APPENDIX A

DESIGN GASIFIER SYSTEM

The Details of Gasifier Design

1. Design of downdraft gasifier

The parameter of designing downdraft gasifier

a) Diameter of Throat

b) Diameter of Fuel Hopper

c) Length of Reduction Zone

d) Nozzle Area

e) Airflow Rate

Given Heating value of LPG = 46.72 MJ/kg

Heat required = 46.72x5.9

= 275.6 MJ/kg

1.1. Gasifier Volume

Given Working time	= 5	hr
Energy Require	= 276	MJ
Energy Rate	= 55.2	MJ/hr
Gas Heating value of mushroom substrate waste	= 3.81	MJ/Nm^3
Gas Flow rate	= 55.2/3.8	Nm^3/hr
	= 14.53	Nm^3/hr
	= 0.00404	Nm^3/s
A producer gas of 1 kg mushroom substrate waste	= 1.92	Nm^3
Fuel consumption Rate	= 14.53/1.92	kg/hr
	= 7.57	kg/hr
Mushroom substrate waste total require	= 7.57x5	
	= 37.85	kg
Bulk Density of mushroom substrate waste	= 238.8	kg/m^3
Mushroom substrate waste Volume	= 37.85/238	m^3

$= 0.16 \quad m^3$

Given $h = 2.d$

Diameter of Hopper $d = \{0.16x2/(22/7)\}^{1/3}$

$= 0.467 \quad m$

Height of Hopper $h = 2x0.467 \quad m$

$= 0.934 \quad m$

1.2. Designing of Throat

Gas Flow rate = 14.53 Nm^3/hr

Hearth load for downdraft of double throat design = 0.3-0.9 $Nm^3/hr\text{-}cm^2$ [29]

Hearth load = 0.5 $Nm^3/hr\text{-}cm^2$

Throat area = 14.53/0.5 cm^2

= 29.06 cm^2

Diameter of throat = 6.08 cm

Design 20% increase = 7.30 cm

1.3. Designing of Nozzle

Oyster mushroom substrate waste require = 37.85 kg

The appropriate air require of oyster mushroom substrate waste = 2.23 kg.Air/kg.Fuel

Air require = 37.85x2.23

= 84.4 kg

Airflow rate = 84.4/5 kg/hr

= 16.88 kg/hr

Air mass flow rate = 0.0047 kg/s

Density of air at 30 °C, 1 atm = 1.16 kg/m^3

Air Volume flow rate = 0.0047/1.16

= 0.0041 m^3/s

Combustion air velocity = 15-30 m/s [29]

Given airflow rate = 20 m/s

Area of air duct = 0.0041/(1.16x20)

= $1.77x10^{-4}$ m^2

Assume using 6 nozzles = $2.95x10^{-5}$ m^2

Diameter of nozzles = 6.13 mm

Designing 10% increase = 6.74 mm

1.4. Gap of Nozzle and Throat

From Design guideline of Imbert Gasifier

Gap of nozzle and throat = 0.5-1.4 Throat diameter

For small Gasifier(<50 kW) [34]

Gap of Nozzle and Throat ≅ Throat diameter

Therefore gap of nozzle and throat = 7.3 cm

Designing of Reduction zone

For small Gasifier (<50 kW) [34]

Reduction zone length ≅ 3xThroat diameter

Therefore reduction zone length = 21.9 cm

1.5. Designing of Combustion zone

For Swedish design rules

Combustion zone ≅ 2-4 x Throat diameter

Assume combustion zone = 3 x Throat diameter

= 21.9 cm

2. Design of Cyclone

Parameter of cyclone designing

a) Gas outlet temperature to cyclone

b) Gas flow rate to cyclone

c) Gas velocity to cyclone

Producer gas flow rate = 14.53 Nm^3/hr

= 0.00404 Nm^3/s

Assume gas outlet temperature to cyclone = 200 °C (473 K) Nm^3/s

Ideal gas theory

PV/T = const.

