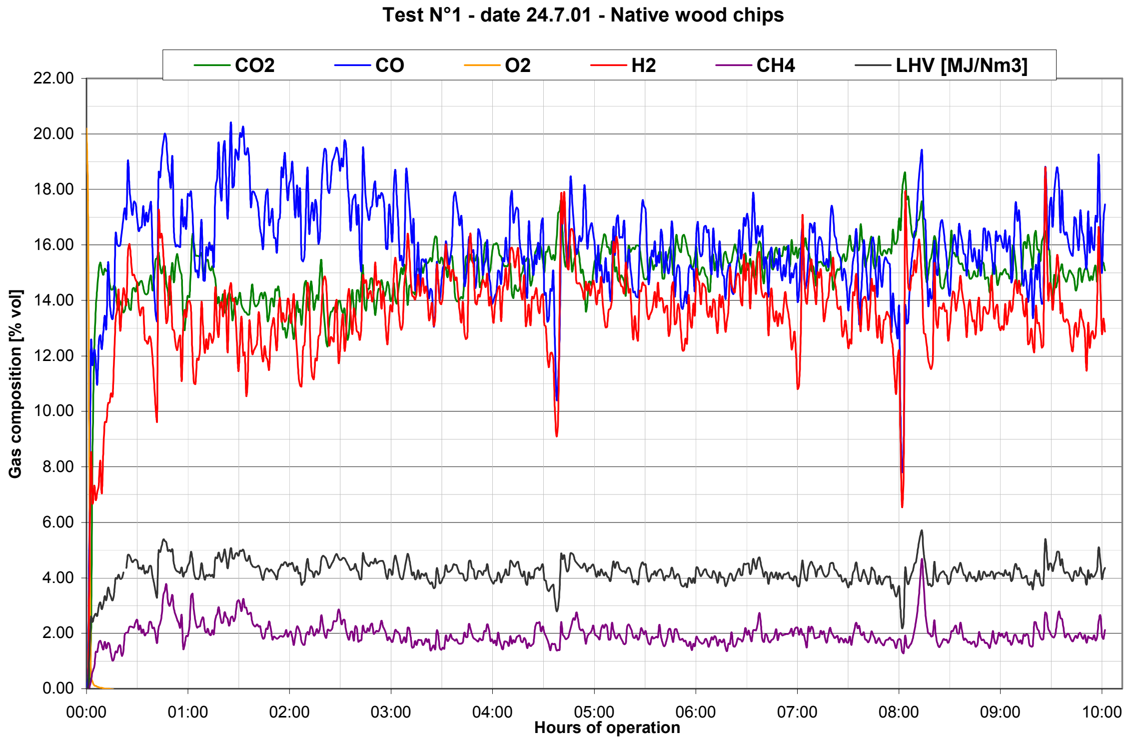
OFEFP, incinération des déchets, de bois et de résidus de bois dans des chauffage au bois, 3003 Berne, 1996

