CHAPTER 06

DISCUSSION AND CONCLUSION

The successful implementations of the hot air generating systems for tea drying could be discussed in following ways.

a) Fuelwood gasifire system

b) Continues fuelwood charging system

c) Fuelwood combusting ,steam boiler system

According to the study and details presented in this work, fuelwood gasifire system is the most suitable hot air generating system in the tea industry due to less fuelwood consumption and a short simple pay back period. However each of the above three systems has there own advantages and disadvantages. Also the suitability of a system depends on the regional concern, quality of incoming fuelwood, skill levels and method of operations and the type of heat exchangers used.

a) Continues Fuelwood Charging System:

The present available hot air generating system in the tea industry can easily be converted to operate as continues fuelwood charging system with low capital investment. By maintaining a constant dryer temperature and the excess air available in the flue gas, this system gives an average of 40 % fuelwood saving with compared to the present available system. The main bottleneck is to implement this system is an additional labor and time requirement to prepare fuelwood prior to screw feeder. In the present available furnaces, the size of fuelwood is not much concerned and even the sizes of 2m long wood logs have been used. However the screw feeding system requires an average size of 6 - 8cm long and 3 cm diameter wood chips. Even though a wood slizer was introduced to the particular tea factory, the daily fuelwood requirement could not be achieved. Glirizeedia is the most suitable fuelwood in this system, but potential is very low in the particular area.

b) Fuelwood Gasifire System

The successful results have obtained after three months endurance test. The capital requirement to implement this system is reasonable for small and medium level tea factories. This system also acts as continues fuelwood charging system; because the fuelwood storage hopper has ability to store fuelwood requirement for more than six hours of continues combustion. Therefore a steady hot air temperature level and stack temperature level can be maintained. The tested and analyzed data shows the significant fuelwood saving and the percentage reduction is 50 % compared to the present available hot air generating system. The simple payback period of fuelwood gasifire system in tea industry is in the range of 3 – 6 years according to the regional concerned. However, the unfavorable considerations are the increase in labor for the preparation of fuelwood and the excessive maintenance requirements. There is also a tendency for explosions due to poor operator's attention and improper maintenance. The implementation barrier of this system is also similar to the screw feeding system, because excessive labor and time requirement for fuelwood preparation. Except of those barriers, skilled labor requirement is also required.

c) Fuelwood Boiler System

The fuelwood combusting boiler system in tea industry is not popular in Sri Lanka. Only a few plants are being operated in the up country. The main constraint in using a fuelwood boiler system is its high capital which is Rs. 7.5 Millions compared to the other systems. Also the tested fuelwood boiler plants have not much significant fuelwood savings compared to the other systems. The fuelwood charging to the boiler is done by manually and therefore the combustion properties are similar to the present available system. An introducing continues fuelwood charging system is much more difficult than other systems due to high pressure inside the boiler. Except of those an additional space required to install a radiator far away from the dryer to eliminate fly tea dust deposit on the radiator surface. Also a high skilled boiler operator's assistance would be required an always.

This study was limited only for the area of hot air generating system of tea industry. On the other hand, this study has not covered the improvement of heat exchanger part. Since most of the heat exchangers, which presently used in tea industry, are very old and having high thermal inertia. Hence there performances are considerably low. Therefore the improvement of heat exchanger part in parallel to the modifications of hot air generating systems would be an essential to achieve better results than the results which have already obtained. As due concern that, the study of potential improvement of heat exchanger, with less thermal inertia, suited to modified hot air generating system in tea industry can be opened.

Also this study was limited to the particular sites and particular type of fuelwood. Therefore the outcome of field tests carried out could be tolerated while changing the regional considerations, quality of incoming fuelwood, operational patterns and human skills etc. According to general practices and experiences gained, maintaining quality of fuelwood and the ambient air conditions of up country region are much more difficult than the other regions in the country. Since the field tests carried out are based on the up and the mid regions in the country, the negative error reputability can not be achieved. If the modified systems will be introduced to the low region or any other part of the country, the performance would be high. However personnel skills would be affected to the error repeatability and it is common in any areas in the country.

Tea - as a main exporting product, the quality; both the taste and the color, of made tea is very important. The quality of made tea can be achieved by maintaining the uniform temperature variation within the dryer. This can be easily done by linking dryer temperature and rate of fuel wood charging and the facility is available in the case of continues fuelwood charging system. Also the trial test results revealed that the improving of quality of made tea.

As far as the energy conservation measures are concerned, it is competitive with most of the other areas like harvesting, labor etc., because thermal energy cost to the overall production cost in tea industry is much significant. In most cases tea industry does not consider energy conservation methods in their investment options. Therefore it is the duty of the energy managers and the relevant authorities to implement the aspects like gasifire system in tea industry.

When the gasifire system is concerned with respect to the traditional air heaters or hydro carbon combusting air heaters, environmental aspects too will come to the scene and it will be very helpful in the case of reducing CO_2 which effect to the global warming. Also half reduction of fuelwood consumption in tea industry would be caused to reduce the rate of deforestation. However the estimation of CO_2 transaction; from and to the environment, by combusting fuelwood and controlling deforestation is very difficult.

