GASIFICATION OF PELLETIZED BIOMASS IN MULTISTAGE AIR SUPPLY DOWNDRAFT GASIFIER

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ENERGY TECHNOLOGY & MANAGEMENT

JGSEE

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OUTLINE

- INTRODUCTION
- THEORIES
- METHODOLOGY
- RESULTS & DISCUSSION

INTRODUCTION

- Based on Energy Efficiency Action Planning in ASEAN, 10 ASEAN member states would be able to reduce primary energy consumption, Indonesia (25%), Thailand (22%), Malaysia (21%), Brunei (20%), consecutively

- For example, Thailand's government assigned Energy Ministry to establish Renewable and Alternative Energy Plant for 25% in 10 years, so called "AEDP (2012-2021)"

ENERGY MIX

BIOMASS

GASIFICATION

How to improve producer gas quality in terms of higher HHV and lower tar content and conditioning of raw material before being processed in gasifier

?

Biomass Gasification

No	Name / Year	Title	Results
1	Son et al / 2011	Gasification and power generation characteristics of woody biomass utilizing a downdraft gasifier	Tar concentration in raw syngas was low, around 3.9-4.4 g/Nm^3. It has been confirmed that stable power generation can be done, and that an HC emission below 200 ppm, and a NOx emission below 40 ppm, can be achieved.
2	Virginie et al / 2012	Effect of Fe–olivine on the tar content during biomass gasification in a dual fluidized Bed	An inexpensive and non-toxic Fe/olivine can act as catalyst for tar and hydrocarbon reforming and also as an oxygen carrier that transfers oxygen from the combustor to the gasifier.
3	Bhattacharya, S. C and A. Dutta	Two-stage gasification of wood with preheated air supply: a promising technique for producing gas of low tar content	Very clean gas having a tar content of about 10 mg/Nm^3 or lower could be obtained. Increase in the secondary airflow rate of the two-stage gasifier resulted in a decrease in tar content and CO_2 concentration while the concentration of CO and H_2 increased.

Biomass Gasifier

No	Name / Year	Title	Results
1	Jaojaruek et al / 2011	Experimental study of wood downdraft gasification for an improved producer gas quality through an innovative two stage air and premixed air /gas supply Approach	The producer gas quality generated by the innovative two-stage approach improved as compared to conventional two-stage. This method can lower tar content sufficiently to feed the gas directly to internal combustion engine. The gas efficiency and capacity were also improved around 15% and 40% respectively.
2	Martínez at al / 2011	Experimental study on biomass gasification in a double air stage downdraft reactor.	The effect of secondary stage air supply can reduce CH 4 concentration which is associated with the decreases of the tar content in the producer gas.
3	Wang et al / 2012	A comparison of biomass gasification and pyrolysis in three kinds of reactors using corn stalk pellets.	Gas LHVs for the downdraft reactor, bubbling reactor, and pyrolysis reactor were 3.91–4.44 MJ/Nm^3, 8.48–9.38 MJ/Nm^3, and 14.51–16.49 MJ/Nm^3. The downdraft reactor consumed the least energy during operation.

Gasifying Medium

No	Name / Year	Title	Results
1	Nipattummakul et al / 2010	Hydrogen and syngas production from sewage sludge via steam gasification	Steam as the gasifying agent increased the hydrogen yield three times as compared to air gasification. Compared to air gasification of sewage sludge, steam resulted in about 40% higher mole fraction of hydrogen.
2	Martínez et al / 2012	Syngas production in downdraft biomass gasifiers and its application using internal combustion engines	The use of air as an oxidizing agent in the biomass gasification process leads to high concentrations of nitrogen in the fuel/air mixture and the nitrogen acts as a knock suppressor which is beneficial in cases when engines with the high compression ratio are employed.
3	Huynh, C. V and S. C. Kong / 2013	Performance characteristics of a pilot-scale biomass gasifier using oxygen-enriched air and steam	Oxygen-enriched air and steam gasification favors the production of combustible gas components including H_2, CO, CH_4, and lighter hydrocarbons. Oxygen and steam gasification is most effective for feedstock with low nitrogen and moisture contents

Gasification of Pelletized Biomass

No	Name / Year	Title	Results
1	Erlich , C and T. H. Fransson / 2011	Downdraft gasification of pellets made of wood, palm oil residues respective bagasse: Experimental study	Gasification of wood pellets resulted in a richer producer gas while EFB pellets gave a poorer one with higher contents of non-combustible compounds. Higher air-fuel ratio resulted in better efficiency.
2	Yoon et al / 2012	Gasification and power generation characteristics of rice husk and rice husk pellet using a downdraft fixed-bed gasifier	The heating value of synthetic gas and cold gas efficiency from rice husk pellet gasification showed higher value than that of rice husk gasification.
3	Garg, A and M. P. Sharma / 2013	Performance evaluation of gasifier engine system using different feed stocks	It was found that cold gas and overall efficiency of the system were in the acceptable range. It is concluded that gasifier engine system supplied by the manufacturer has performed satisfactorily.

OBJECTIVES

- To find the optimum equivalence ratio (ER) of eucalyptus wood pellet gasification
- To find the optimum operating condition in term of tar and HHV producer gas.
- To examine the producer gas composition, tar quantity and heating value of producer gas from eucalyptus wood pellet.

SCOPE OF RESEARCH WORK

Raw Material:

Eucalyptus Wood Pellet

Gasifier:
designed by Thai Steam Service & Supply Company

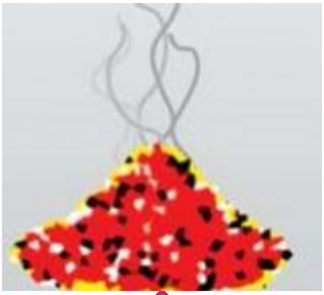
Gasifying medium:
air

This study investigated the effects of equivalence ratio (ER) on the tar quantity and producer gas composition. Also measured temperature profiles along the gasifier height.

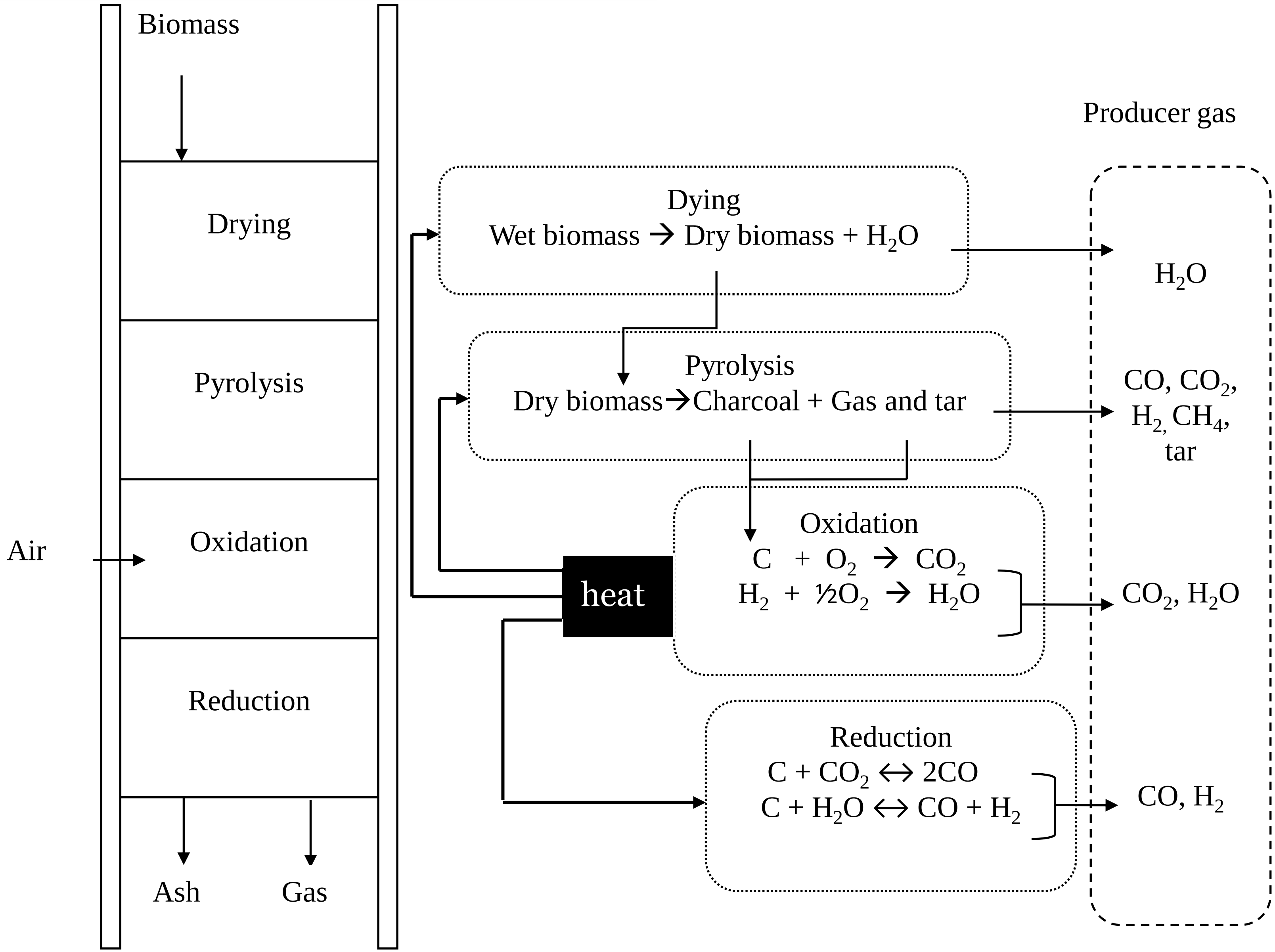
THEORIES

GASIFICATION

4 process in gasification

Drying	Pyrolysis	Combustion	Reduction
H_2O	Charcoal & Tar	H_2O & CO_2	H_2 & CO
Biomass	Biomass		
Heat	Heat no air	O_2/air	CO_2 and H_2O