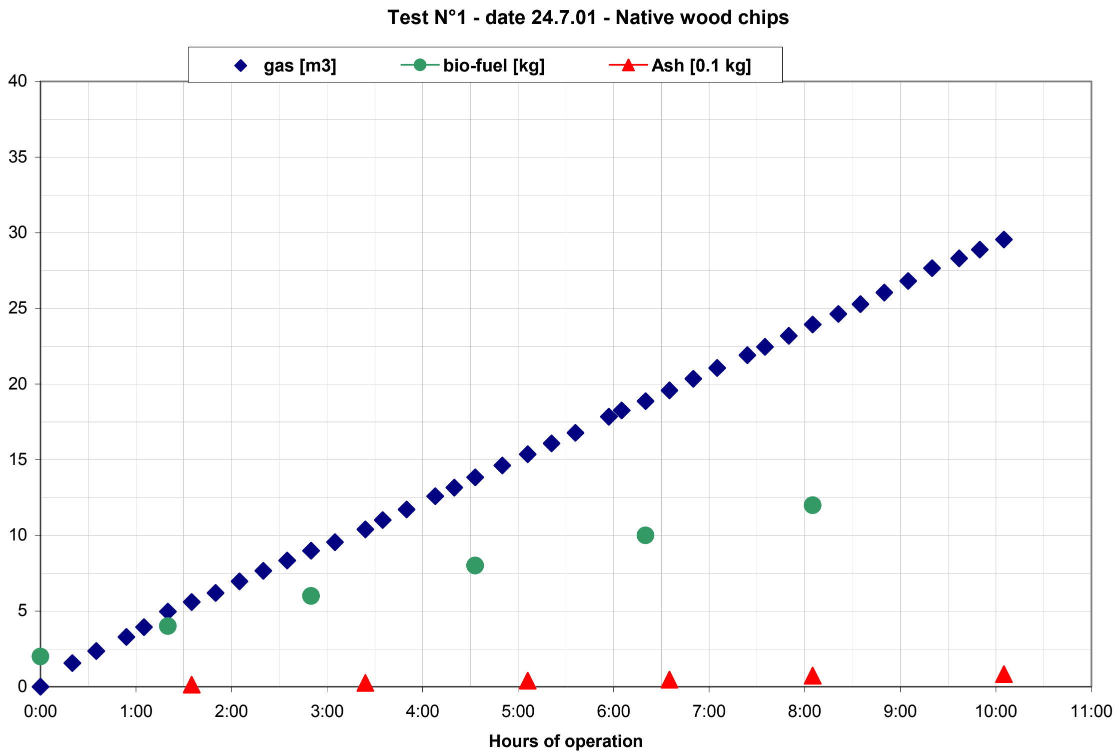
Annexes

Annexes 1: native wood chips

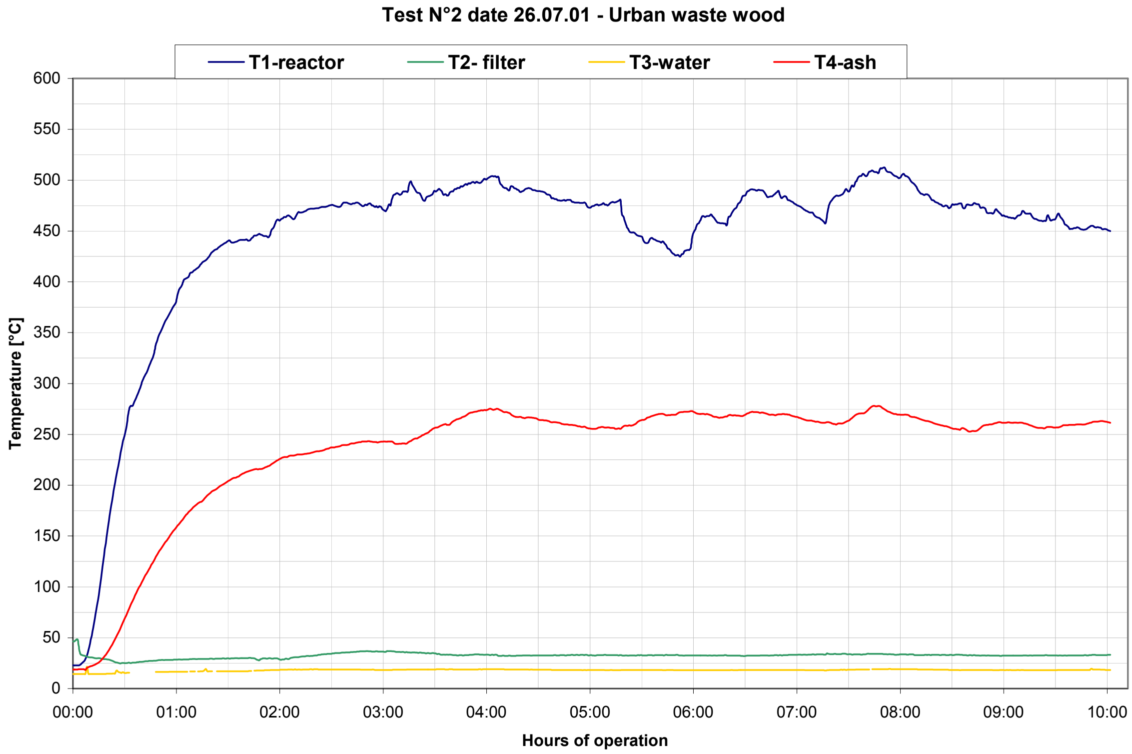


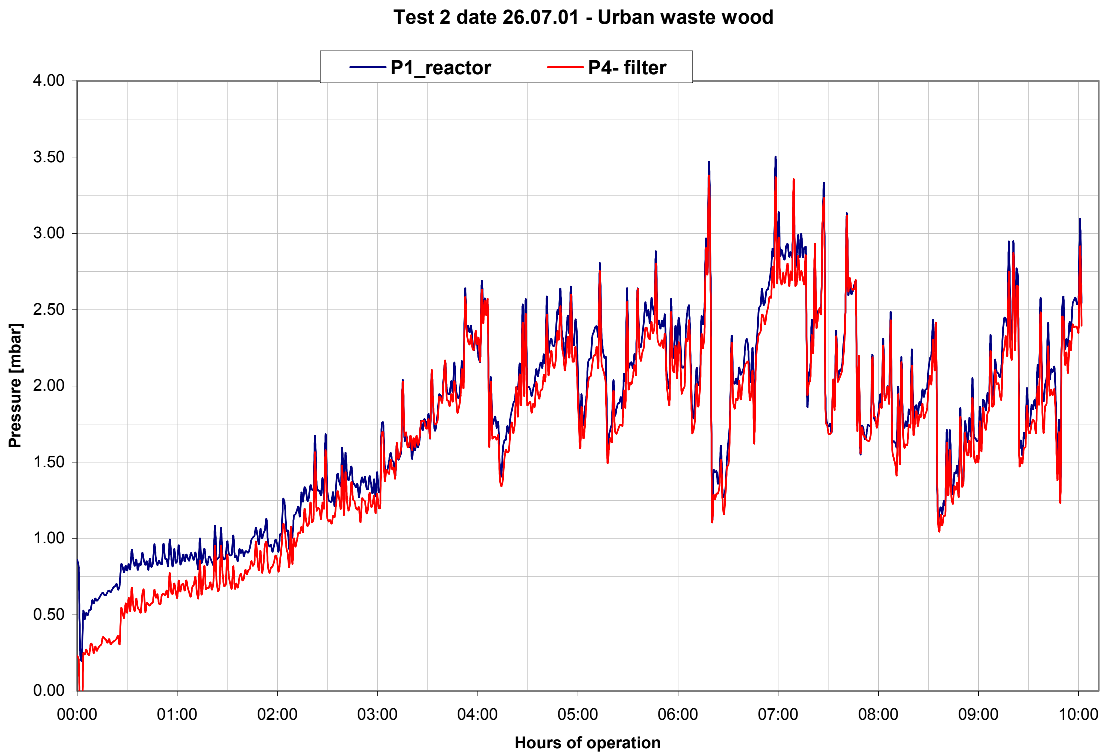


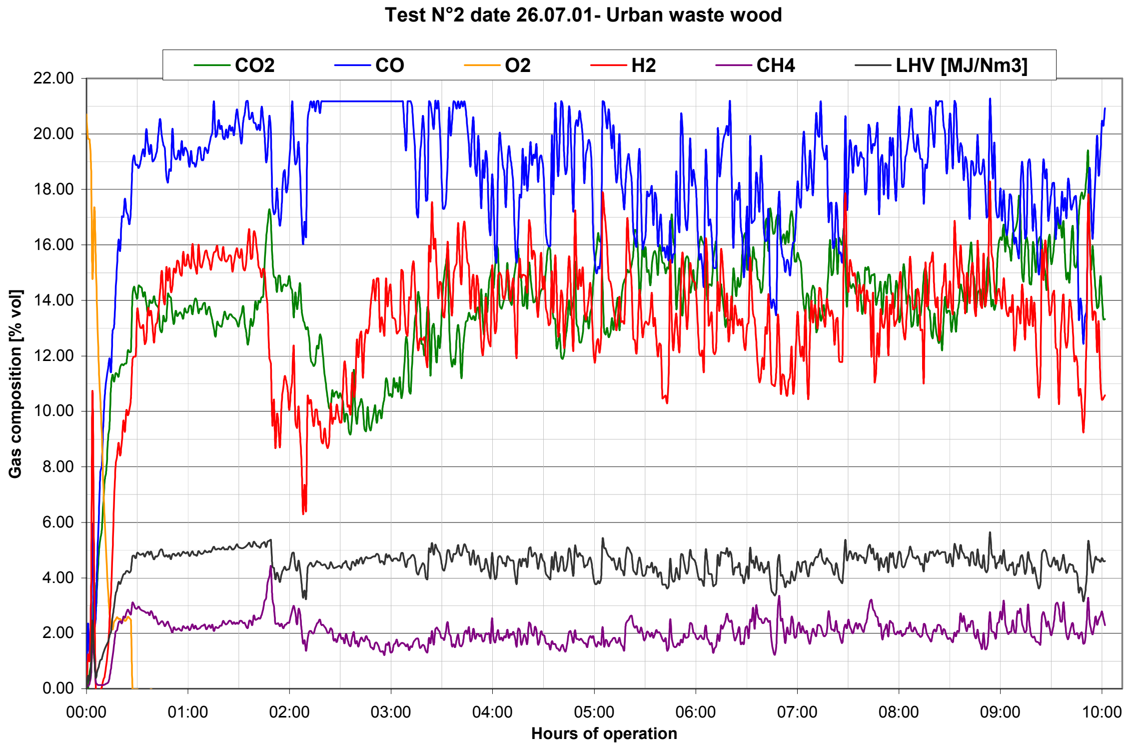

Test N°1 - date 24.7.01 - Native wood chips
CO2
CO
O2
H2
CH4
LHV [MJ/Nm3]
Gas composition [% vol]
22.00
20.00
18.00
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
00:00
01:00
02:00
03:00
04:00
05:00
06:00
07:00
08:00
09:00
10:00
Hours of operation

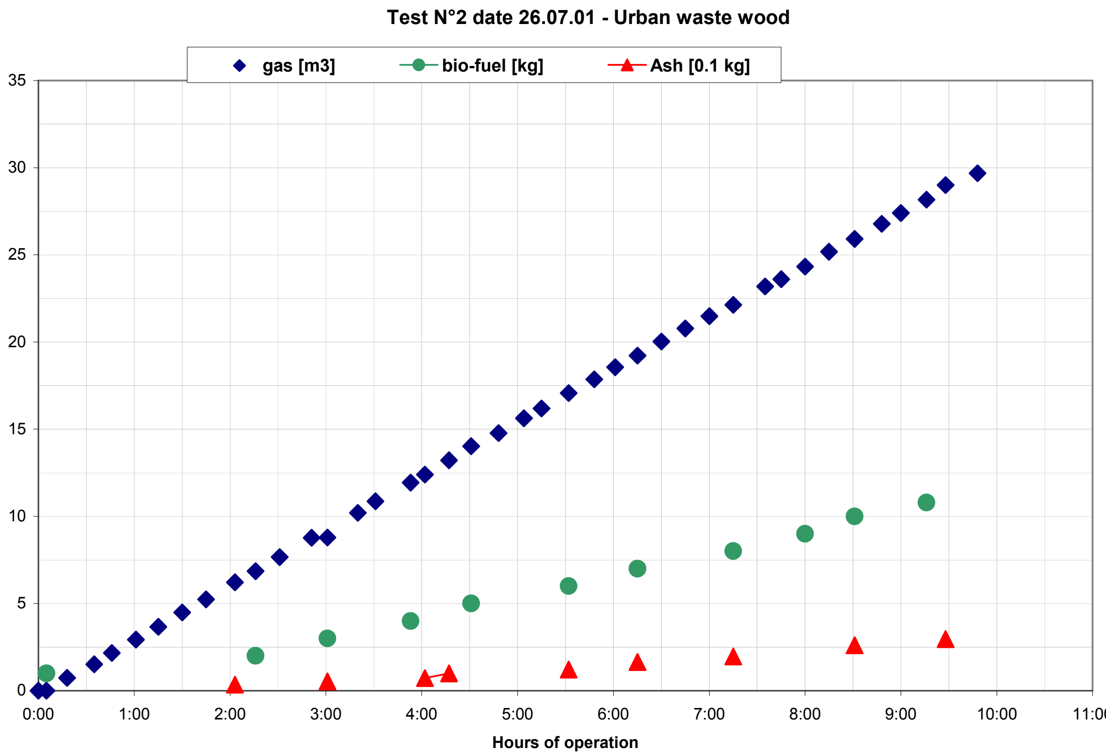

Test N°1 - date 24.7.01 - Native wood chips
gas [m3]
bio-fuel [kg]
Ash [0.1 kg]
40
35
30
25
20
15
10
5
0
0:00
1:00
2:00
3:00
4:00
5:00
6:00
7:00
8:00
9:00
10:00
11:00
Hours of operation