Given P = const.

Gas flow rate to cyclone, Q = 0.00404x(473/303)

= 0.00631 m^3/s

Given Gas velocity in cyclone, v = 15 m/s [7]

Q = vA

Area inlet cyclone, A = 0.00631/15

= 0.000421 m^2

= 4.21 cm^2

Therefor select Area inlet cyclone = 2x4 cm

Gas velocity in cyclone = $0.00631/(2x4x10^{-4})$

= 7.88 m/s

3. Burner Design

Given a producer gas flow rate = 14.53 Nm^3/hr

= 0.00404 Nm^3/s

Diameter of duct = 38.1 mm

A = $\pi(d^2)/4$

	=	$\pi(0.0381^2)/4$	
	=	1.14×10^{-3}	m^2
v	=	$0.00404/1.14 \times 10^{-3}$	
	=	3.54	m/s
Given gas velocity in burner	=	1.5	m/s
vA	=	Constant	
A	=	$3.54 \times 1.14 \times 10^{-3}/1.5$	
	=	2.69×10^{-3}	m^2
d	=	5.85	cm

The diameter of burner 5.85 cm (Cyclone Style)

APPENDIX B

AIRFLOW RATE CALCULATION

Gasifier Airflow Rate Calculation

The inlet airflow rate to gasifier is measured by using Orifice plate, which can be calculated by Linford 1961 Equation.[35]

$$Q = 0.127 C_d A_2 E \sqrt{h_d^4/\rho}$$

Where

Q = Airflow Rate, ft^3/s

C_d = Drag Coefficient

A_1 = Air Duct area, in^2

A_2 = Orifice Plate area, in^2

$E = 1/\sqrt{(1-n)}$, $n = A_1/A_2$

h_d = Difference of waste Level in Manometer, in

ρ = Fluid Density, lb/ft^3

Calculation sample

Given, Airflow rate = 3×10^{-3} m^3/s (= 0.105 ft^3/s)

At 30 °C, ρ_{air} = 1016 kg/m^3

$\nu_{air} = 15.73 \times 10^{-6}$ m^2/s

Orifice area, $A_2 = \pi(0.0264^2)/4$

$= 5.49 \times 10^{-4}$ m^2 (= 0.85 in^2)