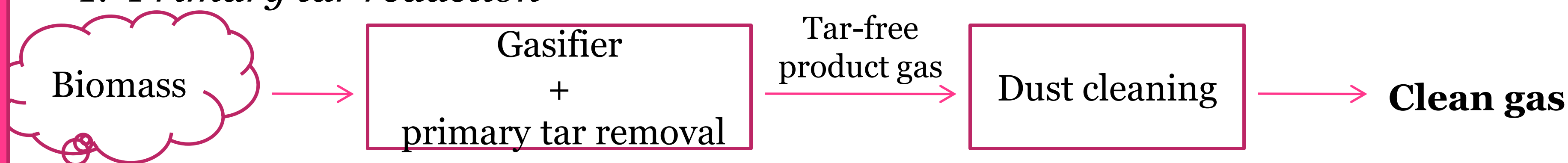
Downdraft Gasifier



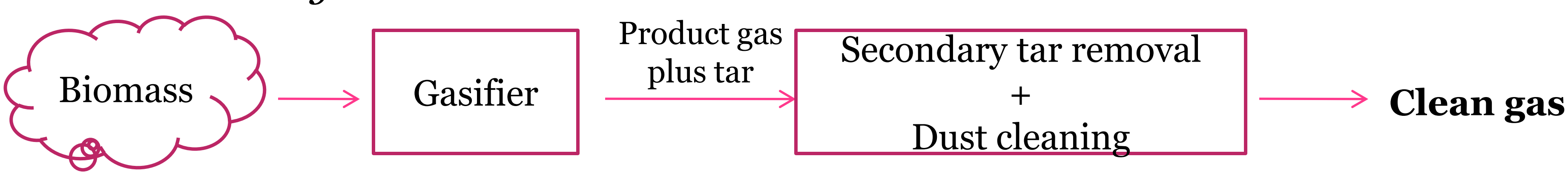
TAR

- Tar is a complex mixture of condensable hydrocarbons
- Tar will condense at Temperature below 250°C
- Tar is highly **undesirable**
- Tar can be reduced by 2 options:

1. *Primary tar reduction*



2. *Secondary tar reduction*



Biomass could be defined as organic materials from various natural source of energy, e.g. agricultural crops and residues, wood and its residues and industrial wastes

BIOMASS

Biomass is very versatile feedstock in its morphology and physical characteristic

Pelletized fuel will operate best in downdraft gasifier type instead of fine light biomass

Eucalyptus

- ✓ Easy grown
- ✓ Good survival
- ✓ Tolerant to various climates and soil types
- ✓ No proven negative effects on soil, environment, human
- ✓ Wide domestic and industrial use

Densified Biomass: Pellet

The Advantages

- Low moisture content
- Uniform size
- Increase of bulk density
- Reduce volume storage
- Easier handling

METHODOLOGY

Raw Material

Eucalyptus wood pellet

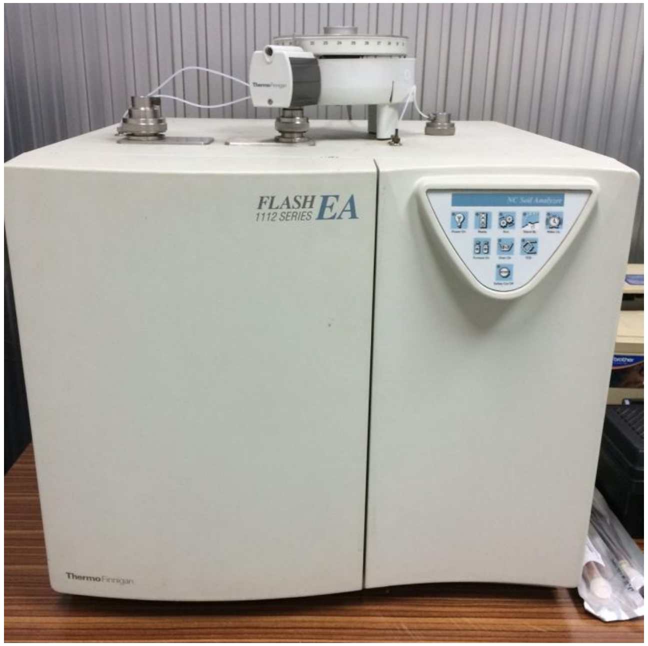
- Sira Intertrade. Co., Ltd.
- Diameter 6-10 mm and length 30-70 mm
- Moisture content 10 % (as-received)

Oven (Memmert, VO500)

Raw Material

Eucalyptus wood pellet

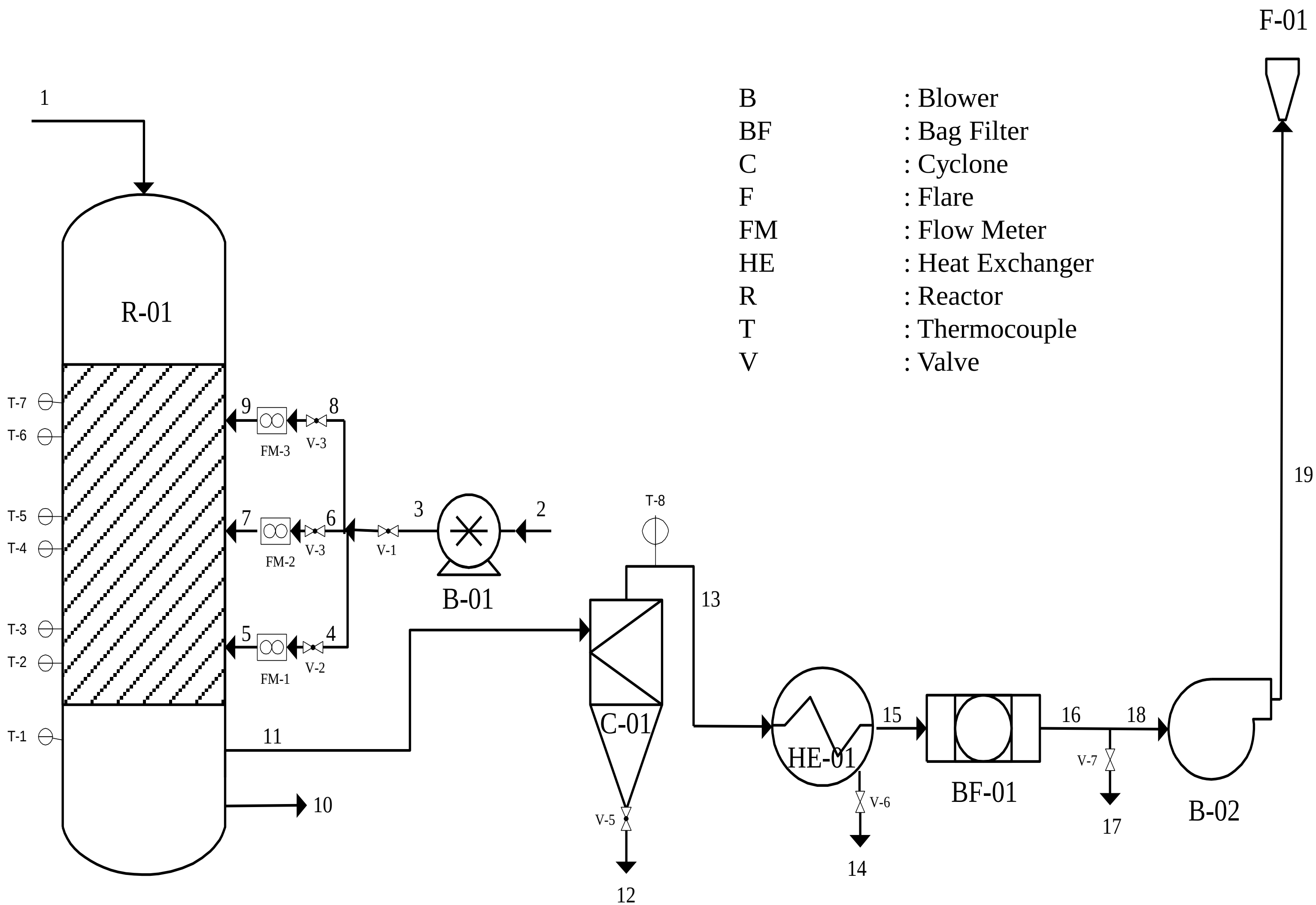
Proximate Analysis | **Ultimate Analysis**