Annexes 2: urban waste wood

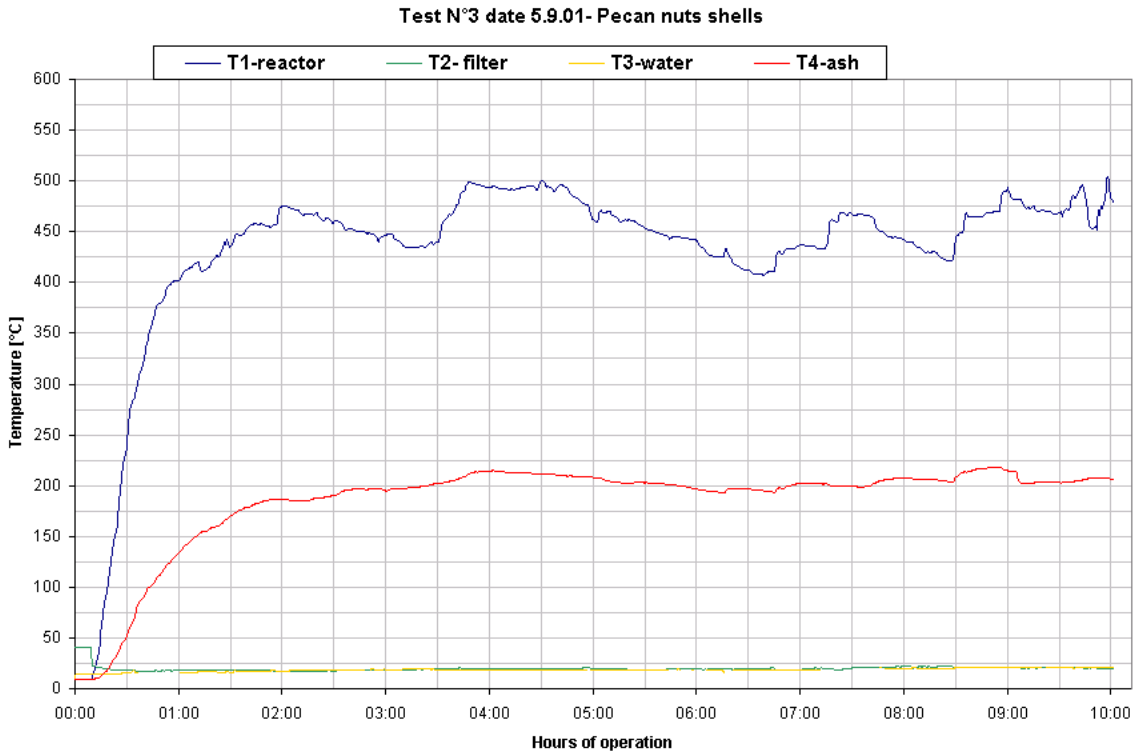


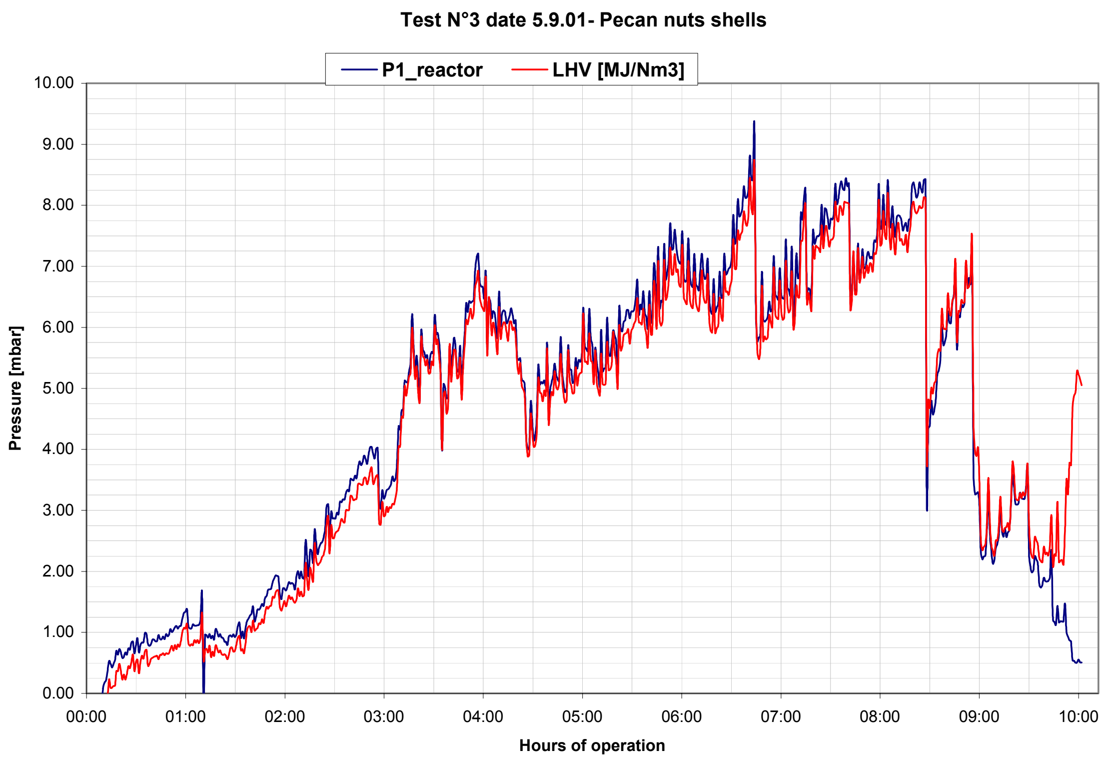



Test N°2 date 26.07.01- Urban waste wood
CO2
CO
O2
H2
CH4
LHV [MJ/Nm3]
Gas composition [% vol]
22.00
20.00
18.00
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
00:00
01:00
02:00
03:00
04:00
05:00
06:00
07:00
08:00
09:00
10:00
Hours of operation

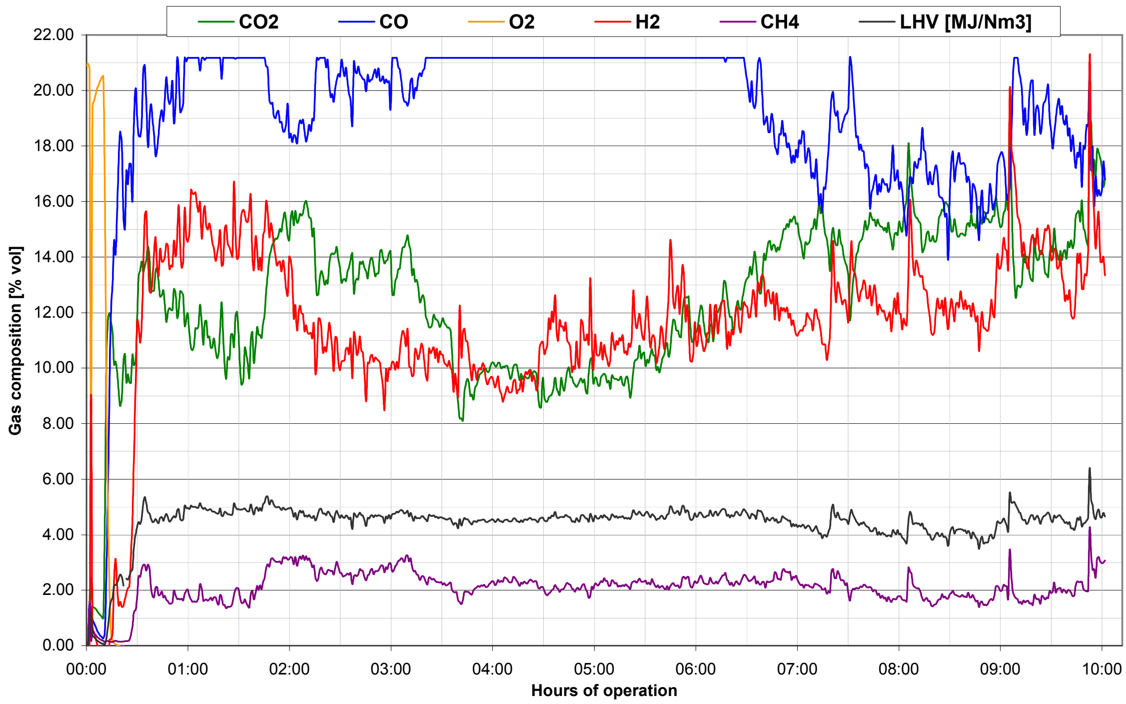

Test N°2 date 26.07.01 - Urban waste wood
gas [m3]
bio-fuel [kg]
Ash [0.1 kg]
35
30
25
20
15
10
5
0
0:00
1:00
2:00
3:00
4:00
5:00
6:00
7:00
8:00
9:00
10:00
11:00
Hours of operation

