Chapter 5

Results and Discussions

5.1 Technical results

Site selection and survey, biomass analysis, the construction of biomass gasification system and test run operation had been performed in 2007-08.

5.1.1 Biomass fuel analysis

The potential biomass samples were analyzed. Results are shown in Tables 5.1-5.3 and Appendix C, for ultimate, proximate and ash analyses, respectively. From the results obtained, it was found that the most suitable biomass fuel is rice husk. It has heating value of 13.8 MJ/kg, with high fixed carbon content. Its ash content is mainly SiO_2 with highest ash melting temperature among the fuels considered.

Table 5.1 Ultimate Analysis

	Rice husk	**Bamboo**	**Wood**	**Rice straw**
C	35.145 %	45.66 %	44.925 %	39.875 %
H	3.706 %	4.32 %	4.935 %	5.1165 %
N	0.211 %	0.243 %	0.188 %	0.594 %
S	0.1215 %	0.064 %	0.074 %	0.216 %
O	60.438 %	48.329 %	49.616 %	53.829 %

Table 5.2 Proximate analysis, heating value and density

	Sample	**Heating Value (MJ/kg)**	**Proximate analysis (as received, % wt/wt)**				**bulk density (kg/m^3)**
			moisture	**volatile matter**	**ash**	**fixed carbon**	
1	Bamboo	17.8	5.73	74.68	5.55	14.04	1,720
2	Rice straw	15.3	7.76	65.58	12.44	14.22	nd
3	Rice husk	13.8	5.60	56.41	13.45	24.54	nd
4	Wood	16.4	7.49	74.82	6.36	11.33	1,910

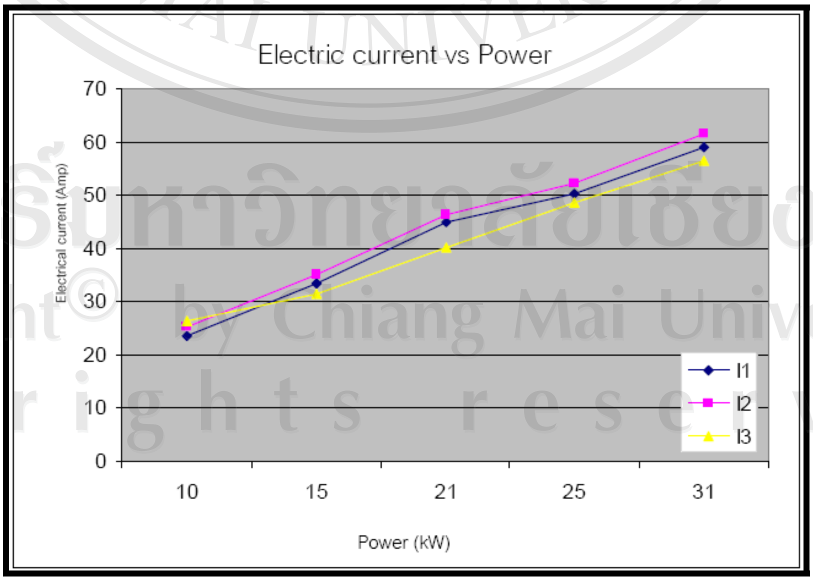
nd = not determined

Table 5.3 Ash analysis

Sample	Bamboo	Rice Straw	Rice husk	Wood
1. Ash Composition (%)				
Fe_2O_3	3.68	0.76	1.20	3.24
Al_2O_3	4.79	2.42	0.14	5.57
MgO	5.92	1.87	0.64	5.85
SiO_2	44.08	72.73	88.72	43.24
CaO	23.09	5.40	3.92	23.43
K_2O	12.69	12.87	2.58	12.21
Na_2O	0.44	0.24	0.25	1.73
TiO_2	0.28	0.01	0.07	0.29
Mn_3O_4	0.10	0.78	0.09	0.37
SO_3	1.61	0.28	0.00	2.39
2. Ash Fusion Temperature (°C)				
2.1 Initial Deformation Temperature	1,142	1,000	1,440	1,138
2.2 Softening Temperature	1,152	1,194	1,500	1,138
2.3 Hemispherical Temperature	1,163	1,220	>1,500	1,189
2.4 Fluid Temperature	1,178	1,268	>1,500	1,205