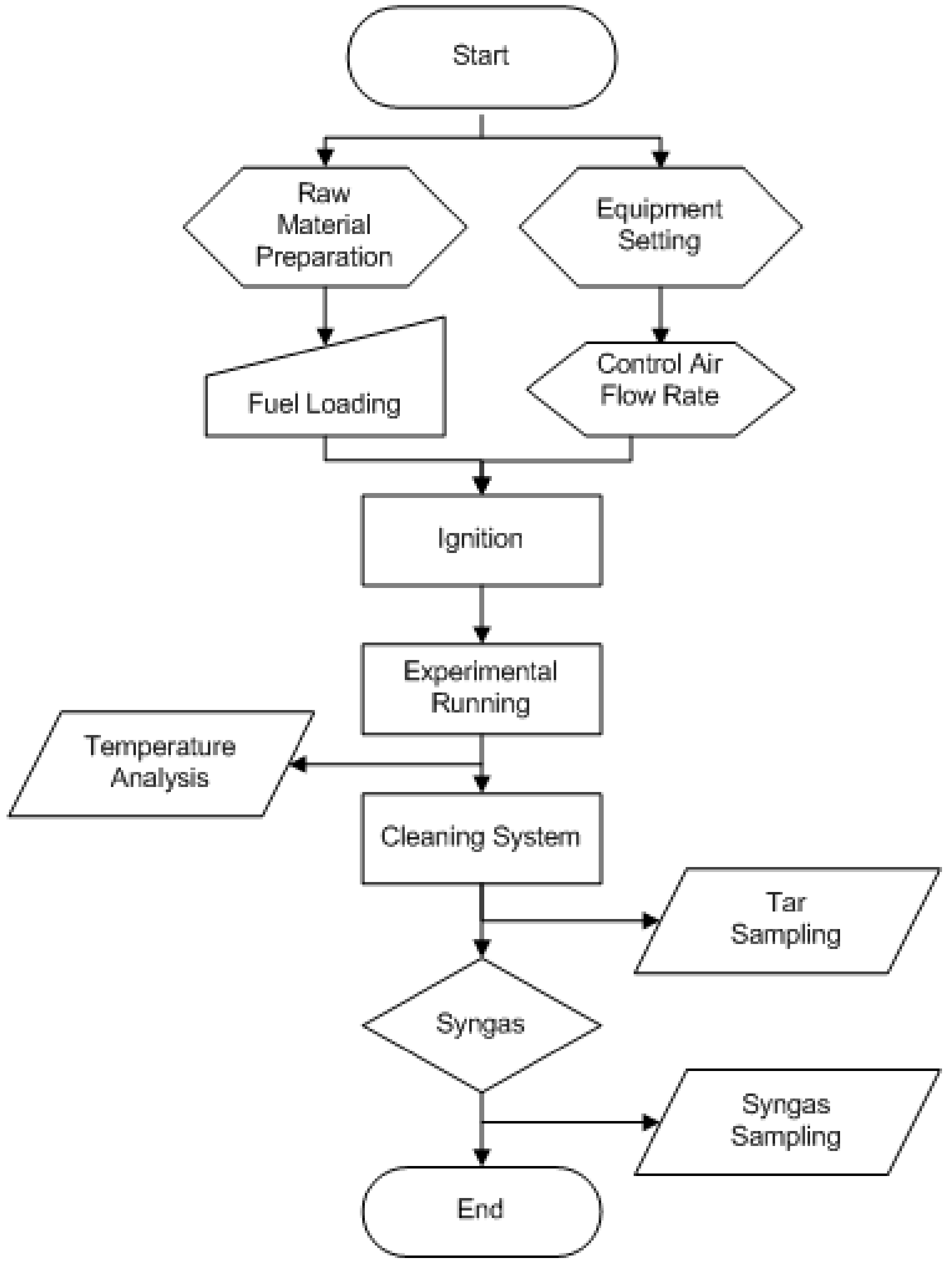
OEA (ThermoFinnigan, Flash EA)

TGA (Perkin Elmer, TGA Phyris 1)

Gasification Equipment



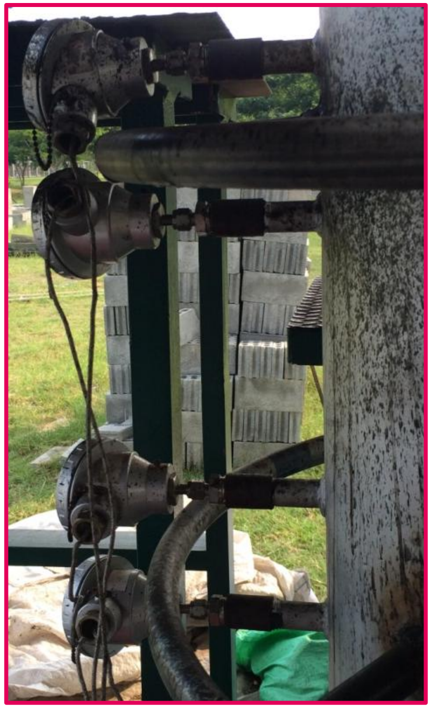
Experiment Procedure



Experimental Set Up

Stage	Total Air Flow (L/min)	Air flow (L/min)			ER
		First Stage	Second Stage	Third Stage	
1	179	179	-	-	0.11
	208	208	-	-	0.13
2	283	132	151	-	0.18
	3554	165	189	-	0.23
	420	193	227	-	0.27
3	293	85	113	95	0.19
	401	127	142	132	0.26
	467	151	179	137	0.30
	543	170	194	179	0.35
	580	179	212	189	0.37