Annexes 3: pecan nuts shells

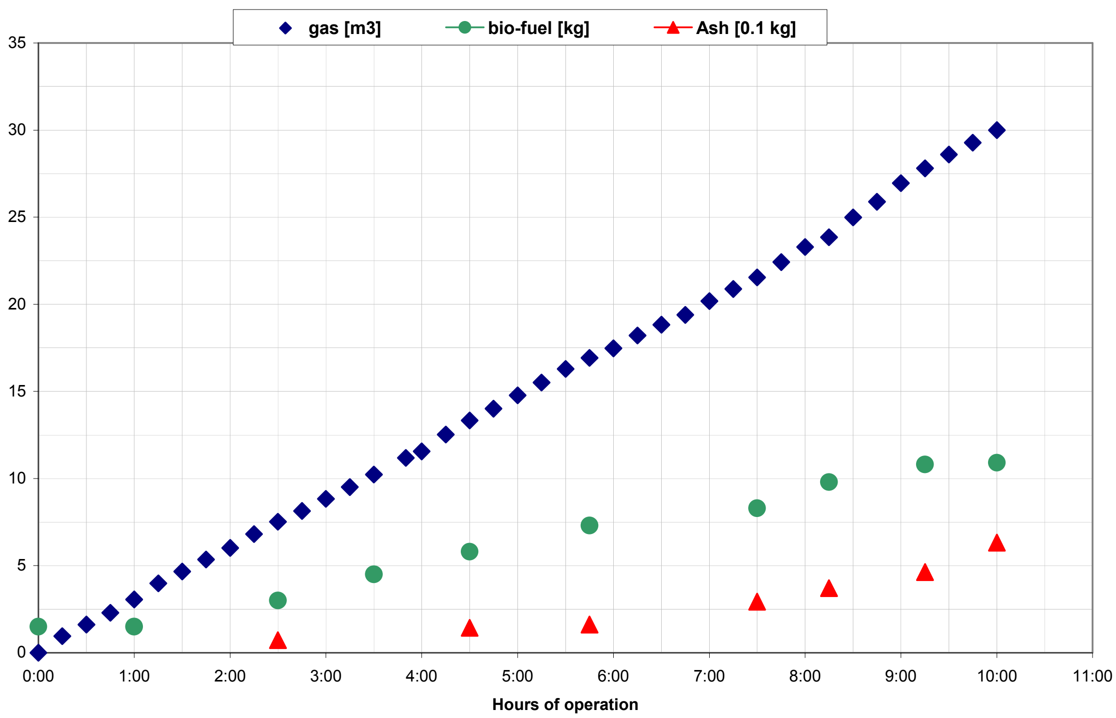




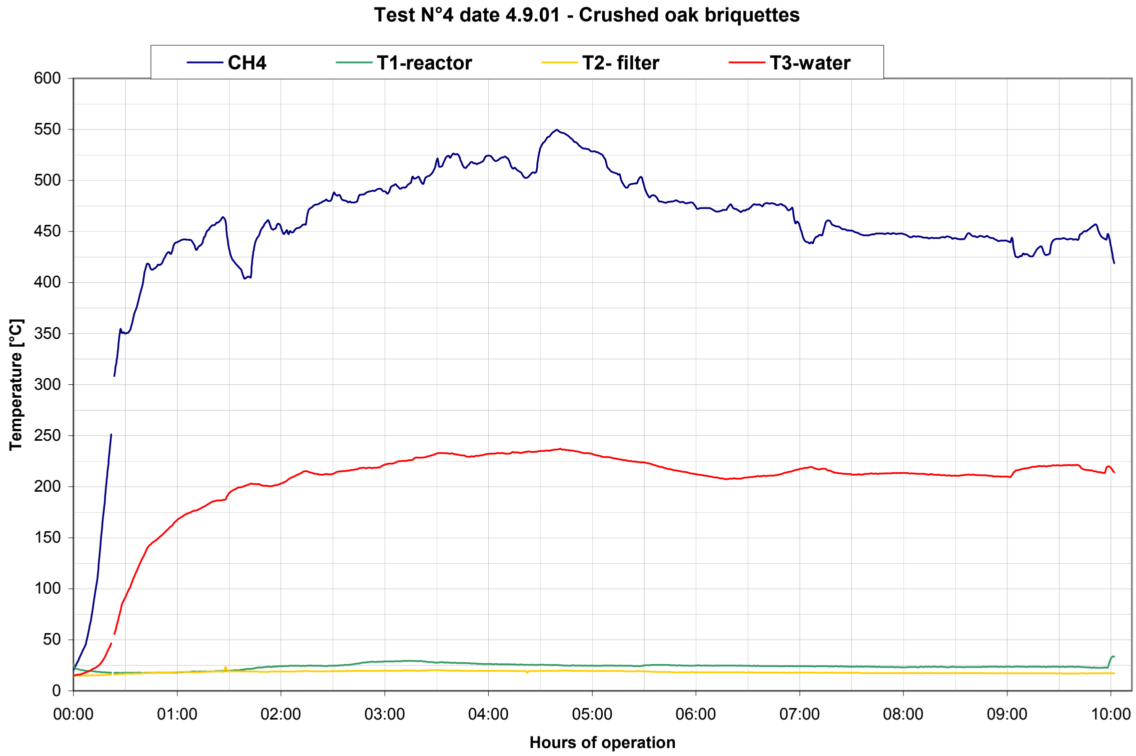
Test N°3 date 5.9.01- Pecan nuts shells

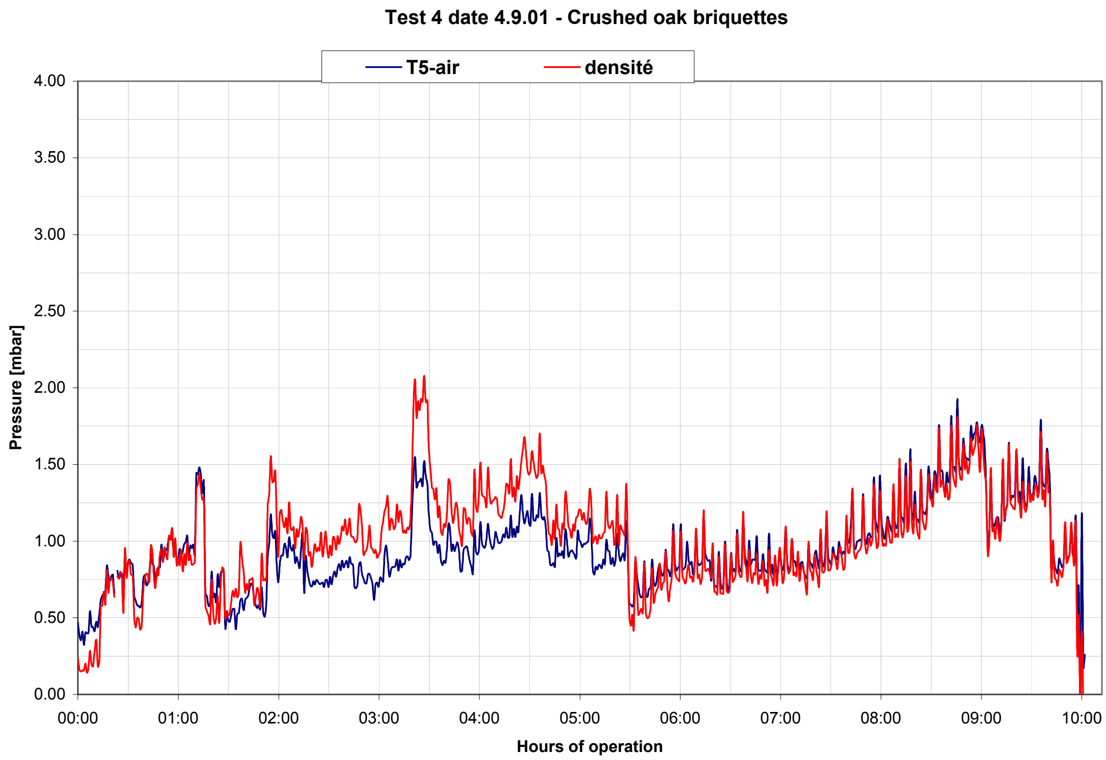


Test N°3 date 5.9.01- Pecan nuts shells

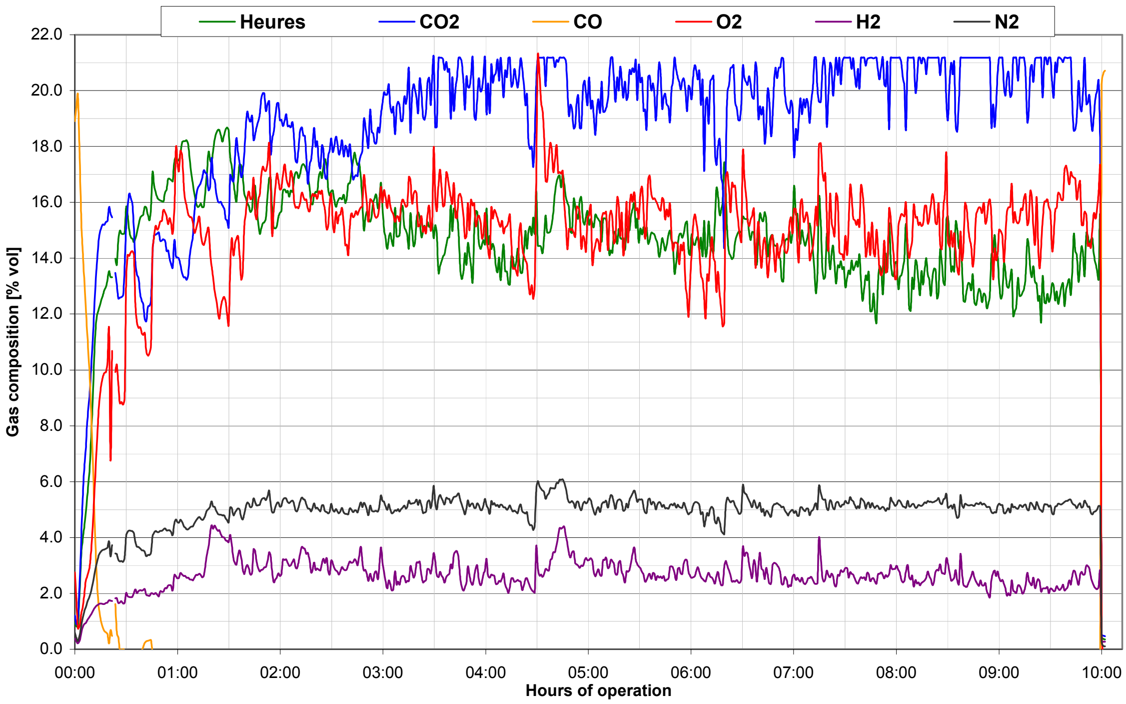