REFERENCES & BIBLIOGRAPHY

1.0 NERDC ,"Energy Conservation in the Tea Industry in Sri Lanka" – 1989.

2.0 Energy Conservation Fund, "Sri Lanka Energy Balance 2002",No 410/34, Bauddhaloka Mawatha, Colombo 07, Sri Lanka. – 2002.

3.0 Tea Research Institute, "Handbook on Tea".

4.0 NERDC, "Energy Audit Report ", St.Joachim Tea Factory, Ratnapura, Report No. A83 – 2003.

5.0 NERDC, "Energy Audit Report ", Gangaboda Tea Factory, Baddegama , Report No. A 81 – 2003

6.0 Dr. Thusita Sugatapala, "; Master of Engineering Lecture Note- Bio Energy (PME203)" – 2002-2003

7.0 Harrie knoef, "Hand Book- Bio Mass Gasification", BTG biomass technology group, PO Box 217, 7500 AE Enschede, Netherlands - 2005.

8.0 "Wood Energy in Asia; the use, Supply and Production of Wood Energy", Regional Wood Energy Development, Bangkok – 1999.

9.0 Keegel E L, "Monograph of Tea Production in Ceylon", The Tea Research Institute, Sri Lanka -1956.

10.0 Nunn Arthur B , "NO_X Emission Factors for Wood Fired Boilers", Interagency Energy/Environmental R&D Program Report; Industrial Environmental Research Laboratory, Washington – 1979.

11.0 Dr. Kulasinghe A N S , De Silva, Harischandra and Jayatunga D N, "Tea Drying With Gasifire", NERDC - 1986

12.0 Ridwan Ali, Yusuf A Choudrhy and Douglas W Lister, "World Bank Discussion Paper No 368", Sri Lanka's Tea Industry, Succeeding in the Global Market – 1997.

13.0 NERDC, "Energy Audit Report ", DeenSide Tea Factory, Gampola - 2003.

14.0 NERDC, "Tea Dryer Test Report", Luckyland Estate, Udupussallawa, Report No. M298 – 2004.

15.0 NERDC , "Tea Dryer Test report", Maskeliya Plantation Ltd., Maussakele, Report No. M 299 – 2004.

16.0 Nandana Edirisinghe, "Thermal Efficiency Improvement in Biomass Conversion Technology in the Tea Industry in Sri Lanka" – 2004.

17.0 NERDC, "Energy Audit Report", Carolina Tea Estate, Watawala, Report No. A 12-1986.

18.0 Sri Lanka World Bank Report – 2004

19.0 Wulfinghoff Donald R, "Energy Efficiency Manual", Energy Institute Press -1999.

20.0 Osborn Peter D, "Handbook of Energy Data and Calculations", Butterworth, London - 1985.

21.0 Jaluria Yogesh, "Natural Convection Heat and Mass Transfer" Pergamon, Oxford - 1980.

22.0 "Small & Medium Scale Industries in Asia", Energy & Environmental Tea Sector

23.0 NERDC, "Energy Audit Report ", Great Western Tea Estate, Report No. A 14 -1987

24.0 NERDC, "Energy Audit Report ", Stellenburg Tea Estate, Report No. A 15 – 1987.

25.0 NERDC, "Energy Audit Report ", Lelwela Tea Estate, Report No. A 16 – 1987.

26.0 NERDC, "Energy Audit Report ", Hapugastenne Tea Estate, Report No. A 17- 1987.

27.0 NERDC, "Energy Audit Report ", Aislaby Tea Estate, Report No. A 18 -1987.

28.0 NERDC, "Energy Audit Report ", Pedro Tea Estate, Report No. A 19 - 1987.

29.0 NERDC, "Energy Audit Report ", CEYTEA Factory, Agarapatana, Report No. A 63 - 2000.

APPENDIX 01

NOMENCLATURE

* Gross Calorific Value of Firewood	-	C_f	(kJ/kg)
* Firewood Consumption Rate	-	m_f	(kg/hr)
* Moisture Content of Firewood	-	m_w	(%)
* Electrical Energy Input	-	E_e	(MJ/hr)
* Energy Taken by Dry Flue Gas	-	E_g	(MJ/kg)
* Energy Content of Moisture in Firewood	-	Em	(MJ/kg)
* Moisture Generated by Combusting Firewood	-	M_{mo}	(MJ/kg)
* Moisture Generated by Reaction	-	M_{re}	(MJ/kg)
* Enthalpy of Steam @ 273 ^{0}C	-	h_s	(kJ/kg)
* Energy Loss by Radiation	-	E_r	(MJ/kg)
* Total Energy Loss	-	E_{tl}	(MJ/kg)
* Useful Energy from Furnace	-	E_u	(MJ/kg)
* Furnace Efficiency	-	η_f	(%)
* Wet Dhool Input Rate	-	T_w	(kg/hr)
* Made Tea Out Put Rate	-	T_m	(kg/hr)
* Specific Energy (Energy Required/ kg of Wet Dhool)	-	SP_{ew}	
* Specific Energy (Energy Required/ kg of Made Tea)	-	SP_{em}	
* Specific Fuel Consumption (Firewood required/ kg of Wet Dhool)	-	SP_{fw}	
* Specific Fuel Consumption (Firewood required/ kg of Made Teal)	-	SP_{fm}	