Equipments



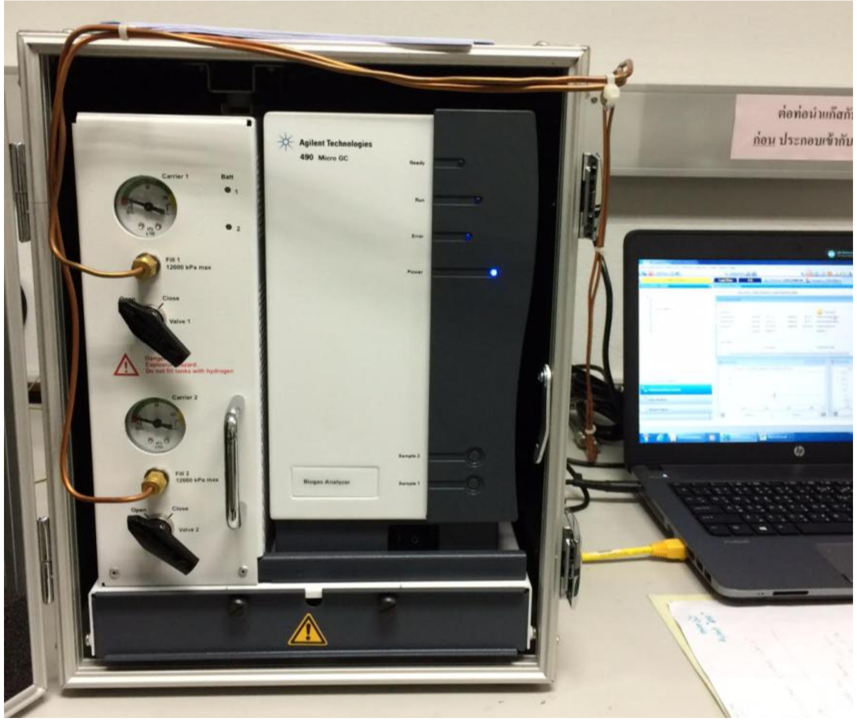
Temperature Measurment

Tar Sampling

Gas Bag

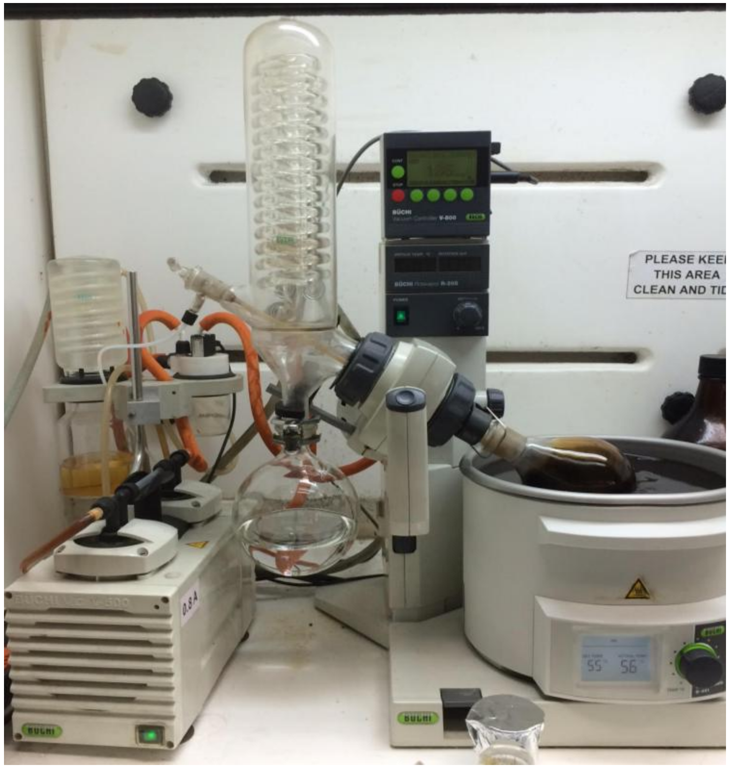
Product Analysis

Producer gas analysis

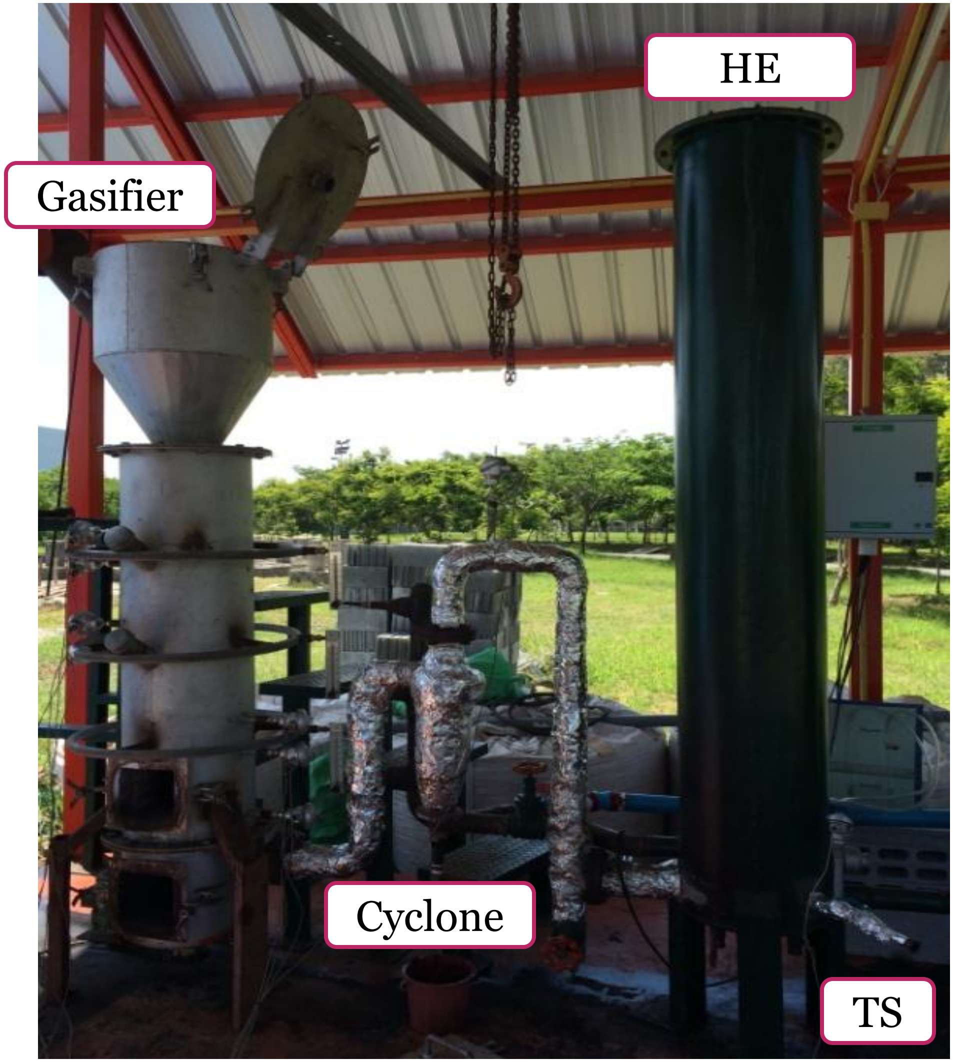


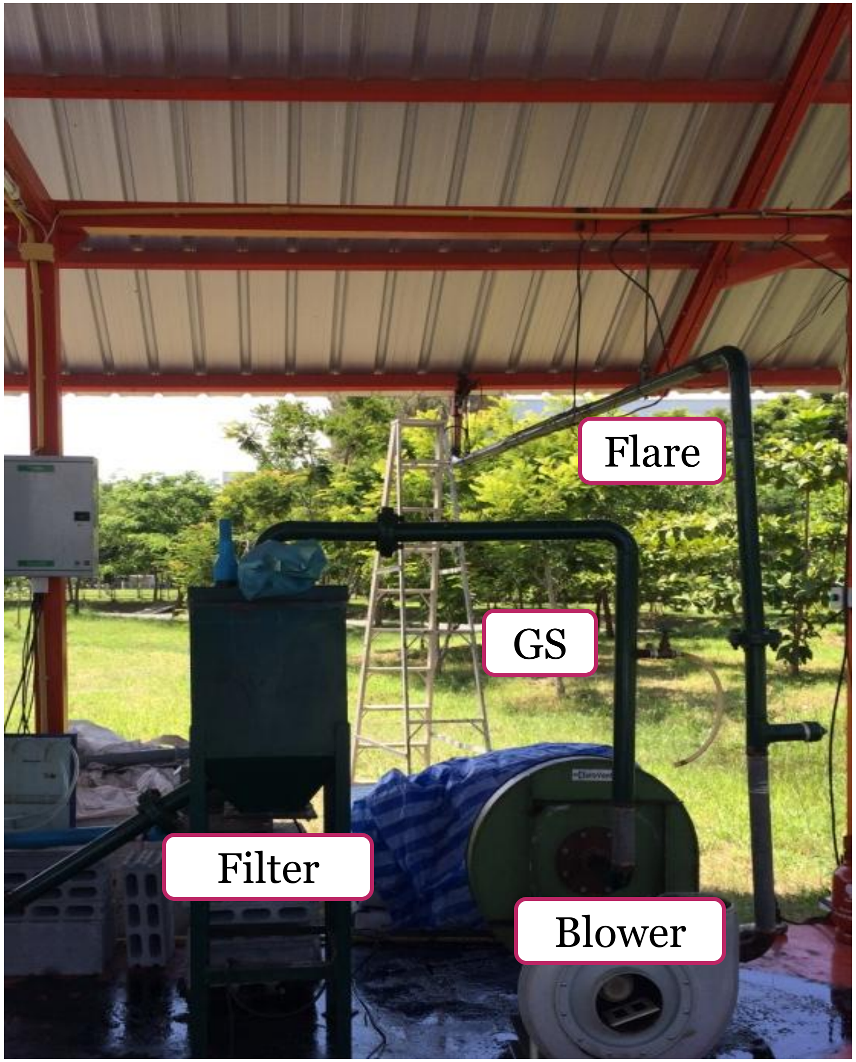
Micro GC, Agilent 490

Tar analysis



Rotary evaporator



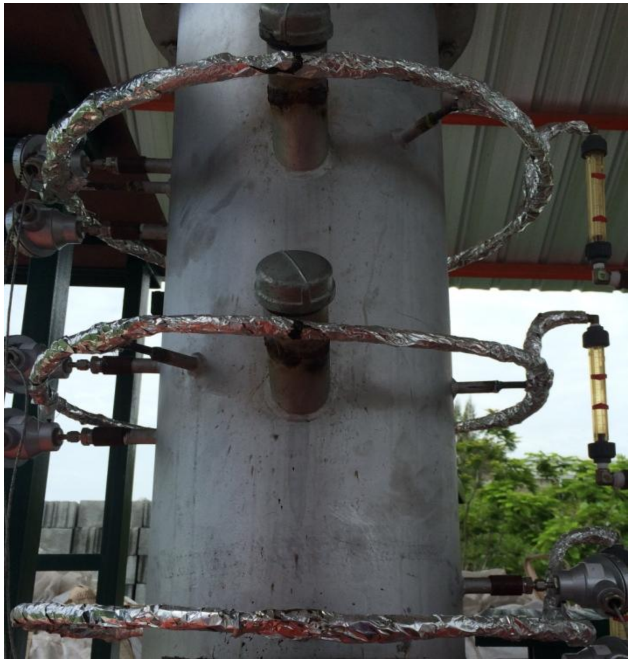


Multistage air supply downdraft gasification system

RESULTS
&
DISCUSSION

Modification

Air inlet pipe



A new bigger air inlet pipe

Modification

The old grate