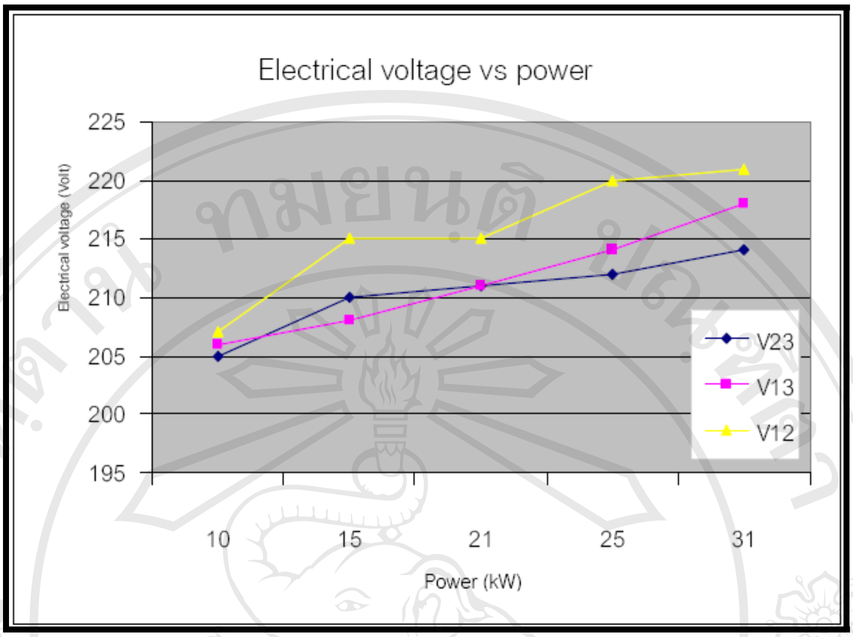
5.1.2 System testing

During the test run at varying load, it was found that producer gas from rice husk can replace diesel of up to 70%. Results are shown in Figure 5.1-5.5.



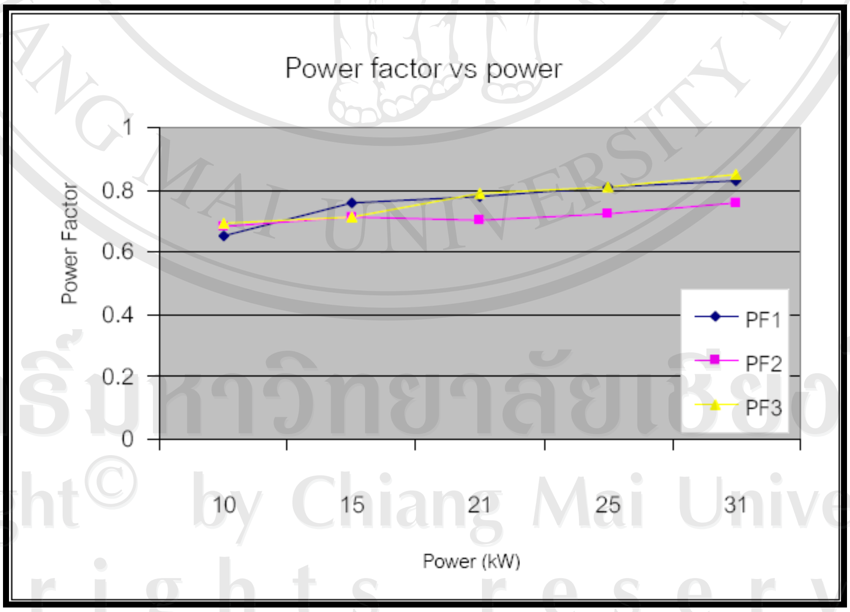
I=Electrical Current (Amp)

Figure 5.1 Electrical current and power



V=Electrical Voltage (Volt)