Annexes 4: crushed oak briquettes

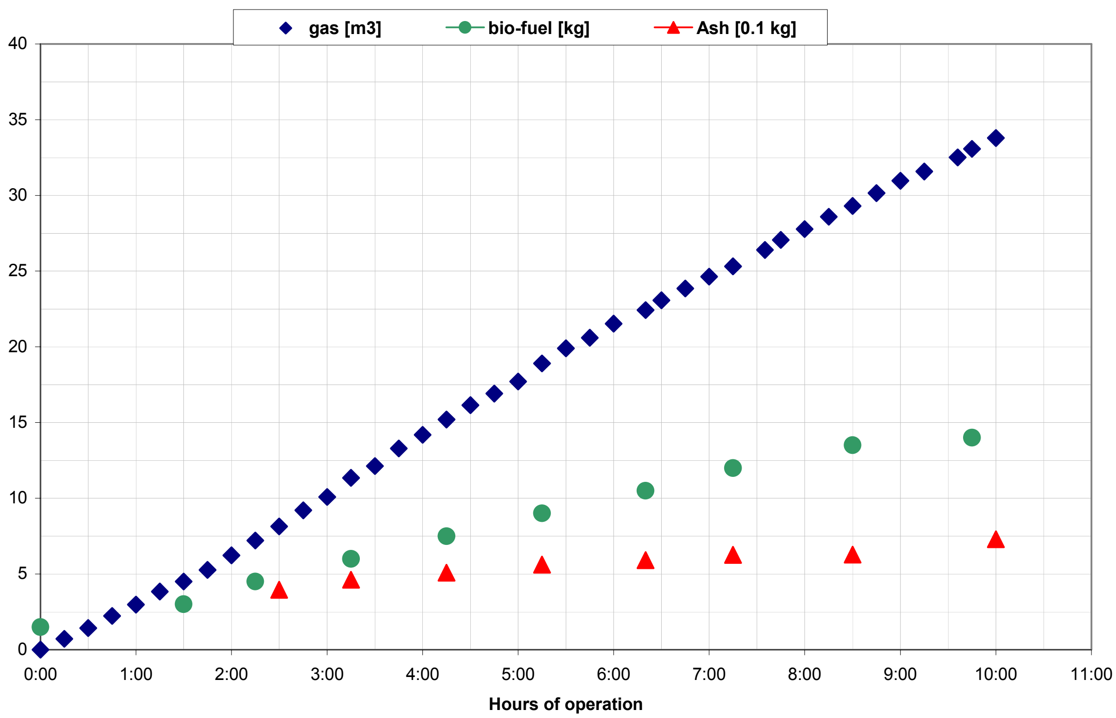




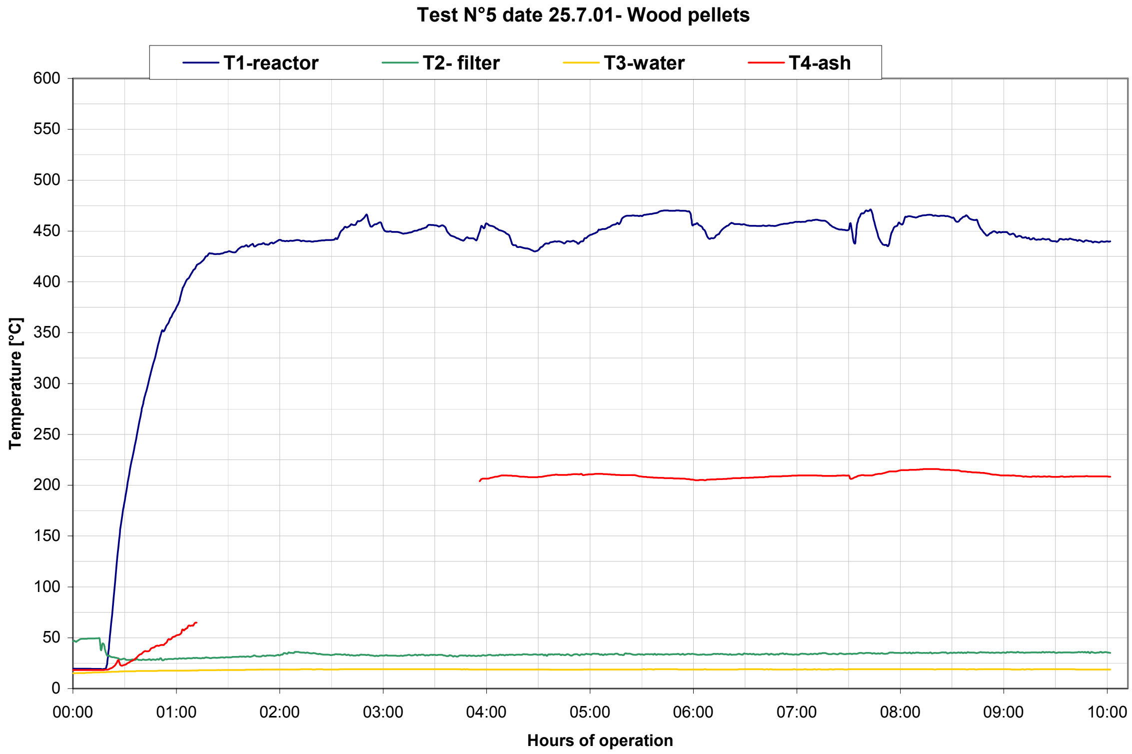
Test N°4 date 4.9.01- Crushed oak briquettes

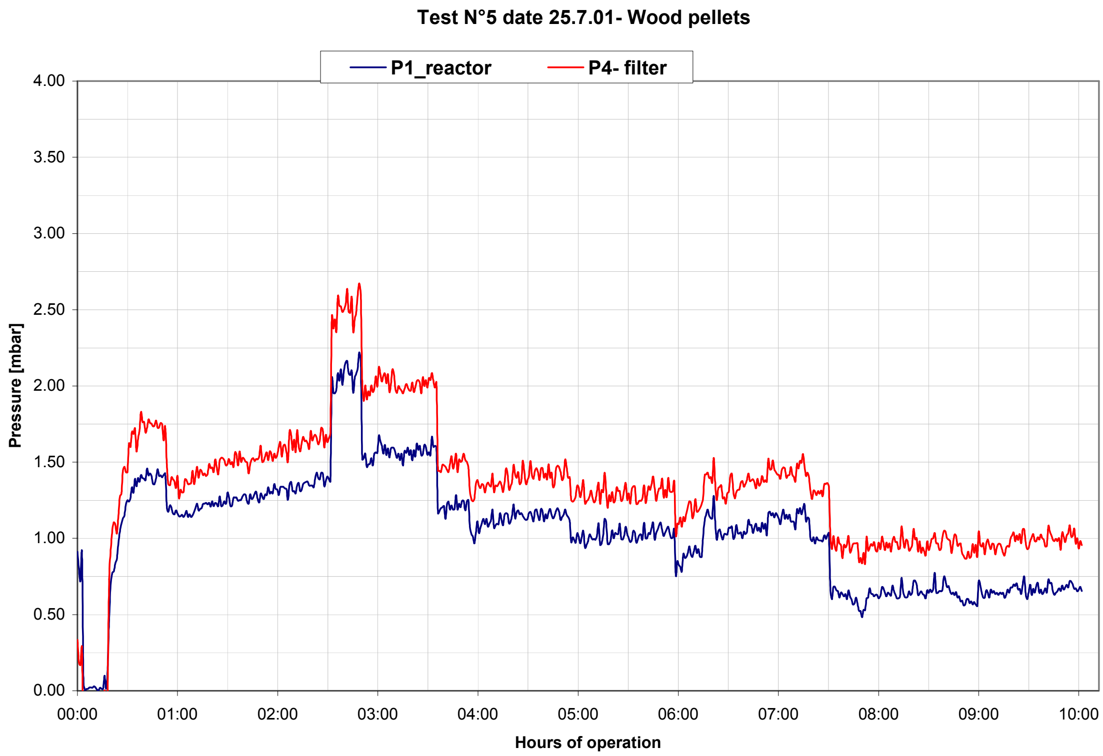


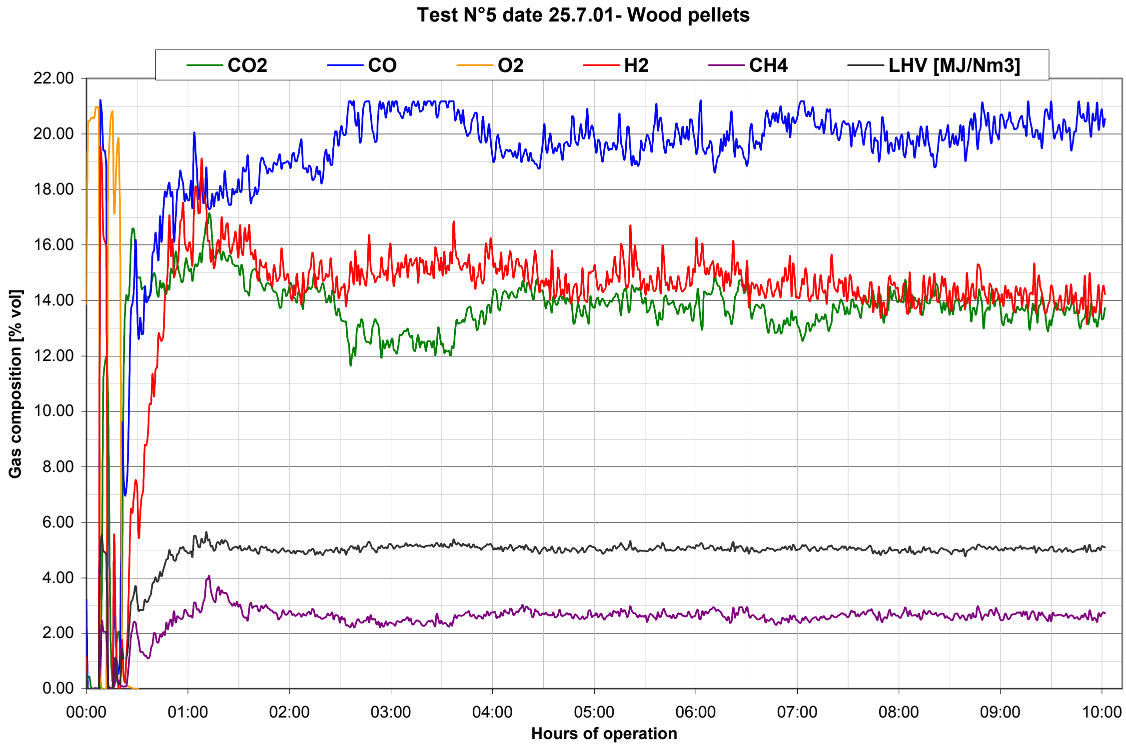
Test N°4 date 4.9.01 - Crushed oak briquettes