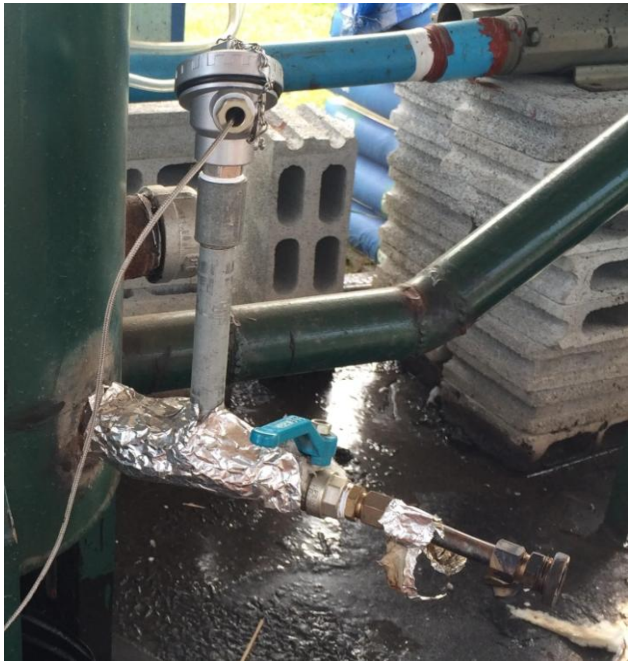
Agitator in grate

New size of grate's hole

Modification

Tar sampling line

A shorter tar sampling line



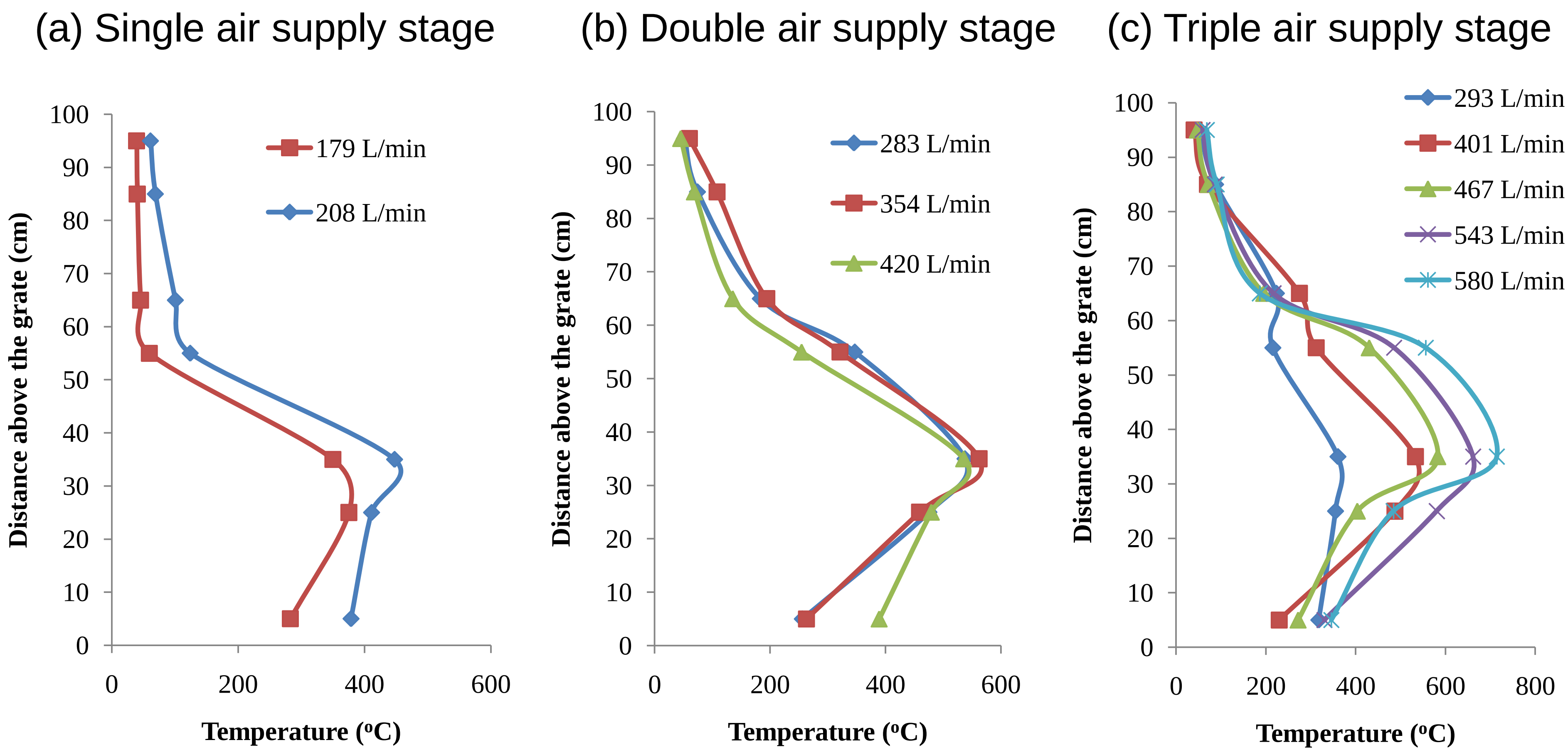
Modification

Air supply line

A by-pass air supply line

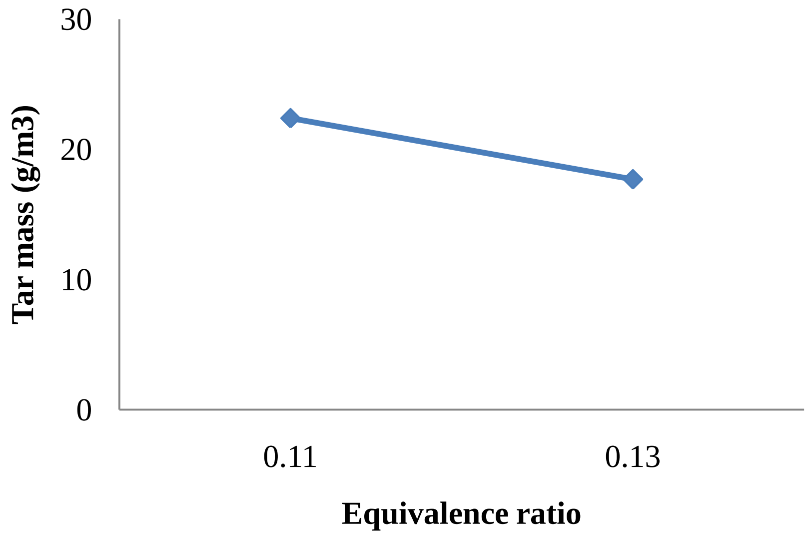
Eucalyptus pellet properties

Ultimate Analysis (wt. %d.a.f)	
Carbon	48.17
Hydrogen	6.02
Oxygen	45.15
Nitrogen	0.66
Proximate Analysis (wt. %dry)	
Volatile matter	66.37
Fixed carbon	12.07
Ash	21.56
Moisture content (wt. % as received)	10.07
HHV (MJ/kg)	14.42
LHV (MJ/kg)	13.46