Figure 5.2 Electrical voltage and power



PF=Power Factor

Figure 5.3 Power factor and power

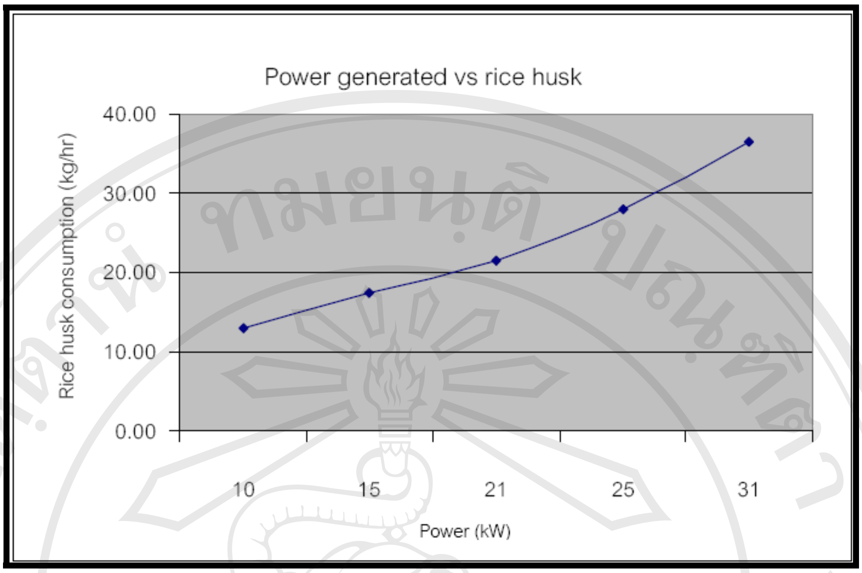


Figure 5.4 Relationship between power generated and rice husk consumption

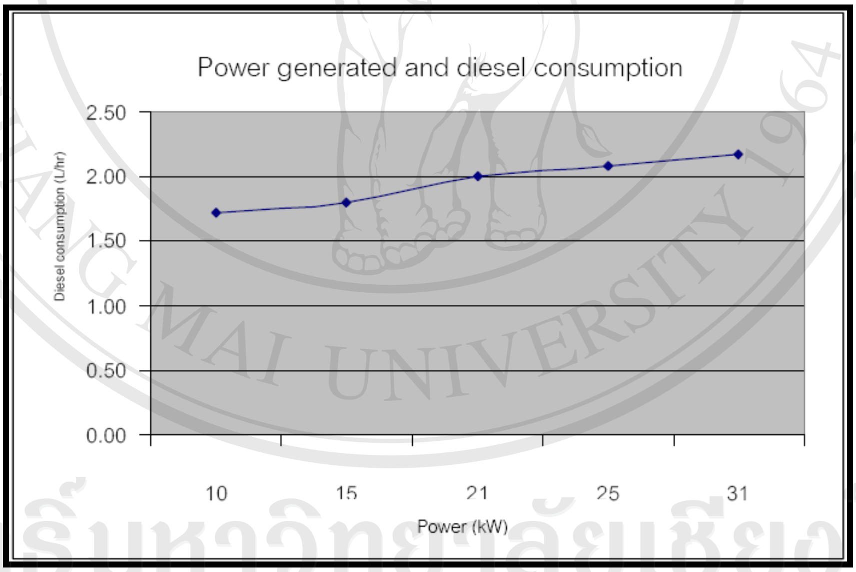


Figure 5.5 Relationship between power generated and diesel consumption

Figure 5.4 and 5.5 shows that at 31.28 kW electricity generate, rice husk and diesel consumption rate was 32.64 kg/hr and 2.17 L/hr, respectively as shown in Table 5.4. With only diesel operation, diesel consumption rate was 7.39 L/hr. More than 70% saving in diesel was achieved with the rice husk gasification system. Electricity consumption in the villages at different loads result is shown in Table 5.5.

Table 5.4 Properties of rice husk at different loads

Power (kW)	**Rice husk consumption (kg/hr)**	**Diesel consumption (L/hr)**
10	13.00	1.72
15	17.50	1.80
21	21.50	2.00
25	28.00	2.08
31	36.50	2.17

Note: measurements made at a diesel substitution rate by producer gas of 65 %

Table 5.5 Electricity consumption in the villages at different loads

Electricity phase 1	I_1	23.5	33.5	45.1	50.3	59.1	Amp
	V_{23}	205	210	211	212	214	Volt
	Power Factor	0.65	0.76	0.78	0.81	0.83	
	Power 1	3.131	5.347	7.423	8.638	**10.5**	kW
Electricity phase 2	I_2	25.2	35.2	46.4	52.2	61.5	Amp
	V_{13}	206	208	211	214	218	Volt
	Power Factor	0.68	0.71	0.7	0.72	0.76	
	Power 2	3.53	5.198	6.853	8.043	**10.19**	kW
Electricity phase 3	I_3	26.3	31.5	40.3	48.6	56.4	Amp
	V_{12}	207	215	215	220	221	Volt
	Power Factor	0.69	0.71	0.79	0.81	0.85	
	Power 3	3.756	4.808	6.845	8.661	**10.59**	kW
Total power (P1 + P2 + P3)		**10.42**	**15.35**	**21.12**	**25.34**	**31.28**	**kW**

The engine testing was performed by fixed the engine speed at 1500 rpm. The electricity load was applied respectively at different power (kW).