APPENDIX 02

USEFUL EQUATIONS

- Thermal Energy input

$(E_t) = C_f\,(1\text{-}m_a)m_f/1000$ MJ/hr

- Total Energy Input

$(E_f) = E_f + E_e$

- Energy Loss through Dry Flue Gas

$(E_g) = \{m_f\,(1\text{-}\,m_w)\rho_{air}\}\{1 + A_e/1000\}\{(SP_f)(Tf - Ta)\}/1000$

- Energy Loss Through Moisture

$(E_{mo}) = (m_{mo} + m_f)h_s$

- Energy Loss Through Radiation

$E_{rd} = E_t * R_f$

- Total Energy Loss

$E_{tl} = E_g + E_{mo} + E_{rd}$

- Usefull Energy

$E_u = (E_l - E_{tl})$

- Specific Energy Consumption

$SP_{ew} = (E_u * 100 / T_w)$ or

$SP_{et} = (E_u * 100/T_m)$

- Specific Fuel Consumption

$SP_{fw} = (m_f * 100/T_w)$ or

$SP_{fm} = (M_f * 100/T_m)$

- **Fuelwood Combustion ;**
  - $C + O_2 \longrightarrow CO_2$
  - $4H + O2 \longrightarrow 2\,H_2O$
  - 1 kg of Carbon requires $\longrightarrow$ 2.66 kg of Oxygen
  - 1 kg of Hydrogen requires $\longrightarrow$ 8 kg of Oxygen
  - Oxygen requirement = 0.48 x 2.66 +0.065 x 8.0

    = 1.797 kg of Oxygen

Since 44% of Oxygen is already available in the fuel wood,

Theoretical Oxygen requirement = 1.797 – 0.44

= 1.3568 kg of Oxygen

Since the Air being 23.2% of Oxygen by weight, theoretical air requirement for combustion = (100 x 1.3568/23.2)

= 5.85 kg of air

Theoretical Air Requirement = 4.5 m^3 of air

APPENDIX 3

USED DATA

1.0 Modified Fuelwood Charging System

Table A –1 -1; Flue Gas Temperature Variations in Traditional and Modified Fuel Wood Charging Systems [16]

Tested Date	17/02/2005	24/02/2005
Fuelwood	Rubber wood logs	Rubber wood chips
Time	Existing System	Modified System
10:00	31	37
10:05	32	69
10:10	33	135
10:15	34	182
10:20	34	187
10:25	33	202
10:30	47	216
10:35	59	251
10:40	88	254
10:45	121	261
10:50	129	241
10:55	136	216
11:00	152	222
11:05	189	228
11:10	191	246
11:15	220	260
11:20	233	253
11:25	248	264
11:30	256	263
11:35	250	253
11:40	274	258
11:45	276	246
11:50	270	255
11:55	265	274
12:00	254	271

Table A – 1 -1 ;Flue Gas temperature Variations in Traditional and Modified Fuelwood Charging Systems (Cont.) [16]

Tested Date	17/02/2005	24/02/2005
Fuelwood	Rubber wood logs	Rubber wood chips
Time	Existing System	Modified System
12:05	258	231
12:10	256	249
12:15	244	259
12:20	235	276
12:25	239	248
12:30	251	251
12:35	267	247
12:40	274	254
12:45	279	248
12:50	299	253
12:55	296	259
13:00	295	277
13:05	275	246
13:10	287	276
13:15	282	254
13:20	257	257
13:25	282	278
13:30	281	254
13:35	272	282
13:40	279	268
13:45	262	273
13:50	283	242
13:55	283	232
14:00	275	240
14:05	290	244

Table A – 1 -1; Flue Gas temperature Variations in Traditional and Modified Fuelwood charging Systems (Cont.) [16]

Tested Date	17/02/2005	24/02/2005
Fuelwood	Rubber wood logs	Rubber wood chips
Time	Existing System	Modified System
14:10	295	250
14:15	294	252
14:20	286	243
14:25	273	276
14:30	265	253
14:35	263	245
14:40	264	253
14:45	255	252
14:50	251	260
14:55	246	256
15:00	236	273
15:05	275	252
15:10	269	272
15:15	262	252
15:20	249	250
15:25	276	251
15:30	276	253
15:35	271	254
15:40	259	252
15:45	283	249
15:50	268	249
15:55	256	243
16:00	277	243
16:05	277	249
16:10	267	277

Table A – 1 -1; Flue Gas temperature Variations in Traditional and Modified Fuelwood Charging Systems (Cont.) [16]

Tested Date	17/02/2005	24/02/2005
Fuelwood	**Rubber wood logs**	**Rubber wood chips**
Time	**Existing System**	**Modified System**
16:15	264	253
16:20	261	271
16:25	252	271
16:30	270	264
16:35	256	240
16:40	248	251
16:45	234	250
16:50	246	253
16:55	267	265
17:00	261	253
17:05	256	242
17:10	259	246
17:15	260	232
17:20	257	264
17:25	236	265
17:30	255	256
17:35	251	264
17:40	252	258
17:45	243	259
17:50	239	279
17:55	269	242
18:00	262	-
18:05	256	-
18:10	253	-
18:15	245	-
18:20	237	-
18:25	224	-
18:30	214	-