Temperature profiles along the height of the gasifier

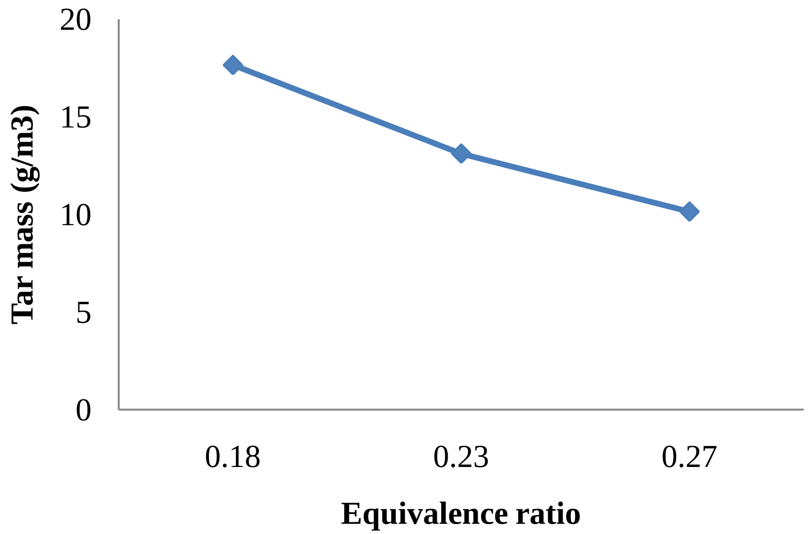
Effect of ER on Tar Quantity



Gravimetric tar in single air supply stage

$$Tar\ content = \frac{m_{tar}}{V_{sampling\ gas}}$$

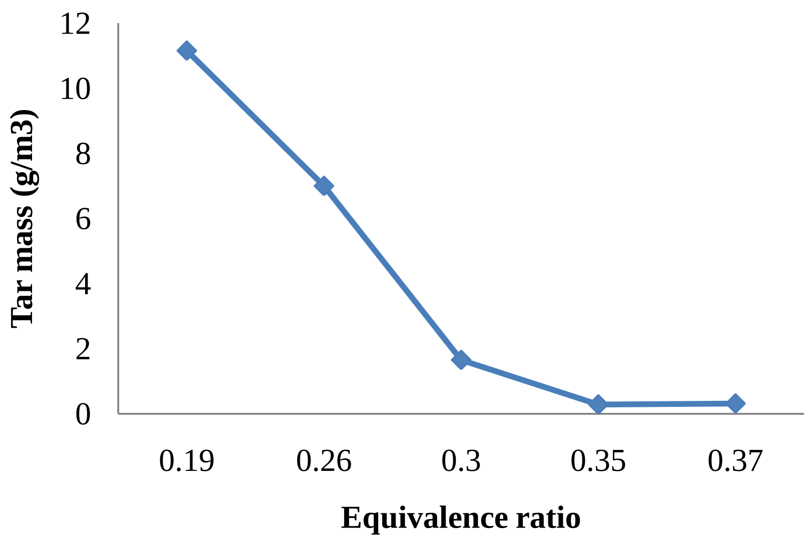
Effect of ER on Tar Quantity



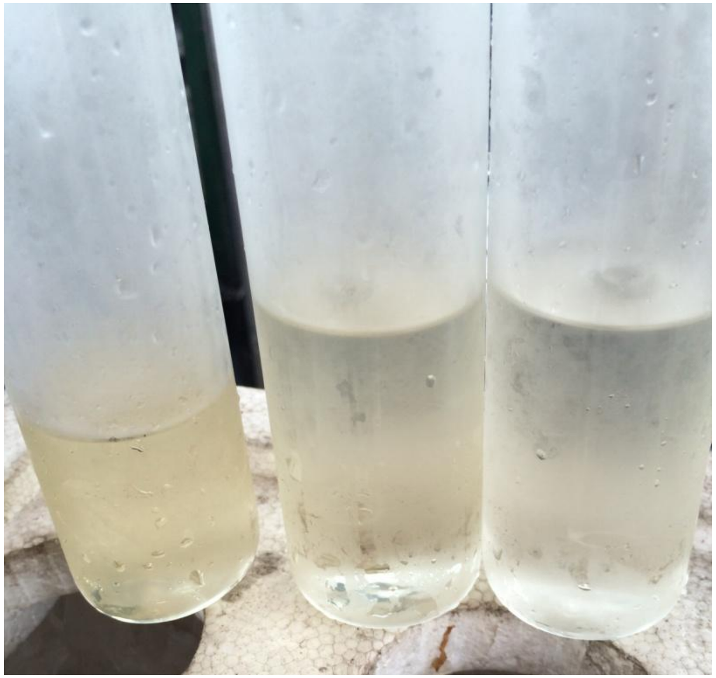
Gravimetric tar in double air supply stage

ER	Tar Content
0.18	17.65
0.23	13.12
0.27	10.15

Effect of ER on Tar Quantity

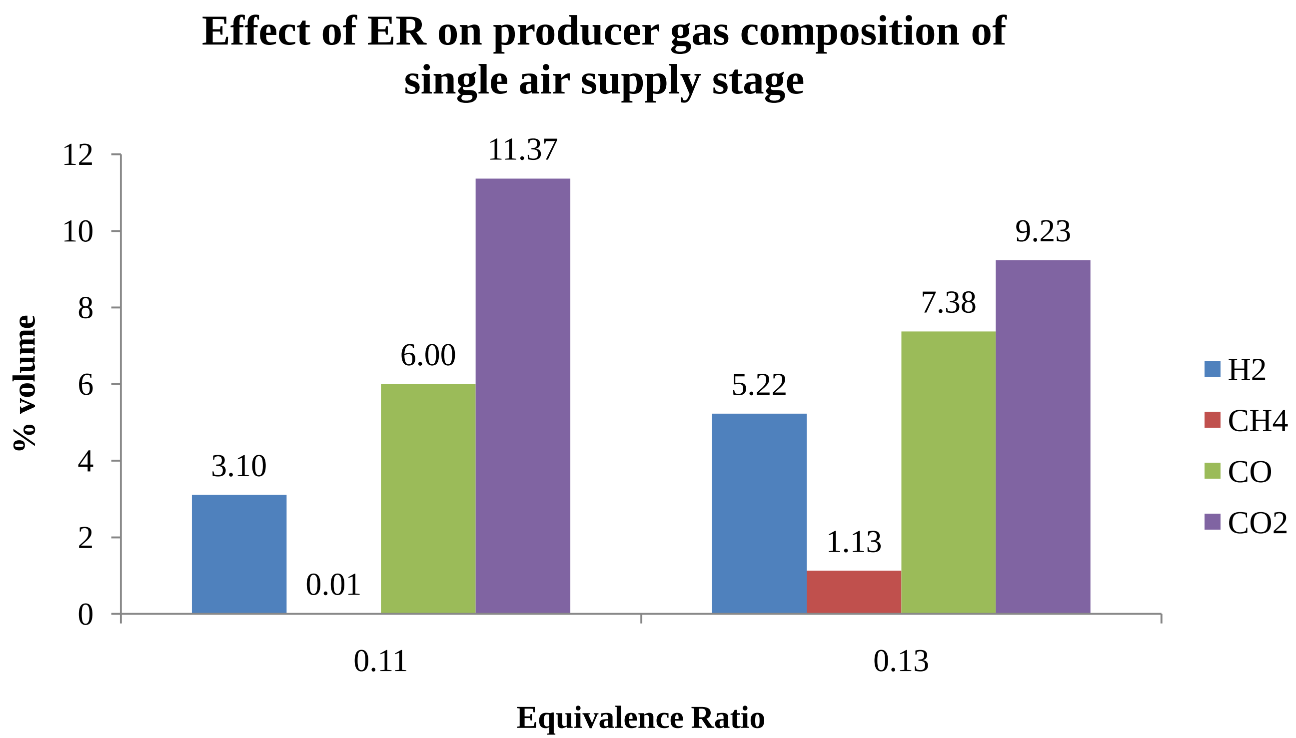


Gravimetric tar in triple air supply stage



Of all single, double and triple air supply stage presented the decreasing of tar along with the increasing of ER. The tar mass of ER 0.11 was 22.4 gr/m^3 and it reduced to 0.31 gr/m^3 of ER 0.37.

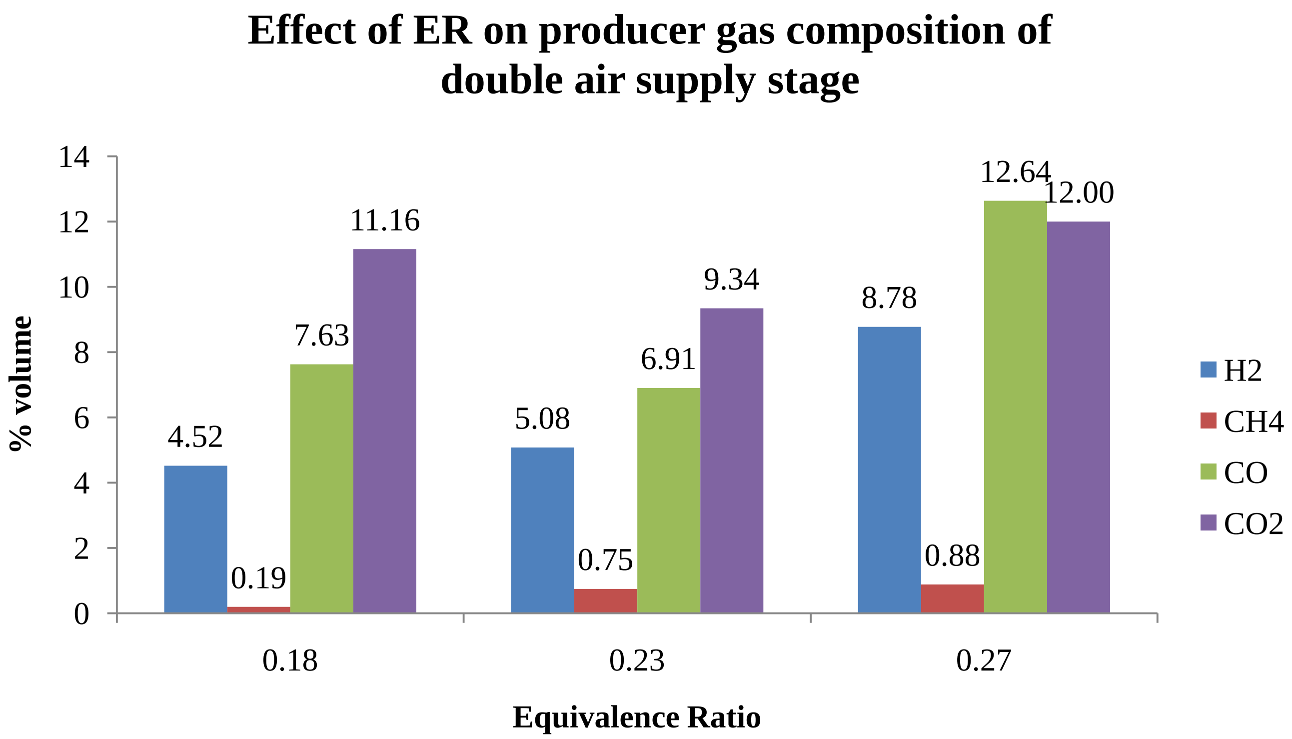
Effect of ER on Producer Gas Composition



ER 0.11 was not suitable for this gasification system. A low air flow rate along with a low ER, resulted a low gasification temperature that made an amount of pellet un-burnt or even has left a lot of char