$Q = vA$

$v = 0.003/5.49 \times 10^{-4}$

$= 5.46$ m/s

$R_e = vD/\nu_{air}$

$= 5.46 \times 0.0264/15.73 \times 10^{-6}$

$= 9.16 \times 10^4$

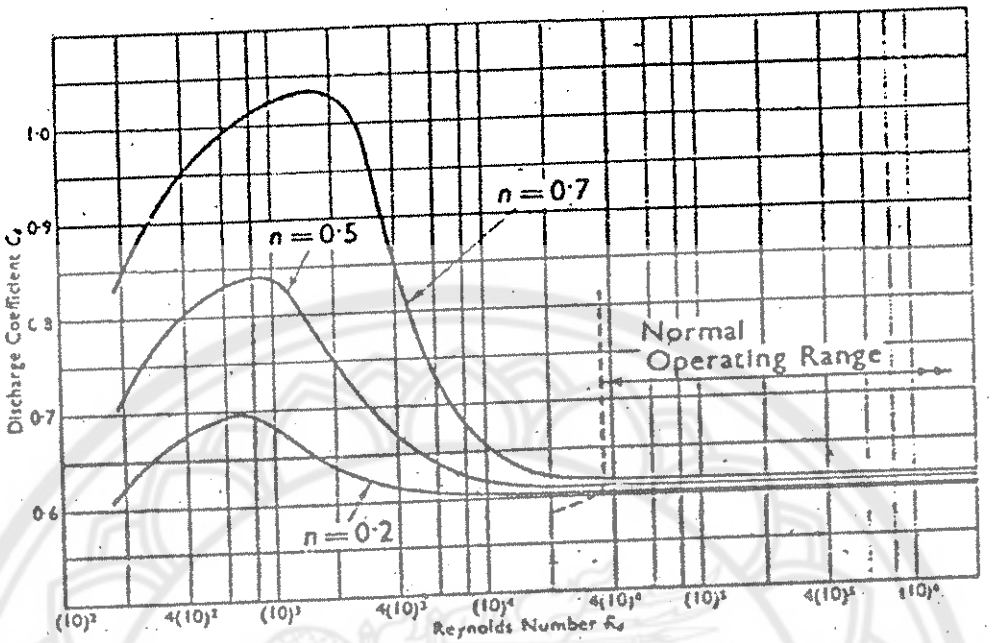

Figure 37 Curves relating discharge Coefficient [35]

Which using curves relating discharge coefficient with Reynolds Number for Orifice plate.

Therefore,

$$n = 26.4/52.7$$
$$= 0.5$$
$$C_d = 0.62$$
$$E = 1/(1-n)^{0.5}$$
$$= 1.414$$

Substitutes into Eq. (1)

$$0.105 = 0.127(0.62)(0.85)(1.414)\sqrt{h_d^4/0.072}$$
$$h_d = ((0.105)(0.072)^{0.5}/(0.127)(0.62)(0.85)(1.414))^{0.5}$$
$$= 0.543 \quad \text{in}$$
$$= 13.80 \quad \text{mm}$$

Similarly, given airflow rate at $5x10^{-3}$ and $7x10^{-3}$ m^3/s, the water difference levels in manometer are obtained as 16.33 mm, 19.47 mm, respectively.

APPENDIX C

APPROPRIATE AIR IN A PRODUCER GAS PRODUCTION

Table 11. Oyster mushroom substrate waste ultimate analysis

Ultimate Analysis (%)	
Carbon	35.26
Hydrogen	2.75
Oxygen	36.91
Nitrogen	0.47
Sulfur	0.52
Ash	13.83

Source: EGAT, Mae Moh, Lampang Service

Table 12. Oyster mushroom substrate waste substance analysis

Substance	% wt	kg(kg/mole)	mole	mole/mole of C
C	35.26	35.26/12	2.94	1.0
H	2.75	2.75/1	2.75	0.94
O	36.91	36.91/16	2.31	0.79
N	0.47	0.47/14	0.034	0.012
S	0.52	0.52/32	0.016	0.0054

Therefore, the chemistry formula of oyster mushroom substrate waste may be written as

$$CH_{0.94}O_{0.79}N_{0.012}S_{0.0054}$$

The complete combustion equation is

$$C_AH_BO_CN_DS_E + [\,A + B/4 + E - C/2\,]\,O_2 + (\,0.79/0.21\,)\,[\,A + B/4 + E - C/2\,] \rightarrow$$

$$[A]\ CO_2 + [B/2]\ H_2O + [[(0.79/0.21)[A + B/4 + E - C/2] + D]\ N_2 + \text{Heat}$$

The appropriate air in theory may be written as

$$[CH_{0.94}O_{0.79}N_{0.012}S_{0.0054}] + [XO_2 + 3.76XN_2]$$

Where, $X = 1 + (0.94/4) + 0.0054 - (0.79/2) = 0.845$

$$[CH_{0.94}O_{0.79}N_{0.012}S_{0.0054}] + [(0.845)\ O_2 + 3.76\ (0.845)\ N_2]$$

kg/kg mole; 13.28 27.04 + 88.96

1 8.73

Therefore, 1 kg of mushroom substrate waste require appropriate air for complete combustion in theory are 8.73 kg

Given, Equivalent ratio = 0.255 [7]