Table A – 1 - 2; Dryer Inlet Temperature Variations in Traditional and Modified Fuelwood Charging System [16]

Tested Date	17/02/2005	24/02/2005
Fuelwood	Rubber wood logs	Rubber wood chips
Time	Existing System	Modified System
10:00	30	28
10:05	31	28
10:10	31	29
10:15	31	31
10:20	31	36
10:25	31	40
10:30	31	49
10:35	31	78
10:40	32	86
10:45	32	88
10:50	32	92
10:55	33	97
11:00	34	97
11:05	34	97
11:10	38	99
11:15	35	103
11:20	40	106
11:25	41	108
11:30	72	111
11:35	75	111
11:40	77	112
11:45	81	112
11:50	83	111
11:55	83	111
12:00	82	110

Table A –1- 2; Dryer Inlet Temperature Variations in Traditional and Modified Fuelwood Charging Systems (Cont.) [16]

Tested Date	17/02/2005	24/02/2005
Fuelwood	Rubber wood logs	Rubber wood chips
Time	Existing System	Modified System
12:05	82	109
12:10	81	110
12:15	84	111
12:20	84	112
12:25	83	111
12:30	84	112
12:35	85	111
12:40	86	110
12:45	88	109
12:50	91	109
12:55	95	109
13:00	96	109
13:05	98	110
13:10	100	109
13:15	101	109
13:20	102	110
13:25	102	109
13:30	103	110
13:35	103	112
13:40	103	113
13:45	103	113
13:50	102	112
13:55	103	112
14:00	103	109
14:05	103	107

Table A – 1- 2; Dryer Inlet Temperature Variations in Traditional and Modified Fuelwood Charging Systems (Cont.) [16]

Tested Date	17/02/2005	24/02/2005
Fuelwood	Rubber wood logs	Rubber wood chips
Time	Existing System	Modified System
14:10	104	108
14:15	105	108
14:20	106	109
14:25	105	109
14:30	104	109
14:35	102	110
14:40	101	110
14:45	100	110
14:50	98	111
14:55	97	111
15:00	95	112
15:05	94	111
15:10	95	110
15:15	96	110
15:20	95	110
15:25	96	109
15:30	98	110
15:35	98	111
15:40	98	110
15:45	99	111
15:50	100	111
15:55	100	110
16:00	100	109
16:05	102	110
16:10	102	111

Table A – 1 -2; Dryer Inlet Temperature Variations in Traditional and Modified Fuelwood Charging Systems (Cont.) [16]

Tested Date	17/02/2005	24/02/2005
Fuelwood	**Rubber wood logs**	**Rubber wood chips**
Time	**Existing System**	**Modified System**
16:15	102	112
16:20	101	112
16:25	99	111
16:30	99	110
16:35	98	110
16:40	98	110
16:45	96	109
16:50	94	110
16:55	95	111
17:00	95	112
17:05	95	110
17:10	94	109
17:15	94	108
17:20	94	106
17:25	93	106
17:30	92	106
17:35	92	107
17:40	91	108
17:45	91	107
17:50	90	107
17:55	91	105
18:00	93	-
18:05	92	-
18:10	92	-
18:15	91	-
18:20	88	-
18:25	86	-
18:30	91	-

2.0 Gasifire System

2.1 Test Data in 29th April 1998 [11]

Date29/04/ 1998

Fuelwood Charging Started at	-	6:45 Hrs
Gsifire Warming Started at	-	7:15 Hrs
Gsifire Warming Completed at	-	8:05 Hrs
Heat Release Started at	-	8:05 Hrs
Heat Release Completed at	-	18:45 Hrs
Blower ON at	-	8:00 Hrs
Burner Ignited at	-	8:05 Hrs
Main Fan ON at	-	8:45 Hrs
Heat Exchanger Warming Started at	-	8:05 Hrs
Heat Exchanger Warming Completed at	-	9:11 Hrs
Feeding Terminated at	-	18:30 Hrs
Firing Terminated at	-	18:45 Hrs
Weight of Ash Generated	-	10 kg
Weight of Charcoal Generated	-	55 kg
Moisture Content of Fuelwood	-	8.5 %
Fuelwood Consumption	-	1236 kg
Made Tea Output	-	1246 kg
Dryer Operating Period	-	9.5 Hrs
Gasifier Operating Period	-	11.25 Hrs

Table A- 2 – 1; Temperature Measurements on 29 th April, 1998 [11]