Fuel consumption rate (f_c)

$$f_c = \frac{1}{\eta_{Engine}} \times P_{Match} \times \frac{1}{LHV_{Ricehusk}} \times 3{,}600 \qquad (5.1)$$

where
f_c fuel consumption rate (kg/hr)
η_{Eng} engine efficiency (~0.25)
P_{Match} power (kW)
$LHV_{Rice\ husk}$ rice husk heating value = 13,800 kJ/kg

From (5.1), $$f_c = \frac{1}{0.25} \times 31.28 \times \frac{1}{13{,}800} \times 3{,}600$$

$$f_c = 32.64\, kg/hr$$

Diesel substitution rate by producer gas

$$\% = \{1 - \frac{(\rho Q LHV)_{Diesel}}{(\rho Q LHV)_{Diesel} + (\rho Q LHV)_{Ricehusk}}\} \times 100 \qquad (5.2)$$

where
$\%$ percentage substitute
ρ density (kg/m^3)
Q flow rate (m^3/hr)
LHV heating value (MJ/kg)

Operating at 1,500 rpm found that,

Q_{Diesel} = 7.39 L/hr Q_{Ricehusk} = 53.76 L/hr
LHV_{Diesel} = 43.0 MJ/kg LHV_{Ricehusk} = 13.8 MJ/kg
ρ_{Diesel} = 850 kg/m^3 ρ_{Ricehusk} = 679 kg/m^3

From (5.2), $$\% = \{1 - \frac{(850 \times 7.39 \times 43)}{(850 \times 7.39 \times 43) + (679 \times 53.76 \times 13.8)}\} \times 100$$

$$\% = 65.10$$

The percentage of diesel substitution rate by producer gas from rice husk gasification was 65.1% on an energy basis for all power output levels considered.

System efficiency (η_{Total})

$$\eta_{Total} = \left(\frac{P_{EI} \times 3{,}600}{Q \times LHV}\right) \times 100 \qquad (3.2)$$

where η_{Total} system efficiency (%)

P_{EI} electrical power (kW)

Q fuel consumption (m^3/hr)

LHV heating value (kJ/m^3)

At 1,500 rpm and P_{EI} = 31.28 kW

Q_{Diesel}	= 2.17	L/hr	$Q_{Ricehusk}$	= 53.76	L/hr
LHV_{Diesel}	= 43,000	kJ/kg	$LHV_{Ricehusk}$	= 13,800	kJ/kg
ρ_{Diesel}	= 850	kg/m^3	$\rho_{Ricehusk}$	= 679	kg/m^3

From (3.2), $$\eta_{Total} = \left(\frac{P_{EI} \times 3{,}600}{(Q \times LHV)_{Diesel} + (Q \times LHV)_{Ricehusk}}\right) \times 100$$

$$\eta_{Total} = \left(\frac{31.28 \times 3{,}600}{(2.17 \times 43{,}000) + (53.76 \times 13{,}800)}\right) \times 100$$

$$\eta_{Total} = 13.48\%$$

Engine efficiency (η_{Eng})

$$\eta_{Eng} = \frac{\eta_{Total}}{\eta_{Motor}} \times 100 = \frac{Overall \cdot efficiency}{Mortor \cdot efficiency} \times 100 \qquad (3.3)$$

where η_{Eng} engine efficiency (%)

η_{Motor} motor efficiency (%)

At 1,500 rpm system efficiency is 13.49 % and generator efficiency is 90 %

From (3.3), $$\eta_{Eng} = \frac{\eta_{Total}}{\eta_{Motor}} \times 100 = \frac{13.49}{90} \times 100$$

$$\eta_{Eng} = 14.98\%$$

The engine efficiency with dual fuel operation achieved was 14.98%, while pure diesel operation gave 39.32% efficiency for the same load.

Electricity generation cost (*EGC*)

After installation of the system, fuel consumption rate, operating hour, power demand from the local community were evaluated. This information was used to calculate unit base cost of electricity. The electricity generation cost can be determined from:

$$EGC = \frac{\sum m_f c_f + c_L + c_M}{Pt} \tag{5.3}$$

where EGC electricity generation cost (kyat/kWh)

m_f fuel mass consumption for both diesel and rice husk (L, kg)

c_f fuel cost for both diesel and rice husk (kyat/L, kyat/kg)

c_L total labor costs (kyat)

c_M total maintenance costs (kyat)

P power (kW)

t the specified operation time (hr)

At 4 hr/day between 1800 – 2200 rpm,

m_f (Rice husk) is 32.64 kg/hr (Rice husk is obtained at no cost since it is available free within the local community.)