The appropriate air in a producer gas production of fuel = 0.25 x 8.73

= 2.23 kg

1 kg of fuel require air = 2.23 kg

Therefore, air/fuel ratio, A/F = 2.23/1

= 2.23 kg. Air/kg Fuel

Air at 30 °C 1 atm, density (ρ) = 1.16 kg/m^3

Require air for a producer gas production = 2.23/1.16

= 1.92 kg. Air/kg Fuel

APPENDIX D

GASIFIER TEMPERATURE EXPERIMENTS WITH VARIABLE AIRFLOW RATE

Table 13 Gasifier Temperature at Airflow Rate $3x10^{-3}$ m^3/s

Time (min)	T_1 (°C)	T_2 (°C)	T_3 (°C)	T_4 (°C)	T_5 (°C)
0	39.2	39.4	39.6	34.2	35.2
20	204.5	140.5	87.6	34.1	81.6
40	263.4	205	109.7	33.9	100.6
60	321.6	280.1	121.4	33.7	156.5
80	354.1	299.5	125.7	34	153.8
100	395.6	309.5	135.1	33.6	163.4
120	382.6	284.7	117.8	33.7	115.5
140	432.2	312.6	120.5	33.6	125.6
160	488.5	357.6	108.7	34.1	214.6
180	569.4	412.6	128.3	33.9	227.5
200	647.9	473.7	134.7	34.1	186.7
220	701.4	556.3	130.1	33.7	183.2
240	704.2	604.8	127.4	33.8	176.4
260	845.6	712.1	134.2	33.5	240.4
280	901.4	721.4	134.5	33.8	251.7
300	912.2	749.8	136.5	33.6	214.9

Table 14 Gasifier Temperature at Airflow Rate $5x10^{-3}$ m^3/s

Time(min)	T_1 (°C)	T_2 (°C)	T_3 (°C)	T_4 (°C)	T_5 (°C)
0	39.2	39.1	39.7	34.1	39.2
20	304.1	150.6	89.1	34.8	104.2
40	289.5	201.3	108.6	34.5	119.5
60	347.5	290.4	110.4	34.1	128.3
80	378.9	294.2	114.5	33.8	152.4
100	401.7	357.6	128.6	33.9	163.5
120	456.8	344.9	132.5	34	169.4
140	577.4	421.7	147.6	34.1	176.5
160	670.8	488.3	139.4	34.2	182.1
180	684.2	483.9	115.6	33.4	161.3
200	690.7	485.6	124.8	33.8	176.5
220	780.6	530.7	125.8	33.1	234.7
240	880.9	623.4	135.4	33.5	251.6
260	954.7	714.9	128.4	33.9	263.5
280	920.4	750.4	122.6	33.6	256.4
300	917.5	759.4	119.5	33.8	246.1

Table 15 Gasifier Temperature at Airflow Rate 7×10^{-3} m^3/s

Time(min)	T_1 (°C)	T_2 (°C)	T_3 (°C)	T_4 (°C)	T_5 (°C)
0	39.7	39.4	40.8	34.2	40.2
20	201.5	145.2	104.5	34.1	101.6
40	256.4	170.4	116.1	33.8	140.3
60	389.4	264.4	121.2	33.9	149.5
80	507.6	321.4	124.3	33.5	152.4
100	405.6	331.4	98.9	33.6	140.1
120	574.1	351.2	116.5	33.6	175.3
140	633.4	463.4	135.1	33.8	188.1
160	674.9	465.8	131.2	33.8	184.5
180	759.1	540.1	136.7	33.9	214.5
200	789.4	553.4	120.9	34.1	217.3
220	845.3	682.4	123.8	34	235.9
240	897.1	704.6	129.4	33.8	304.6
260	975.1	754.2	135.6	33.9	312.7
280	977.1	758.9	135.9	33.7	302.1
300	947.1	798.5	128.6	33.8	298.6