Time	Temperature (^0C)			Damper Position	
	Dryer Inlet	Dryer Outlet	Flue Gas	Main Fan	ID Fan
8:45	128	64	282	Location 4	3/4 Open
9:00	119	48	275	Location 5	3/4 Open
9:15	114	48	296	Location 5	3/4 Open
9:30	113	45	283	Location5	3/4 Open
9:45	110	46	292	Location 5	3/4 Open
10:00	110	46	298	Location 5	3/4 Open
10:15	111	45	294	Location 5	3/4 Open
10:30	111	39	298	Location 5	3/4 Open
10:45	111	36	294	Location 5	3/4 Open
11:00	111	37	294	Location 5	3/4 Open
11:15	122	36	297	Location 5	3/4 Open
11:30	117	43	294	Location 5	3/4 Open
11:45	113	46	294	Location 5	3/4 Open
12:00	111	48	297	Location 5	3/4 Open
12:15	111	43	292	Location 5	3/4 Open
12:30	109	47	296	Location 5	3/4 Open
12:45	111	41	293	Location 5	3/4 Open
13:00	111	36	294	Location 5	3/4 Open
13:15	109	36	289	Location 5	3/4 Open
13:30	108	47	293	Location 5	3/4 Open
13:45	108	49	293	Location 5	3/4 Open
14:00	108	47	292	Location 5	3/4 Open
14:15	109	49	293	Location 5	3/4 Open
14:30	108	47	292	Location 5	3/4 Open
14:45	108	42	295	Location 5	3/4 Open
15:00	109	43	292	Location 5	3/4 Open
15:15	109	47	293	Location 5	3/4 Open

Table A- 2 – 1; Temperature Measurements on 29th April, 1998 (Cont.) [11]

Time	Temperature (^0C)			Damper Position	
	Dryer Inlet	Dryer Outlet	Flue Gas	Main Fan	ID Fan
15:30	111	39	292	Location 5	3/4 Open
15:45	111	36	292	Location 5	3/4 Open
16:00	108	42	297	Location 5	3/4 Open
16:15	108	36	290	Location 5	3/4 Open
16:30	108	46	290	Location 5	3/4 Open
16:45	119	36	314	Location 5	3/4 Open
17:00	136	64	311	Location 5	3/4 Open
17:15	125	42	303	Location 5	3/4 Open
17:30	119	36	297	Location 5	3/4 Open
17:45	117	33	293	Location 5	3/4 Open
18:00	117	53	288	Location 5	3/4 Open
18:15	118	53	293	Location 5	3/4 Open
18:30	118	53	293	Location 5	3/4 Open

Fuelwood Consumption Rate - 110 kg/hr

Made Tea Output Rate - 131 kg/hr

Specific Fuelwood Consumption - 1.0 kg of Fuelwood/kg of Made Tea

2.2 Summarized Test Data

Table A- 2 – 2; Summarized Test Data [11]

Date	Gasifire Operation Period		Fuelwood Data			Production Data			Combustion Products		SFC
	Warming up	Firing	Consumption	M/C	Rate	Made Tea	Drying Period	Rate	Ash	Charcoal	kg of FW/ kg of MT
	hrs	hrs	kg	%	kg/hr	kg	hrs	kg/hr	kg	kg	
29:04:1998	1.10	9.30	1236	18.5	119	1246	9.3	134	10.0	55.5	1.0
30:04:1998	1.08	17.40	1971	18.0	107	2746	17.4	158	10.0	50.0	0.7
05:05:1998	1.10	6.00	670	18.5	94	830	6.0	138	6.0	31.5	0.8
06:05:1998	1.30	8.00	1154	19.0	124	1041	8.0	130	5.0	32.0	1.1
07:05:1998	1.25	6.00	757	18.0	104	855	6.0	143	6.0	31.0	0.9
08:05:1998	1.20	5.50	1068	20.0	159	607	5.5	110	5.0	25.0	1.8
09:05:1998	1.00	8.50	992	35.0	104	923	8.5	109	5.0	26.0	1.1
10:05:1998	1.20	8.30	1068	40.0	112	747	8.3	90	4.0	27.0	1.4
14:05:1998	1.20	9.25	1416	41.0	136	986	9.3	107	5.0	33.0	1.4
15:05:1998	1.25	10.50	1588	41.0	135	1160	10.5	110	5.0	24.0	1.4
16:05:1998	1.25	3.60	560	41.0	115	388	3.6	108	3.0	23.0	1.4
18:05:1998	1.30	7.30	1164	42.0	135	864	7.3	118	5.0	37.0	1.3
19:05:1998	1.30	7.75	1110	40.5	123	1036	7.8	134	3.0	25.0	1.1
20:05:1998	1.25	2.75	547	27.2	137	335	2.8	122	2.0	18.0	1.6
21:05:1998	1.00	3.75	541	20.0	114	468	3.8	125	2.0	19	1.2
22:05:1998	1.00	3.75	591	22.7	124	459	3.8	122	2.5	20	1.3
23:05:1998	1.00	4.30	689	30.3	130	554	4.3	129	3.0	27	1.2

Table A- 2 – 2; Summarized Test Data (Cont.) [11]