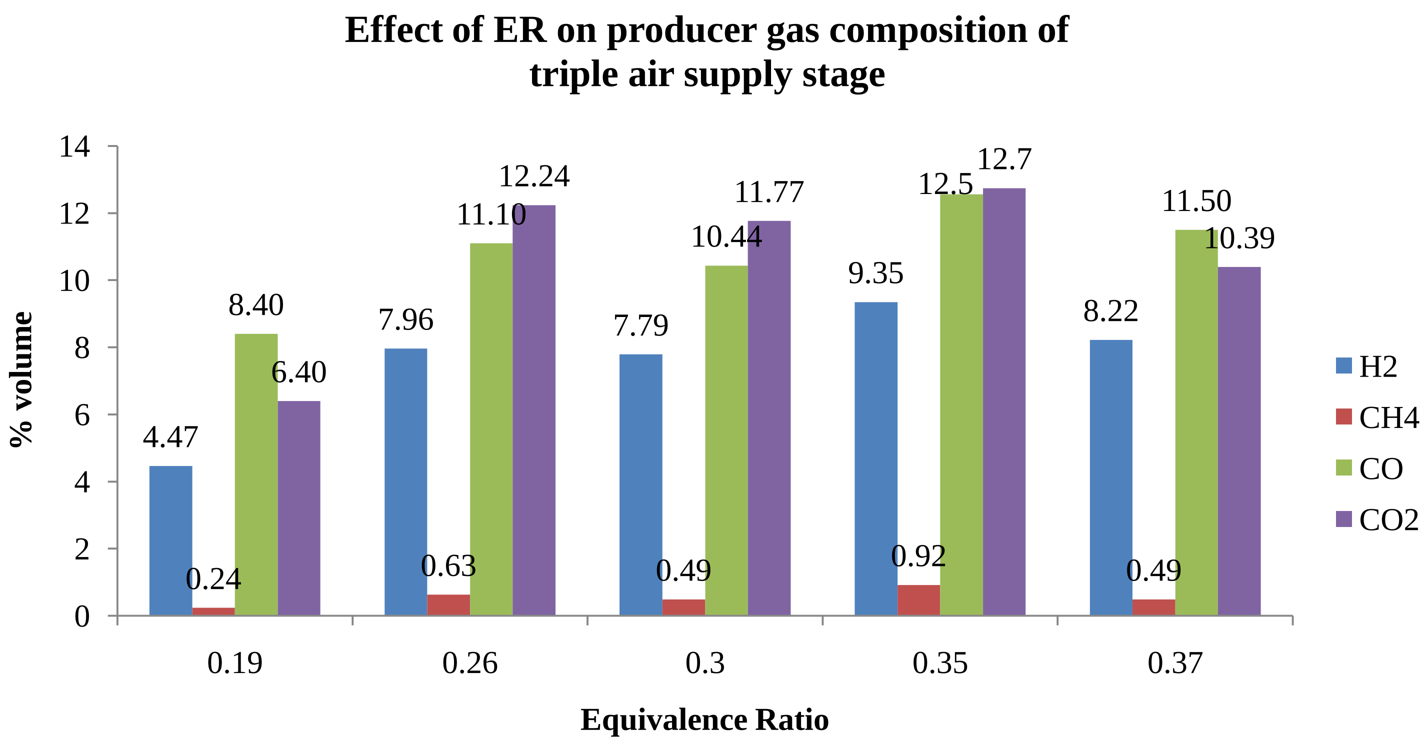
ER 0.13 showed a better result than ER 0.11. Higher producer gas quality was achieved, even the oxygen required still insufficient yet

Effect of ER on Producer Gas Composition



The trend of H_2 increased along with the increasing of ER. As the temperature increased, CO and H_2 could have been expected as dominant products and the trend of CO_2 will almost opposite to CO (Erlich, 2011 & Guo, 2014), however this case was not appear here. Nevertheless, changes in ER cannot be the only explanation for changes in this gasification performance.

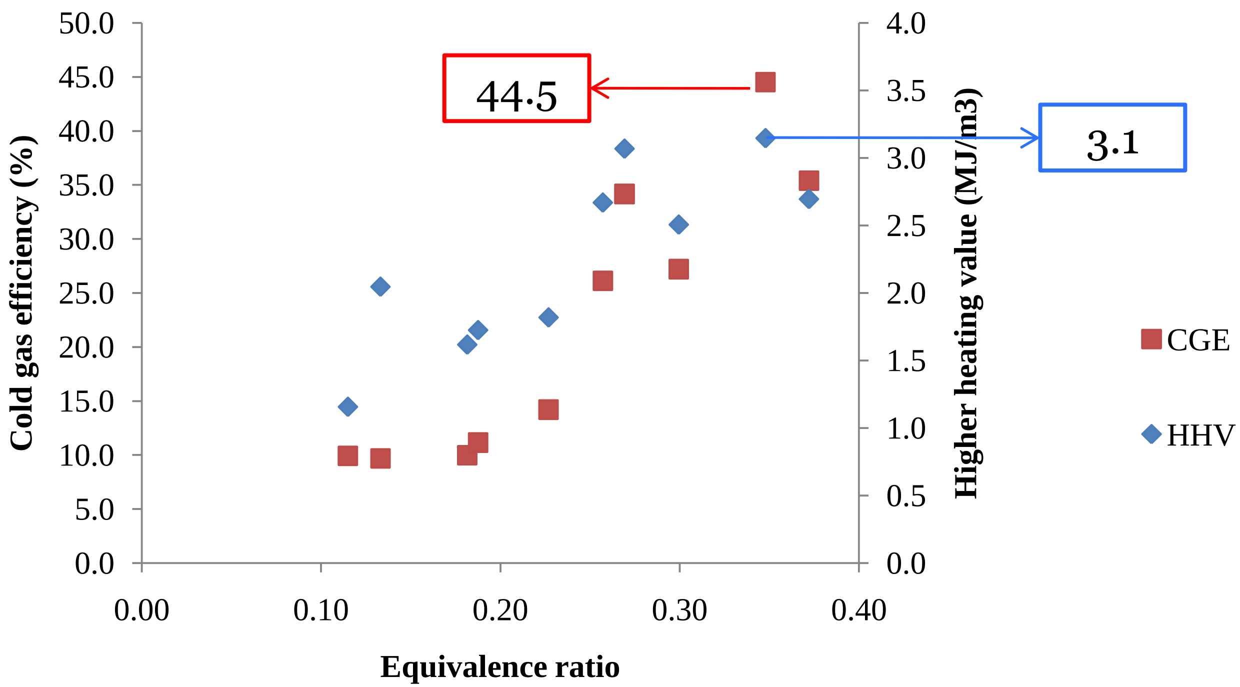
Effect of ER on Producer Gas Composition



The ER range which worked well was 0.27 – 0.35 with CO and H_2 of 12.64%, and 9.35%. H2O and CO2 formed during partial oxidation reactions reacted with the charcoal bed, was favored the Shift and Boudard endothermic reaction. $C + H_2O \leftrightarrow CO + H_2$ and

$C + CO_2 \leftrightarrow 2CO$.

Effect of ER on Cold Gas Efficiency and HHV



Cold gas efficiency is the energy input over the potential energy output.

$$\eta_{cg} = \frac{Q_g M_g}{LHV_f M_f}$$

Where, η_{cg} : Cold-gas Efficiency (%)
Q_g : LHV of product gas (MJ/kg)
M_g : Mass of product gas (kg)
LHV_g : LHV of the solid fuel (MJ/kg)
M_f : Mass of solid fuel (kg)

Higher Heating Value of producer gas is dependent on the percentage quantities of CO, CH_4 and H_2 in producer gas and it can be calculated from the equation:

$$HHVg = Y_{CO}\ HHV_{CO} + Y_{CH4}\ HHV_{CH4} + Y_{H2}\ HHV_{H2}$$

Where, Y = Volume fraction of each gas species that can be obtained from gas analyser
HHV each gas is presented in Table C.2 (Basu, 2010)

Slag & Ash Analysis

Compositions of eucalyptus wood pellet slag	
Compositions	% wt
SiO_2	60
Fe_2O_3	22.5
CaO	6.68
Al_2O_3	5.17
K_2O	2.60

The ash content of most biomass is typically much less than that of coals (<3%), but some forms have a high as content (D0gru, 2002). Proximate analysis of eucalyptus wood pellet showed that the amount of ash was quite high (21.56 % dry basis). So, it can be assumed that sand and soil could be added and mixed with the eucalyptus wood in the making of pellet.

CONCLUSIONS & SUGGESTIONS

Conclusions

- The suitable ER which gave a good gas composition result was 0.27 – 0.35 with CO and H_2 of 12.64%, and 9.35% with higher heating value around 3.1 MJ/m^3. The cold gas efficiency was 44.5%.
- The tar mass was significantly reduced by controlling the equivalence ratio. The tar mass of ER 0.11 was 22.4 gr/m^3 and it reduced to 0.31 gr/m^3 of ER 0.37.
- XRF analysis investigated that slag of eucalyptus wood pellet contents of SiO2, Fe2O3, CaO, Al2O3, etc. it can be assumed that in the making of pellet, sand and soil could be added and mixed with the eucalyptus wood.