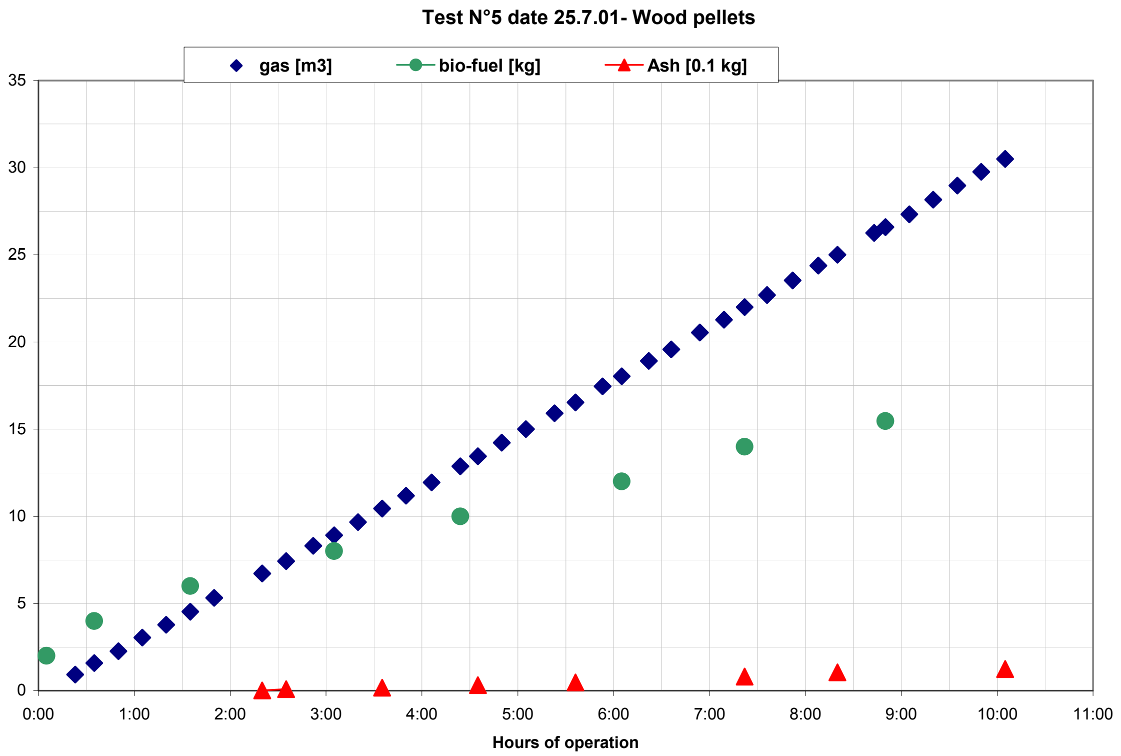


Annexes 5: wood pellets

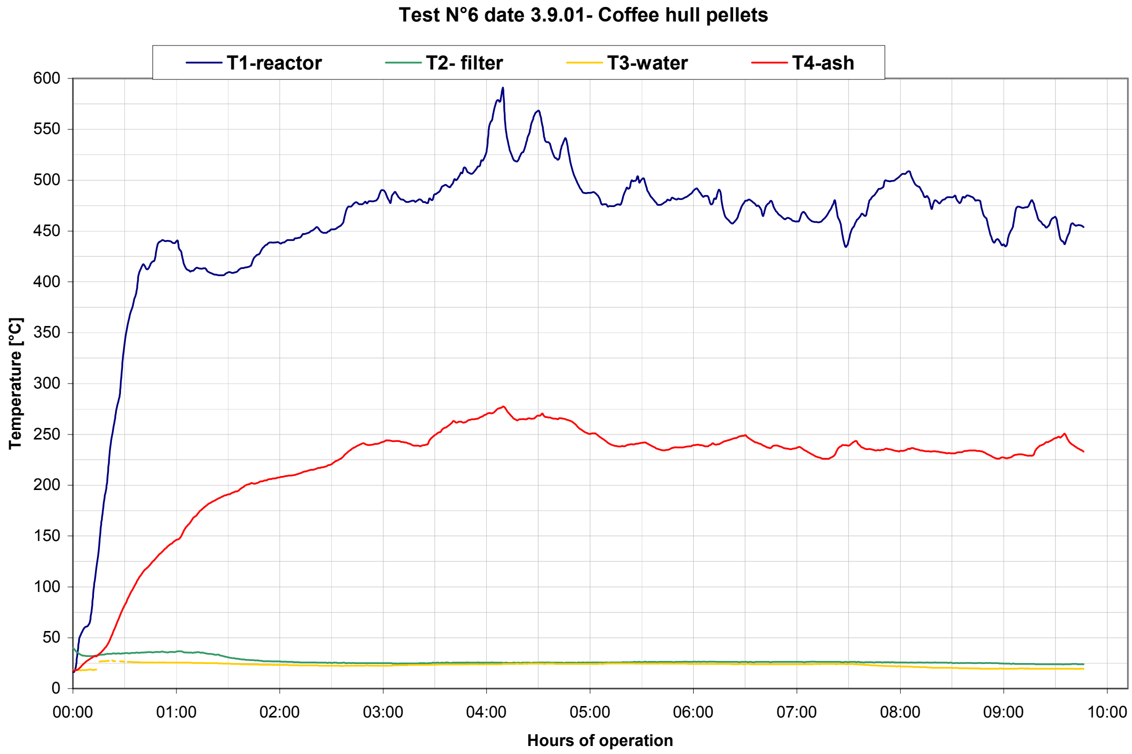


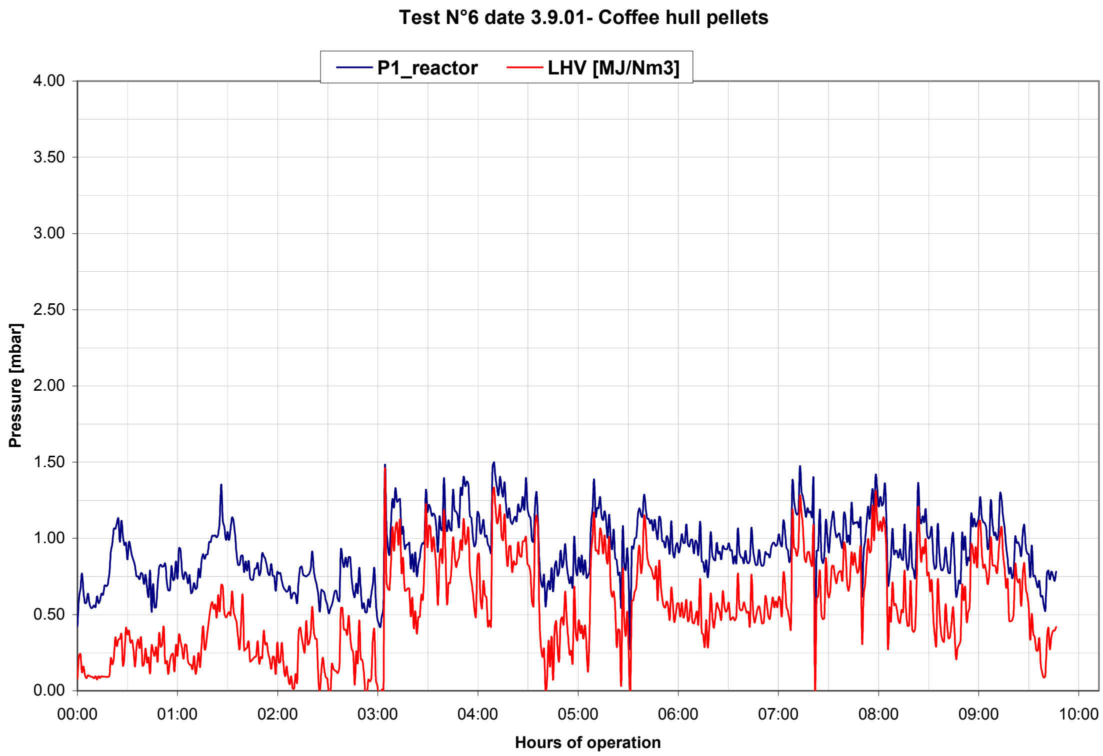


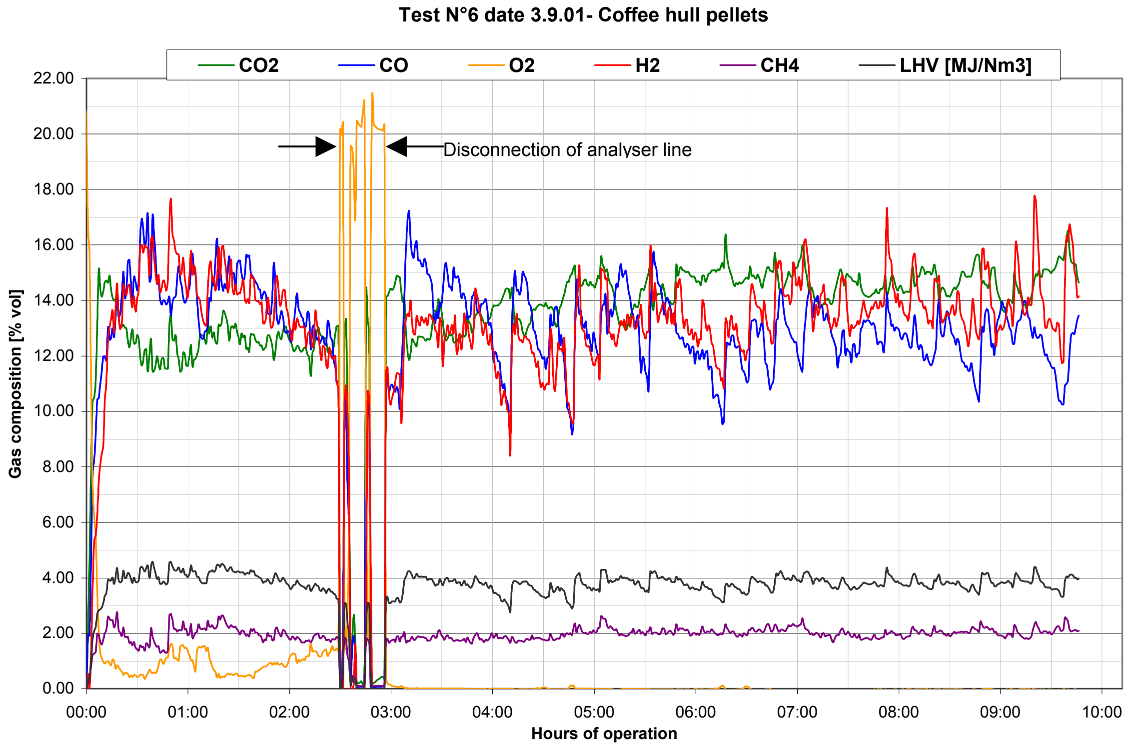

Test N°5 date 25.7.01- Wood pellets
CO2
CO
O2
H2
CH4
LHV [MJ/Nm3]
Gas composition [% vol]
22.00
20.00
18.00