Date	Gasifire Operation Period		Fuelwood Data			Production Data			Combustion Products		SFC
	Warming up	Firing	Consumption	M/C	Rate	Made Tea	Drying Period	Rate	Ash	Charcoal	kg of FW/ kg of MT
	hrs	hrs	kg	%	kg/hr	kg	hrs	kg/hr	kg	kg	
25:05:1998	1.00	4.00	586	30.3	117	583	4.0	146	2.0	19	1.0
26:05:1998	1.00	4.50	671	37.0	122	609	4.5	135	4.0	33	1.1
27:05:1998	1.00	5.00	963	44.3	161	655	5.0	131	5.0	36	1.5
28:05:1998	1.20	5.75	986	43.6	142	704	5.8	122	6.0	60	1.4
06:07:1998	1.30	14.15	2400	38.4	155	2099	14.2	148	8.0	52	1.1
11:07:1998	1.25	14.25	2178	42.4	141	1866	14.3	131	5.0	2	1.2
12:07:1998	0.20	6.25	771	37.7	120	570	6.3	91	9.0	27	1.4
13:07:1998	0.80	4.75	721	44.0	130	578	4.8	122	4.0	38	1.2
14:07:1998	1.20	5.25	880	29.8	136	777	5.3	148	5.0	36	1.1
15:07:1998	1.00	8.30	920	25.0	99	1035	8.3	125	2.0	35	0.9
16:07:1998	1.20	8.80	1114	29.0	111	1015	8.8	115	4.0	29	1.1
17:07:1998	0.50	6.50	892	40.6	127	790	6.5	122	8.0	20	1.1
18:07:1998	0.15	10.00	1557	38.8	153	1189	10.0	119	4.0	29	1.3
19:07:1998	0.75	7.20	720	32.8	91	594	7.2	83	9.0	24	1.2
20:07:1998	1.00	7.20	737	23.7	90	606	7.2	84	8.0	40	1.2
21:07:1998	1.00	7.60	1200	32.5	140	838	7.6	110	5.0	43	1.4
22:07:1998	0.75	7.20	1439	40.5	181	865	7.2	120	5.0	27	1.7
23:07:1998	1.30	6.50	1020	40.0	131	665	6.5	102	6.0	24	1.5

Table A- 2 – 2; Summarized Test Data (Cont.) [11]

Date	Gasifire Operation Period		Fuelwood Data			Production Data			Combustion Products		SFC
	Warming up	Firing	Consumption	M/C	Rate	Made Tea	Drying Period	Rate	Ash	Charcoal	kg of FW/ kg of MT
	hrs	hrs	kg	%	kg/hr	kg	hrs	kg/hr	kg	kg	
24:07:1998	1.00	5.00	810	22.4	135	505	5.0	101	3.0	26	1.6
25:07:1998	1.00	4.00	722	33.0	144	463	4.0	116	7.0	38	1.6
26:07:1998	0.80	6.50	1132	34.8	155	634	6.5	98	2.5	28	1.8
31:07:1998	1.00	7.00	981	34.8	123	853	7.0	122	2.0	28	1.2
01:08:1998	1.25	7.00	1007	39.0	122	785	7.0	112	4.0	18	1.3
02:08:1998	0.60	5.00	624	39.6	111	516	5.0	103	1.5	36	1.2
04:08:1998	1.00	5.00	951	34.0	159	483	5.0	97	2.0	32	2.0
06:08:1998	0.50	4.50	850	40.5	170	448	4.5	100	4.0	30	1.9
13:08:1998	0.80	4.60	817	42.0	151	746	4.6	162	8.0	15	1.1
14:08:1998	0.50	5.60	673	40.0	110	718	5.6	128	2.5	45	0.9
15:08:1998	0.80	8.30	1400	38.0	154	976	8.3	118	4.0	12	1.4
16:08:1998	1.00	5.50	802	45.0	123	802	5.5	146	6.0	34	1.0
17:08:1998	0.80	4.50	532	40.8	100	543	4.5	121	4.0	45	1.0
19:08:1998	0.80	9.50	1381	40.3	134	782	9.5	82	4.0	25	1.8
20:08:1998	1.00	7.50	1068	35.0	126	715	7.5	95	2.5	45	1.5
21:08:1998	0.50	9.00	1206	34.8	127	917	9.0	102	1.0	20	1.3
27:08:1998	0.50	6.50	1165	44.5	166	658	6.5	101	4.0	18	1.8
29:08:1998	1.00	7.25	1126	40.4	136	778	7.3	107	3.0	37	1.4

Table A- 2 – 2; Summarized Test Data (Cont.) [11]

Date	Gasifire Operation Period		Fuelwood Data			Production Data			Combustion Products		SFC
	Warming up	Firing	Consumption	M/C	Rate	Made Tea	Drying Period	Rate	Ash	Charcoal	kg of FW/ kg of MT
	hrs	hrs	kg	%	kg/hr	kg	hrs	kg/hr	kg	kg	
05:09:1998	1.30	8.75	1344	33.7	134	907	8.8	104	4.8	10	1.5
06:09:2000	1.00	2.50	409	40.0	117	233	2.5	93	3.5	114	1.8
08:09:1998	1.00	14.40	1861	31.0	121	1711	14.4	119	4.0	36	1.1
09:09:1998	0.80	8.20	1055	33.0	117	1106	8.2	135	4.0	33	1.0
10:09:1998	0.90	6.00	980	37.0	142	674	6.0	112	3.0	35	1.5
15:09:1998	1.00	7.25	1236	47.2	150	750	7.3	103	3.0	65	1.6
17:09:1998	1.60	9.00	1410	43.4	133	796	9.0	88	3.0	35	1.8