APPENDIX E

MUSHROOM AGAR MEDIA STERILIZATION EXPERIMENTS

Table 16 Oyster Mushroom Agar Media Sterilization Experiment 1

Time (min)	T_1 (°C)	T_2 (°C)	T_3 (°C)	T_4 (°C)	T_5 (°C)	T_6 (°C)	P_s (lb/in^2)
0	39.7	39.5	39.4	34.7	39.6	49.4	0
20	298.6	140.2	101.5	34.8	96.4	103.3	1.5
40	305.8	187.5	99.7	34.5	108.2	104.4	2
60	299.5	201.4	101.7	34.7	113.9	106.7	4
80	475.8	368.4	118.6	34.1	185.1	111.1	7.5
100	524.6	437.1	124.8	33.8	201.8	117.7	12
120	531.7	455	124.7	33.7	201.7	121.7	15.5
140	687.2	532.5	143.9	34.1	246.3	122.2	16
160	658.2	560.4	131.2	33.8	263.4	122.9	16.5
180	634.5	563.4	131.7	33.4	291.5	123.8	17
200	705.3	611.2	139.4	34	294.8	124.4	18
220	694	604.3	131.2	33.5	295	124.4	18
240	798.4	663.7	119.3	33.1	262.4	122.8	17
260	862.7	681.5	118	34.2	287.4	122.9	16.5
280	962.9	731.8	125.5	33.5	289.8	122.8	17
300	914.3	726.4	125.3	32.8	252.1	122.2	16

Table 17 Oyster Mushroom Agar Media Sterilization Experiment 2

Time (min)	T_1 (°C)	T_2 (°C)	T_3 (°C)	T_4 (°C)	T_5 (°C)	T_6 (°C)	P_s (lb/in^2)
0	39.8	39.2	40.1	34.5	39.1	49.4	0
20	202.4	112.7	82.1	34.6	87.9	101.6	1
40	290.8	204.1	105.8	34.4	137.2	104.4	2
60	303.2	286.3	101.6	34.1	177.4	107.8	4.5
80	436.4	336.9	107.5	33.6	184.8	116.6	11
100	514.3	402.8	115.6	33.2	193.5	122.2	16
120	564.6	480.3	117.6	33.2	207.7	122.8	16.5
140	594.9	491.1	104.8	33.2	256.6	121	15
160	602.8	550.2	134.7	32.9	264.2	121.7	15.5
180	644.4	602.2	136.2	32.7	302.5	123.9	17.5
200	660.1	598.5	130.7	31	297.9	124.4	18
220	670.5	621.2	110.2	32.1	298.1	124.4	18
240	681.7	625.8	120.3	31.1	297.4	122.8	16.5
260	721.5	632.1	118.6	31.4	245.6	122.8	16.5
280	834.1	660.9	117.5	30.4	254.3	121.7	15.5
300	912.4	701.5	118.5	32.1	258.4	121.7	15.5

Table 18 Oyster Mushroom Agar Media Sterilization Experiment 3

Time (min)	T_1 (°C)	T_2 (°C)	T_3 (°C)	T_4 (°C)	T_5 (°C)	T_6 (°C)	P_s (lb/in^2)
0	39.4	39.3	39.8	34.1	39.6	49.4	0
20	195.6	108.5	89.5	34.5	91.2	101.6	1
40	295.3	201.1	104.7	34.2	128.9	108.9	5
60	354.6	268.5	107.6	34.3	187.6	110.5	6.5
80	472.4	355.8	120.5	33.8	186.7	115.5	10
100	468.9	355.6	118.2	33.5	178.4	116.6	11
120	556.7	471.3	119	33.6	212.5	121.7	15.5
140	615.8	504.6	121.3	33.9	257.1	122.2	16
160	689.7	525.8	121.4	33.5	260.3	122.9	16.5
180	742.5	602.2	128.4	32.9	286.7	124.4	18
200	796.1	611.2	129	32.4	297.9	123.9	17.5
220	851.7	623.4	127.4	32.9	297.9	122.9	16.5
240	879.8	625.1	123	33.4	278.5	123.8	17
260	965.7	702.6	128.5	32.9	264.8	123.8	17
280	984.3	694.5	126.1	33.1	253.7	124.4	18
300	896.9	687.5	122.9	32.6	258.4	122.2	16