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
00:00
01:00
02:00
03:00
04:00
05:00
06:00
07:00
08:00
09:00
10:00
Hours of operation

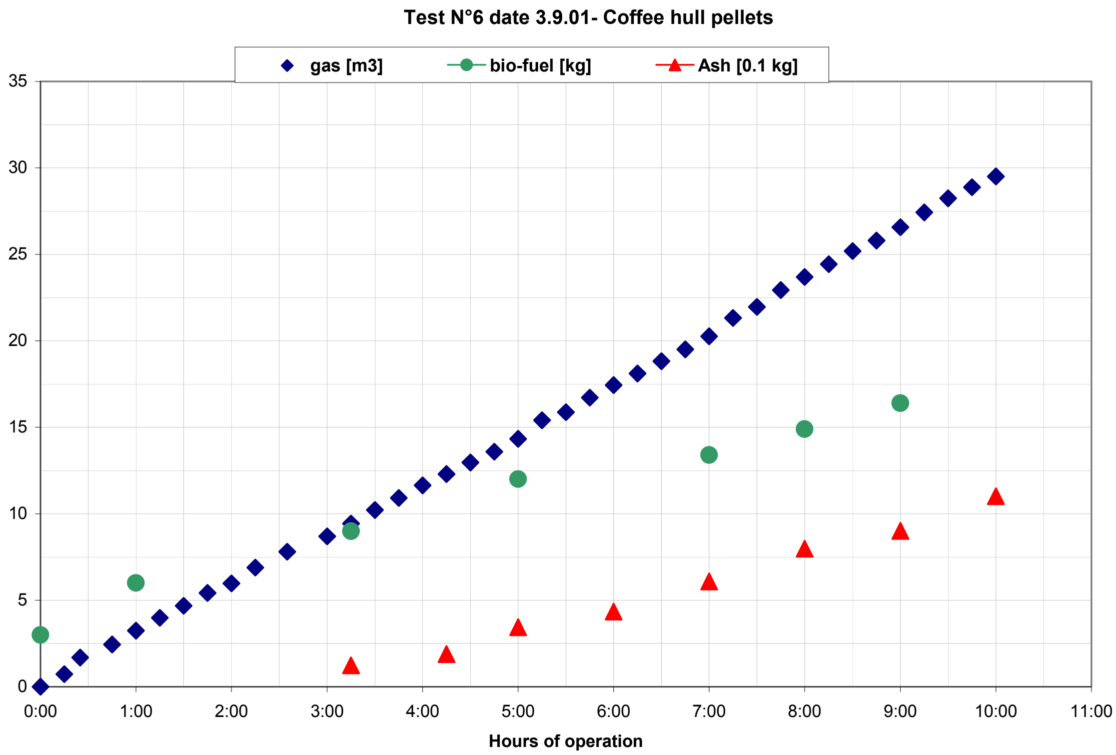

Test N°5 date 25.7.01- Wood pellets
gas [m3]
bio-fuel [kg]
Ash [0.1 kg]
35
30
25
20
15
10
5
0
0:00
1:00
2:00
3:00
4:00
5:00
6:00
7:00
8:00
9:00
10:00
11:00
Hours of operation