Suggestions

1. The fact that single air supply stage could not reach flow rate as high as double or triple air supply stage made it cannot be compared. So, an adjustable air supply pipe with different sizes could help to reach the same air flow rate when run only single stage, double stage or even triple air supply stage.
2. The air flow in each air supply pipe can be varied in order to study the effect of air distribution along the gasifier.
3. Modification of tar sampling equipment such as an additional particle filter can bring down the contamination of solid particles in tar. Tar quality analysis may be required to investigate tar component in each air supply stage.
4. New design of grate and ash removal system might help ash problem to all kind of biomass such as type of rotary grate.
5. Considering that the lab is in the outdoor, keeping the quality and moisture content of raw material is a must especially in rainy season. Some problems with the gasifier such as ash gate that usually get curved when gasifier reach a very high temperature and possibility of gas leakage along the gasifier must be solved. A routine cleaning after finish the experiment and monthly cleaning of whole gasification system can keep the whole gasification efficiency well.

THANKYOU

Gasification Reaction

- Combustion Reactions :
  $C + \frac{1}{2} O_2 \rightarrow CO$ ΔH = -111MJ/kmol (1)
  $CO + \frac{1}{2} O_2 \rightarrow CO_2$ ΔH = -283 MJ/kmol (2)
  $H_2 + \frac{1}{2} O_2 \rightarrow H_2O$ ΔH = -242 MJ/kmol (3)
- The Boudouard Reaction :
  $C + CO_2 \rightarrow 2\ CO$ ΔH = +172 MJ/kmol (4)
- The Water Gas Reaction :
  $C + H_2O \rightarrow CO + H_2$ ΔH = +131 MJ/kmol (5)
- The Methanation Reaction :
  $C + 2\ H_2 \rightarrow CH_4$ ΔH = -75 MJ/kmol (6)
- Water – gas Shift Reaction :
  $CO + H_2O \rightarrow CO_2 + H_2$ ΔH = -41 MJ/kmol (7)
- The Steam Methane Reforming Reaction :
  $CH_4 + H_2O \rightarrow CO + 3\ H_2$ ΔH = +206 MJ/kmol (8)
- CO_2 Reforming Reaction :
  $CH_4 + CO_2 \rightarrow 2\ CO + 2\ H_2$ ΔH = +247 MJ/kmol (9)

Fuel Feed Rate $M_f = \frac{Q}{LHV_{bm}\eta_{gef}}$

$$ER = \frac{(wt\ of\ air/wt\ of\ fuel)_{actual}}{(wt\ of\ air/wt\ of\ fuel)_{stoiciometri}}$$

Syngas flow Rate $V_g = \frac{Q}{LHV_g}\ Nm^3/s$

Tar content = $m_{tar}\ V_{sampling\ gas}$

$$HHV_g = Y_{CO}\ HHV_{CO} + Y_{CH4}\ HHV_{CH4} + Y_{H2}\ HHV_{H2}$$

Cold gas efficiency is the energy input over the potential energy output.

$$\eta_{cg} = \frac{Q_g M_g}{LHV_f M_f}$$

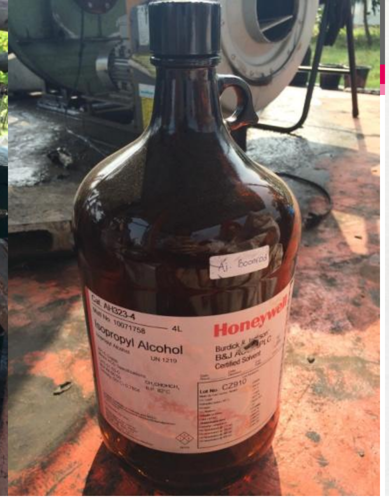
Where, η_{cg} : Cold-gas Efficiency (%)
Q_g : LHV of product gas (MJ/kg)
M_g : Mass of product gas (kg)
LHV_g : LHV of the solid fuel (MJ/kg)
M_f : Mass of solid fuel (kg)

Hot gas efficiency is taking the sensible heat of the hot gas into account.

$$\eta_{hg} = \frac{Q_g M_g + M_g C_p (T_f - T_o)}{LHV_f M_f}$$

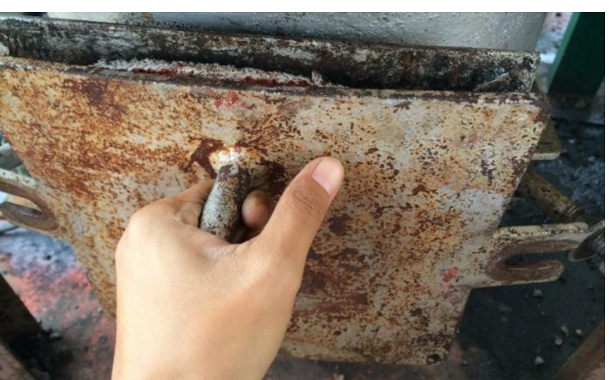
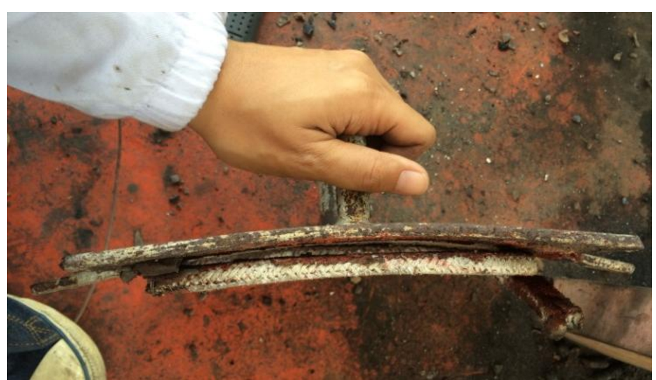
Where, η_{hg} : Hot-gas Efficiency (%)
Q_g : LHV of product gas (MJ/kg)
M_g : Mass of product gas (kg)
C_p : Specific Heat of gas (kJ/kmol.K)
T_f : The gas temperature at the gasifier exit (K)
T_o : The temperature of fuel entering the gasifier (K)
LHV_g : LHV of the solid fuel (MJ/kg)
M_f : Mass of solid fuel (kg)

Comparison of Tar Production in 3 Gasifications Medium			
Medium	**Operating Condition**	**Tar Yield (g/Nm^3)**	**LHV (MJ/ Nm^3 dry)**
Steam	S/B = 0.9	30 – 80	12.7 – 13.3
Steam and Oxygen	GR = 0.9	4 – 30	12.5 – 13.0
Air	ER = 0.3	2 – 20	4.5 – 6.5



Isopropyl Alcohol

Mode
testo 606-1
testo




Description	1S_380SCFH	1S_440SCFH	2S_600SCFH	2S_750SCFH	2S_890SCFH	3S_620SCFH	3S_850SCFH	3S_990SCFH	3S_1150SCFH	3S_1230SCFH
Feed of Raw Material (kg)	19	19	19	19	19	19	19	24	24	24
Air flow rate (SCFH)	380	440	600	750	890	620	850	990	1150	1230
Air flow rate (L/min)	179	208	283	354	420	293	401	467	543	580
ER	0.11	0.13	0.18	0.23	0.27	0.19	0.26	0.30	0.35	0.37
H_2	3.1042	5.2247	4.5224	5.0791	8.7781	4.4656	7.9645	7.7888	9.3502	8.2205
CH_4	0.0088	1.125	0.1931	0.75	0.8833	0.2365	0.6298	0.4865	0.9189	0.4865
CO	6	7.375	7.6304	6.9063	12.6363	8.4007	11.0992	10.4375	12.5625	11.5
CO_2	11.3654	9.2340	11.1553	9.3427	12.0032	6.3987	12.2364	11.7663	12.7456	10.3914
Tar (gr/m3)	22.4	17.7	17.65	13.12	10.15	11.16	7	1.65	0.28	0.31
Char + Ash (kg)	2.05	7.45	3.9	3.3	2.9	3.2	3	4.75	1.15	3
Slag (kg)	very little	0.65	1	1.6	0.95	1.5	1.9	1.3	4.45	3.2
Unburnt (kg)	10.15	very little	-	-	-	-	-	-	-	-
LHV (MJ/m3)	1.0965	1.8990	1.5217	1.6898	2.8610	1.6284	2.4881	2.3342	2.9262	2.5150
HHV	1.1571	2.0456	1.6172	1.8185	3.0669	1.7246	2.6681	2.5050	3.1447	2.6943
Carbon Conversion into gas product (%)	22.2431	12.5517	17.5001	19.8428	42.5424	14.5244	35.1039	36.8638	55.5536	43.9853
Cold Gas Efficiency (%)	9.8963	9.6724	9.9622	14.1810	34.1511	11.1293	26.1081	27.1878	44.4988	35.3781
Hot Gas Efficiency (%)	27.1114	25.8727	25.6223	30.2787	53.0352	28.6468	44.7070	46.4545	64.6133	55.6153