APPENDIX F

MUSHROOM SUBSTRATE PASTEURIZATION EXPERIMENTS

Table 19 Oyster Mushroom Substrate Pasteurization Experiment 1

Time (min)	T_1 (°C)	T_2 (°C)	T_3 (°C)	T_4 (°C)	T_5 (°C)	T_6 (°C)
0	39.4	39.2	39.5	34.3	39.3	26.4
20	209.1	124.5	91.5	34.2	99.4	45.4
40	345.6	254.8	102.1	34.1	108.3	68.3
60	441.8	351.7	154.2	33.2	114.1	80.4
80	479.1	380.2	161	34.1	118.4	98.7
100	480.6	379.8	147.6	33.1	115.4	100
120	504.6	431.5	154.7	34.1	121.4	100
140	521.8	428.2	111.8	33.4	118.2	100
160	569.1	432.8	120	33.8	123.1	100
180	618.3	474.1	118.5	33.9	125	100
200	702.5	501.5	99.6	32.8	145.2	100
220	784.6	564.3	141.2	32.6	162.4	100
240	747.2	522.4	108.9	33.1	200.6	100
260	791.6	608.5	99.4	34	239.2	100
280	884.6	647.2	124.4	32.4	247.6	100
300	902.4	702.3	124.3	33.1	224.3	100

Table 20 Oyster Mushroom Substrate Pasteurization Experiment 2

Time (min)	T_1 (°C)	T_2 (°C)	T_3 (°C)	T_4 (°C)	T_5 (°C)	T_6 (°C)
0	39.2	39.8	39.5	34.1	39.3	26.8
20	218.4	112.9	84	34.2	98.4	48.2
40	302.3	243.8	98.1	34.4	102.3	69.7
60	411.2	261.7	124.5	33.2	105.7	78.5
80	442.5	322.1	121	34.1	108.4	87.6
100	498.3	370.3	124.3	33.8	110.3	98.6
120	481.9	310.4	114.6	33.5	110.1	100
140	497.1	350.3	101.8	33.4	118.2	100
160	550.9	386.8	120	33.8	107.3	100
180	647.5	420.1	123.4	32.1	130.1	100
200	680.4	521.4	112.3	32.8	168.5	100
220	720.3	545.5	115.3	33	172.9	100
240	760.9	568.7	100.4	32.1	208.3	100
260	805.3	584.1	105.4	31.5	224.6	100
280	855.7	624.9	119.7	31.4	230.4	100
300	907.2	711.6	121.8	32	226.2	100

Table 21 Oyster Mushroom Substrate Pasteurization Experiment 3

Time (min)	T_1 (°C)	T_2 (°C)	T_3 (°C)	T_4 (°C)	T_5 (°C)	T_6 (°C)
0	39.6	39.7	38.9	34.2	39.9	26.5
20	221.5	132.1	89.2	34.1	101.8	55.1
40	352.6	241.9	105.6	33.9	128.1	64.8
60	474.1	288.4	148.5	33.4	102.8	80.5
80	510.2	304.2	140.2	34.4	102.5	88.6
100	546.8	378.9	147.2	33.7	125.1	100
120	586.4	421.5	148.1	33.7	119.5	100
140	572.6	419.3	103.5	34.1	116.8	100
160	614.5	487.6	126.7	33.4	124.5	100
180	668.1	528.6	108.1	32.8	141.5	100
200	724.4	588.6	100.9	32.9	157.3	100
220	781.4	604.9	143.5	32.7	186.9	100
240	768.5	609.8	107.2	32.4	109.7	100
260	834.1	675.1	104.2	32.1	228.4	100
280	913.4	745.9	107.8	31.9	245.4	100
300	987.6	809.4	110.2	32.1	245.7	100