2.3 System Comparisons

Table A- 2 – 3; System Comparisons Before and After Modifications

Parameter	St. Joachim		DeenSide	
	Before	**After**	**Before**	**After**
Furnace Operating Time (hrs)	6	11.25	6	5
Fuelwood Consumption (kg)	1200	1236	1180	655
Fuelwood Consumption Rate (kg/hrs)	200	110	197	131
Moisture content of Fuelwood (%)	21	18.5	25	15
Dry Fuelwood Charging Rate (kg/hr)	158	89.5	147.5	111.4
Calorific Value of Fuelwood (kJ/kg)	19500	19500	19500	19500
Energy Input (MJ/hr)	**3081**	**1746**	**2876**	**2171**
Electrical Energy Input				
Main Fan (kW)	12	12	3.3	3.3
ID Fan (kW)	1.2	1.2		
Gasifire Blower (kW)		3.5		
Charging Conveyer (kW)				1.5
Total Electrical Energy (MJ)	13.2	14.7	3.3	4.8
Total Electrical Energy (MJ)	48	53	12	17
Total Energy Input (MJ)	**3129**	**1799**	**2888**	**2189**
Energy Taken by Flue Gas				
Flue Gas Temperature (K)	513	565	558	523
Ambient Air Temperature (K)	302	305	307	313
Excess Air In Flue Gas (%)	122	136	193	230
Theoretical Air Requirement (m^3/kg)	4.5	4.5	4.5	4.5
Density of Flue Gas (kg/m^3)	0.748	0.748	0.748	0.748
Specific Heat of Flue Gas (kJ/kg.K)	1.097	1.097	1.097	1.097
Energy Taken by Dry Flue Gas (MJ/hr)	**328**	**243**	**481**	**342**
Energy Taken by Moisture in Fire Wood				
Rate of Fuelwood Consumption (kg/hr)	200	110	197	131
Moisture Intake from Fuelwood (kg/hr)	42	20	49	20
Moisture generated from Combustion Reaction (kg/hr)	85.3	48.4	79.7	60.1
Total Moisture Generation (kg/hr)	127	69	129	80
Steam Enthalpy (kJ/kg)	2978	2978	2978	2978
Energy Carried by Steam (MJ/hr)	**379**	**205**	**384**	**238**

Table A- 2 – 3; System Comparisons Before and After Modifications (Cont.)

Parameter	St. Joachim		DeenSide	
	Before	After	Before	After
Total Energy Loss Through Flue Gas MJ/hr	**707**	**448**	**864**	**580**
Radiation and Other Losses		**87**	**144**	**109**
Hot Air Flow Rate m3/sec	5.5	4.5	4.8	4.8
Enthalpy of Ambient Air kJ/kg at 29 0C	51	51	51	51
Enthalpy of Hot Air kJ/kg at 120 0C	121	121	121	121
Density of Hot Air kg/m3 at 120 0C	1.2	1.2	1.2	1.2
Energy Taken by Hot Air MJ/hr	**1663**	**1361**	**1452**	**1452**
Furnace Efficiency%	**53**	**76**	**50**	**66**
Total Made Tea kg	610	1246	696	425
Production Rate kg/hr	102	111	116	85
Specific Energy MJ/kg of Made tea	**5.1**	**1.4**	**4.1**	**5.1**
Specific Fuel kg of fuelwood/kg of made tea	**2.0**	**1.0**	**1.7**	**1.5**

3.0 Details for Financial Estimation

Table A-3 – 1; Man Power Requirement for Plant Operation

Man Power	System		
	Traditional System	Boiler System	Gasifire System
Machine Operation	1	1	1
Fuel Wood Preparation	-	-	2
Site Handling	1	1	2
Annual Charges	150,000	165,000	390,000

Table A-3 – 2; Fuel Wood Transport Cost

Fuelwood	System		
	Traditional System	Boiler System	Gasifire System
Annual Fuelwood (kg)	1264899	892870	632449
Truck Loads (No)	253	179	126
Transport Cost (Rs)	505,960.00	357,148.00	252,980.00

Table A-3 – 3; Electrical Energy Requirement in Different Systems [1]

Electricity	System		
	Traditional System	**Boiler System**	**Gasifire System**
Capacity (kW)	10	20	15
Consumption (kWh/day)	60	120	90
Monthly Cost (Rs)	16,350	32,700	24,525
Annual Electricity Cost (Rs)	196,200	392,400	294,300

Table A-3 –4; Specific Electrical Energy Consumption [12-17]

Region	Specific Electrical Energy Consumption
Low Country	0.65
Mid Country	0.76
Up Country	0.93

Table A-3 – 5; Annual Electrical Energy Cost (Rs) [12-17]

Region	System		
	Traditional System	**Boiler System**	**Gasifire System**
Low Country	167,803	274,258	251,704
Mid Country	196,200	320,671	294,300
Up Country	240,087	392,400	360,130

4.0 Trends in Tea

Table A-4 – 1; Trends in Tea [17]

Category/Year	1998	1999	2000	2001	2002	2003	2004
Production (kg mn)	280.1	283.7	305.8	2951	310	303.2	308.1
Total Extent (Hectares '000)	195	180	180	180	180	180	180
Extent Bearing (Heaters ' 000)	180	173	166	165	165	165	165
Cost of Production (Rs/kg)	100.71	101.29	110.64	124.06	124.06	135.58	158.25
Average Export Price (Rs/kg)	184.94	162.39	184.73	208.89	216.26	221.01	249.38
Colomb0o Auction Price (Rs/kg)	134.35	115.31	135.53	143.96	149.3	149.05	180.74
Replanting (Hectares)	1234	1376	1094	935	1028	935	1139
New Planting (Hectares)	400	415	264	642	562	642	22