m_f (Diesel) = 2.17 L/hr

c_f (Diesel) =1100 kyat/L

c_L =200,000 kyat/month x month/30day x day/ 4hr

= 1,666.67 kyat/hr

c_M =50,000 kyat/month x month/30day x day/ 4hr

= 416.67 kyat/hr

P =31.28 kW

t =4 hr

From (5.3), $$EGC = \frac{(2.17\times1100)+1{,}666.67+416.67}{31.28\times1}$$

$$EGC = 142.91 kyat / kWh$$

Expenses in comparison between electricity generation from diesel and duel fuel as shown in Table 5.6. It was found that with diesel operation, cost was about 326.83 Kyat/kWh but if dual fuel operation was used, this would be 142.91 Kyat/kWh. A saving of about 55% can be obtained. It is most likely that villagers in Dagoon Daing are able to sustainably run the system with minimum electricity cost. Electricity cost is calculated as follows:

A household with a 20 W lamb switching on 4 hours a day, it will need

electrical power = 20 x 4 x 30 / 1,000 = 2.40 kWh/month

electricity payment = 142.91 x 2.40 = 342.99 Kyat/month

Table 5.6 Comparison of electricity cost between diesel and dual fuel operation

No	Electricity cost	Diesel	Dual fuel	Unit
1	Diesel price in Myanmar	1,100.00	1,100.00	kyat/L
	Diesel fuel consumption rate	7.40	2.17	L/hr
	Cost	976,800.00	286,440.00	kyat/month
2	Labor cost	200,000.00	200,000.00	kyat/month
3	Maintenance cost	50,000.00	50,000.00	kyat/month
Total cost (30 days)		1,226,800.00	536,440.00	kyat/month
Electricity generation cost		326.83	142.91	kyat/kWh

For running 4 hour per day of the unit (output power electricity is 31.28 kW per day), the consumption rate of rice husk is 53290 kg/yr and diesel 3168.2 liter/yr.

Waste water analysis

Waste water from the system, water was collected and sent for analysis. Results are shown in Table 5.7.

Table 5.7 Waste water analysis

Parameter	Value	Standard
Temperature	24.40	Maximum 3ºC above ambient
Acidity	7.78	5.5-9
Total COD	6,089.00	400
COD after filteration	787.00	…
BOD	…	60
Total solid	3,842.00	3,000
Volatile solid	1,627.00	…
Suspended solid	1,699.00	200
Suspended volatile solid	814.00	…
Nitrogen	131.00	200
Phosphorus	23.00	…

From the results obtained, the water appeared to have high solid content and COD value above standard. The water should therefore be treated before discharge.

1. Primary treatment

This is a physical process to separate impurity from the water which may be done by conditioning and sedimentation.

2. Secondary treatment

This is to remove organic and suspended matter from the water by biological or chemical processes such as aeration.

3. Tertiary treatment

Further treatment such as Ultra filtration reverses osmosis, activated carbon, ion exchange, etc.

The system has a water pond for suspended solid to settle and sediment on the bed. Primary solid separation was done. The water from the pond was pumped to a second pond for further treatment before release to surrounding bamboo bushes.

5.2 Socio-economic impacts

The 4 members of the village who have some technical skills have been trained about the operation, and maintenance of the system as shown in Figure 5.6. They had a hand-on experience with a similar system in other site. With the system installed at the village, the 4 members have operated the system on their own under close supervision by skilled engineers and technicians. They have been able to operate the system with no trouble. Skilled engineers and technicians can be called on for future consultation.

After installation of lamb posts and household lighting, Children and adults can read after sunset. Previously, candles or oil lambs were used but the brightness was not high enough. With a fluorescent lighting, it is easier and more convenient to read as shown in Figure 5.7.

Lighting installed on the main road enabled a safer for dangerous like snake bites when they come back from their farms at night and travel in village.

Villagers enjoy evening activities such as karaoke singing, movie, snooker and TV as shown in Figure 5.8-5.9. Previously, each household had their own battery or diesel engine generators which were expensive.

From a field survey, questionnaires and interviewing, it was found that most are farmers with number of members of 6-8 and monthly income of about 130,000 kyat/family. Now, their incomes are raised because new activities, new jobs and new business are created for villagers.

Figure 5.6 Operators in action

Figure 5.7 Lighting for extra reading at night

Figure 5.8 Snooker game at night

Figure 5.9 Evening entertainment

5.3 Other impacts

When they increase their individual income after project, it can affect indirectly to other impacts as higher knowledge, higher education, and they can create higher living standard and finally they can manage their healthy lives.