Annexes 6: coffee hull pellets

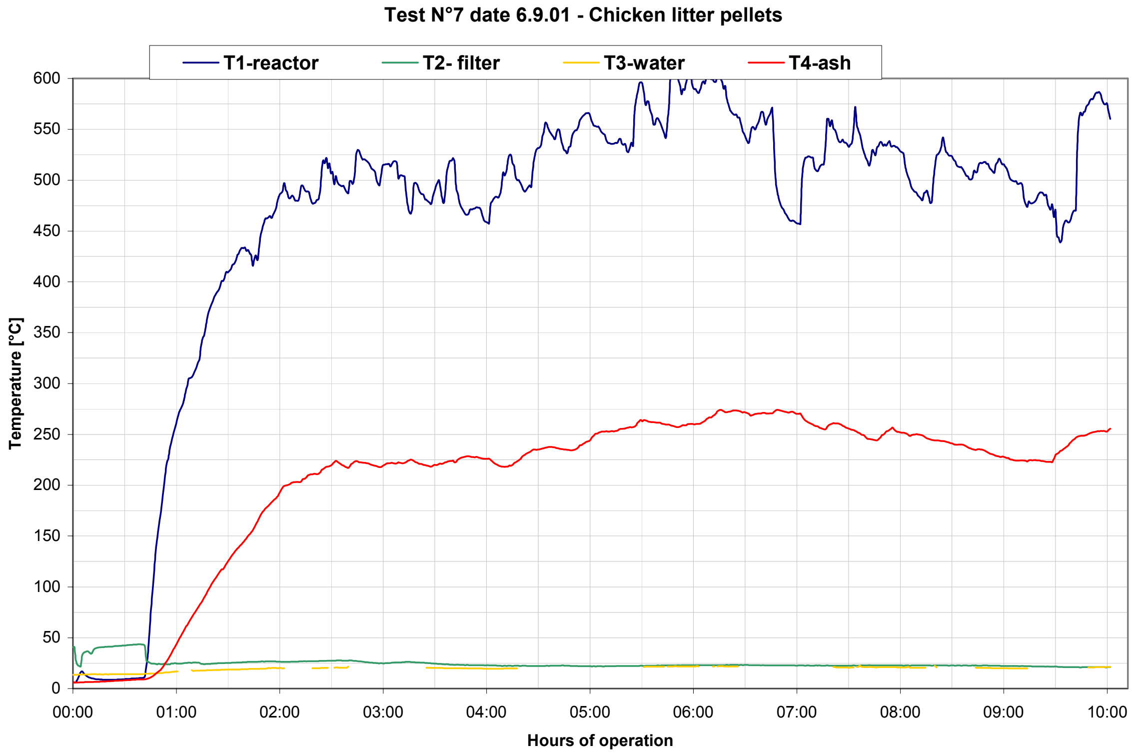


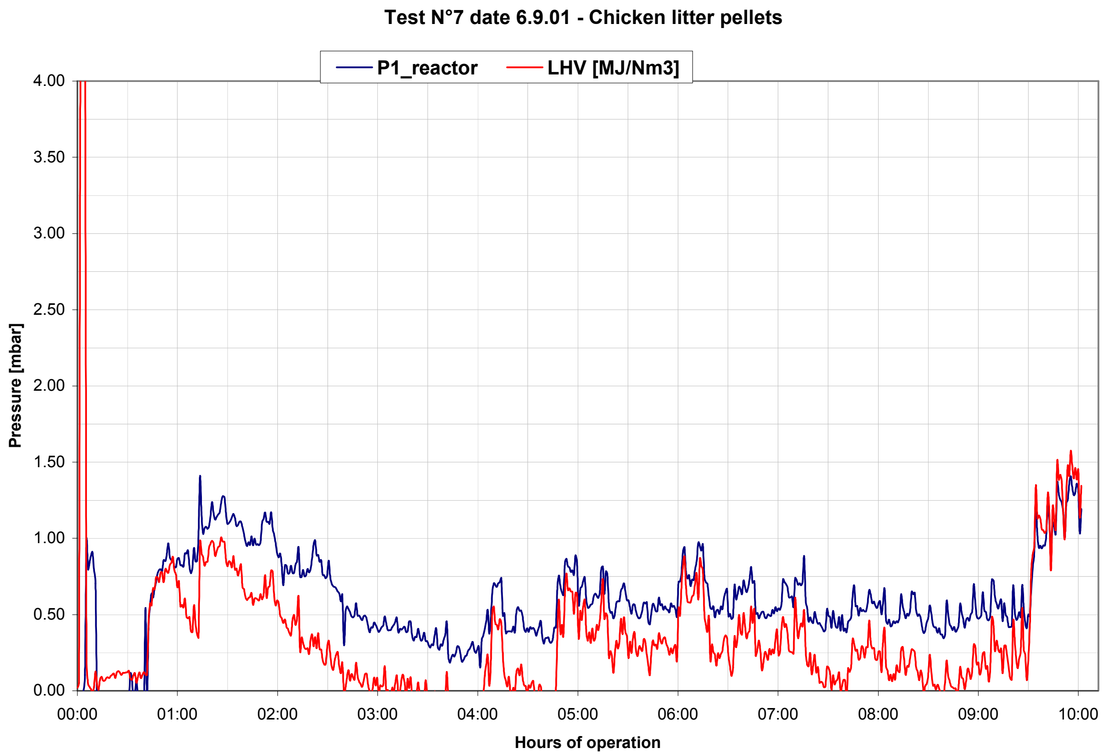


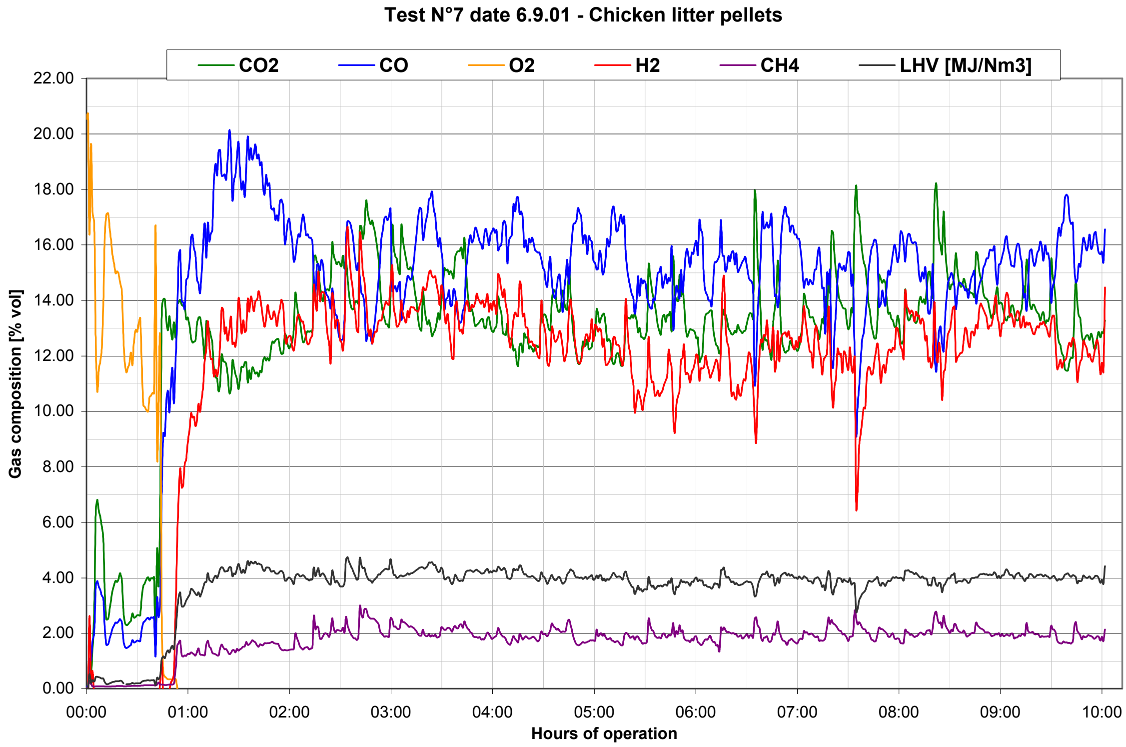

Test N°6 date 3.9.01- Coffee hull pellets
CO2
CO
O2
H2
CH4
LHV [MJ/Nm3]
Disconnection of analyser line
Gas composition [% vol]
22.00
20.00
18.00
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
00:00
01:00
02:00
03:00
04:00
05:00
06:00
07:00
08:00
09:00
10:00
Hours of operation

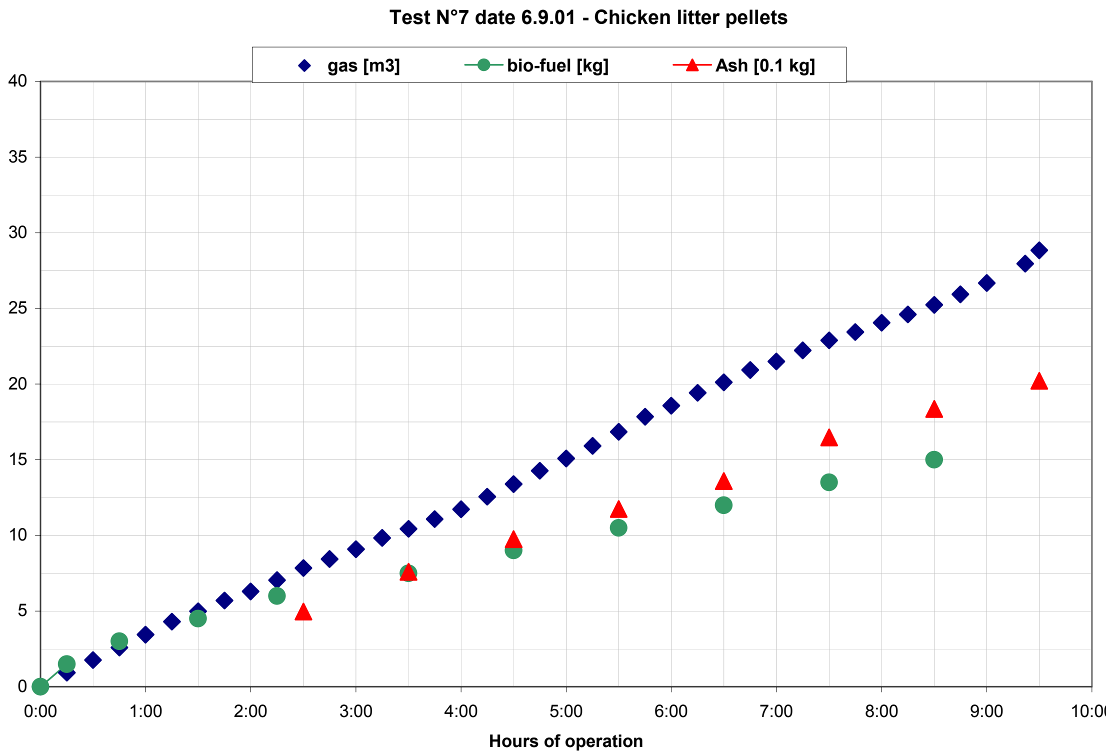

Test N°6 date 3.9.01- Coffee hull pellets
gas [m3]
bio-fuel [kg]
Ash [0.1 kg]
35
30
25
20
15
10
5
0
0:00
1:00
2:00
3:00
4:00
5:00
6:00
7:00
8:00
9:00
10:00
11:00
Hours of operation

Annexes 7: chicken litter pellets






Test N°7 date 6.9.01 - Chicken litter pellets
CO2
CO
O2
H2
CH4
LHV [MJ/Nm3]
Gas composition [% vol]
22.00
20.00
18.00
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
00:00
01:00
02:00
03:00
04:00
05:00
06:00
07:00
08:00
09:00
10:00
Hours of operation


Test N°7 date 6.9.01 - Chicken litter pellets
gas [m3]
bio-fuel [kg]
Ash [0.1 kg]
40
35
30
25
20
15
10
5
0
0:00
1:00
2:00
3:00
4:00
5:00
6:00
7:00
8:00
9:00
10:00
Hours of operation