Table A-4 – 2; Tea Production in Regional Category [17]

Category/Year	1998	1999	2000	2001	2002	2003	2004
High Grown (kg mn)	75.9	81.3	83.5	75.1	87	81.6	74.6
Medium Grown (kg mn)	53.9	53.5	56.2	3.8	54	54	49.7
Low Grown (kg mn)	150.3	148.9	166.1	166.2	169	167.7	183.9
Total (kg mn)	**280.1**	**283.7**	**305.8**	**295.1**	**310**	**303.2**	**308.1**

Table A-4 – 3; Daily Wedges in Tea Industry [17]

Year	Male		Female	
	With Food	Without Food	With Food	Without Food
2002	215	251	154	183
2003	234	276	171	199
2004	263	304	189	218

Table A-4 – 4; Tea Exports, Sales and Price [17]

Period	Exports			Colombo Auctions							
				Quantity Sold (000 kg)				Gross Price (Rs/kg)			
	Volume (000 kg)	Value (Rs .mn)	Price (Rs/kg)	High	Medium	Low	Total	High	Medium	Low	All Teas
1995	240801	24638	102.31	66102	45160	113933	225195	70.04	62.89	77.27	72.21
1996	244109	34068	139.56	63506	43123	123353	229982	93.38	89.70	114.35	103.88
1997	268537	42533	158.39	75163	48582	131032	254777	109.43	107.94	129.47	119.40
1998	271868	50280	184.94	69734	45268	141166	256168	127.60	121.45	141.88	134.35
1999	269279	43727	162.39	72772	51279	136704	260755	106.17	100.68	125.74	115.31
2000	288183	53133	184.73	75597	53040	148388	277025	128.46	119.08	144.79	135.53
2001	294903	61602	208.89	68577	50947	159490	279014	135.56	122.63	154.5	143.96
2002	291798	61105	216.26	83876	53087	174443	311406	135.65	125.45	163.19	149.30
2003	298342	65936	221.01	81783	50456	172126	304365	138.31	126.18	160.86	149.05
2004	300333	74897	249.38	59063	41657	169614	270334	171.78	159.96	189.86	180.74

Table A-4 – 5; Volume and Value of Tea Exports [17]

Item	2000		2001		2002		2003		2004	
	Volume	Value	Volume	Value	Volume	Value	Volume	Value	Volume	Value
	(000 kg)	(Rs. mn)	(000 kg)	(Rs. mn)	(000 kg)	(Rs. mn)	(000 kg)	(Rs. mn)	(000 kg)	(Rs. mn)
Black Tea in Bulk	182836	29105	176097	30407	188134	32954	176275	31097	186612	37979
Black Tea in Packets	85197	16385	99151	21817	83491	20292	98441	22987	84078	22357
Black Tea in Bags	12134	4850	13058	6133	14138	6944	15528	7778	17835	9256
Instant Tea	1218	617	1379	826	1298	838	1324	1017	1425	829
Green Tea	220	129	217	146	222	164	345	287	654	473
Other	6578	2047	5001	2273	4515	1913	6429	2771	9729	4003
Total	288183	53133	294903	61602	291798	63105	298342	65937	300333	74897

5.0 Fire Clay and Castables Specifications

Table A-5 – 1; Specifications of Standard Fire Clay

Code Number	FC -32	FC -40	FC- 50	FC -70
Chemical Analysis:-				
Al_2O_3	32	40	50	70
SiO_2	62	54	44	24
Grain Size:-				
Maximum (mm)	0.5	0.5	0.5	0.5
Less Than 0.1 mm (%)	35	35	35	35
Maximum Service Temperature (^0C)	1300	1400	1500	1560

Source: Lanka Refractory Ltd.

Table A-5 – 2; Specifications of Standard Castables

Code Number	HAC- 40	HAC-52	HAC -70	HAC- 80
Chemical Analysis:-				
Al_2O_3	40	52	70	80
SiO_2	54	44	24	14
Grain Size:-				
Maximum (mm)	5	5	5	5
Less Than 0.1 mm (%)	20	20	20	20
Maximum Service Temperature (^0C)	1350	1450	1550	1600

Source: Lanka Refractory Ltd.

6.0 Gasifire Selection

Table A-6 – 1; Gasifire Selection Data [6]

Parameter	Value Range	
Dryer Capacity (kg/hr)	125	150
Moisture Content (%)	70	70
Dryer Input (kg/hr)	179	214
Moisture Removed (kg/hr)	54	64
Energy Taken by Moisture (kJ/hr)	159536	191443
Dryer Efficiency (%)	40	40
Energy Input to the Dryer (kJ/hr)	398839	478607
(k W t)	111	133
Air Heater Efficiency (%)	50	50
Energy Input to the Air Heater (kW t)	222	266
Gasifire Efficiency (%)	50	50
Energy Input to the Gasifire (kW t)	443	532
(kJ/hr)	1595357	1914429
Calorific Value of Fuelwood (kJ/kg)	19500	19500
Fuelwood Consumption Rate (kg/hr)	82	98