APPENDIX G

PRELIMINARY MUSHROOM SUBSTRATE WASTE MOISTURE CONTENTS EXPERIMENTS

Table 22 Variable (%) Moisture Contents of Oyster Mushroom Substrate Waste with Time

Sun dry (day)	Sample	Initial weight (g)	Final weight (g)	%M.C.wb	Avg.	%M.C.db	Avg.
0	1	8.1	3.3	59.26	52.87	145.45	117.09
	2	5.8	2.5	56.90		132.00	
	3	7.3	4.2	42.47		73.81	
1	1	7.3	4.5	38.36	38.07	62.22	62.29
	2	6.7	3.8	43.28		76.32	
	3	8.9	6.0	32.58		48.33	
2	1	9.0	7.1	21.11	26.37	26.76	36.50
	2	7.3	5.5	24.66		32.73	
	3	6.3	4.2	33.33		50.00	
3	1	6.0	4.9	18.33	19.19	22.45	23.75
	2	7.8	6.3	19.23		23.81	
	3	8.5	6.8	20.00		25.00	
4	1	7.9	6.9	12.66	13.43	14.49	15.52
	2	4.8	4.1	14.58		17.07	
	3	4.6	4.0	13.04		15.00	
5	1	4.1	3.6	12.20	13.09	13.89	15.08
	2	4.8	4.2	12.50		14.29	
	3	4.8	4.1	14.58		17.07	
6	1	4.1	3.6	12.20	10.59	13.89	11.87
	2	7.1	6.5	8.45		9.23	
	3	5.4	4.8	11.11		12.50	
7	1	5.0	4.4	12.00	9.37	13.64	10.39
	2	5.4	5.0	7.41		8.00	
	3	4.6	4.2	8.70		9.52	

Table 22 Variable % Moisture Contents of Oyster Mushroom Substrate Waste with Time

(cont.)

Sun dry (day)	Sample	Initial weight(g)	Final weight(g)	%M.C.wb	Avg.	%M.C.db	Avg.
8	1	7.2	6.7	6.94	7.03	7.46	7.56
	2	6.2	5.8	6.45		6.90	
	3	6.5	6.0	7.69		8.33	
9	1	4.6	4.2	8.70	7.01	9.52	7.56
	2	6.2	5.8	6.45		6.90	
	3	6.8	6.4	5.88		6.25	
10	1	6.5	6.1	6.15	6.81	6.56	7.32
	2	5.7	5.3	7.02		7.55	
	3	5.5	5.1	7.27		7.84	

GLOSSARY

LIST OF SYMBOLS

Symbol		Unit
A_1	Air Duct Area	m^2
A_2	Orifice Plate Area	m^2
A_d	Gas Duct Area	m^2
C_d	Drag Coefficient	(Dimensionless)
D_e	Diameter of Cyclone Exit Duct	m
h_d	Difference of Water Level	mm
m	Mass of Gases	kg
n	Mole of Gases	kmol
P	Atmospheric Pressure	N/m^2
Q	Airflow rate	m^3/s
R	Universal Gas Constant	kJ/kmol K
r	Correlation Coefficient	(Dimensionless)
R_e	Reynolds Number	(Dimensionless)
r^2	Coefficient of Determination	(Dimensionless)
$S_{y/x}$	Standard Error of the Estimate	(Dimensionless)
V	Gases Volume	m^3
V_g	Gases Inlet Velocity	m/s
ρ_a	Air Density	kg/m^3
ρ_g	Gases Density	kg/m^3
ν	Kinematics Viscosity	m^2/s
w_1	Weight of sample	kg
w_2	Weight of sample after oven-drying	kg

NOMENCLATURE

Avg.	=	Average Value
ER	=	Equivalent Ratio
Exp.	=	Experiment
LPG	=	Liquefied Petroleum Gas
Max	=	Maximum Value
Min	=	Minimum Value
min	=	Minute
Temp	=	Temperature
HHV	=	High Heating Value
LHV	=	Low Heating Val