The Potential for Wood Gasifiers for Tea Drying in Sri Lanka

T.H. Jayah, R.J. Fuller, Lu Aye, and D.F. Stewart
International Technologies Centre (IDTC)
Department of Civil and Environmental Engineering
The University of Melbourne
Parkville, Victoria 3010
AUSTRALIA

ABSTRACT

One of the reasons for the higher production cost of tea in Sri Lanka compared to other countries is the high specific energy consumption. In Sri Lanka, 38% more energy is used to produce one kilogram of tea compared to India, largely because of the use of inefficient wood-fired air heaters. Gasifiers have been proposed as an alternative method of providing the hot air used for drying. A locally built gasifier has been tested and found to have a conversion efficiency of 80%, which is comparable to that of an imported unit. The heat loss of the local gasifier was found to be between 11.5-14% of the input energy. An analysis shows that the life cycle cost of energy produced by the gasifier is US$3.00 per GJ, which is 8% less than the cost of energy from a conventional wood heater. Wood consumption is also reduced by 12%. Some transfer of gasifier technology to the crematoria industry in Sri Lanka has already occurred and this enhances the prospect of the successful introduction of this technology to the tea industry.

1. INTRODUCTION

Fossil fuel resources in Sri Lanka are very limited. Apart from a small surface deposit of peat found in the western coast of the island [1], Sri Lanka does not have any fossil fuel resources. As a result, almost all the domestic and industrial thermal energy requirement is met by biomass. In 1993, 66% of the total energy consumption comes from biomass and fuelwood accounted for 88% of this energy [2]. The tea industry, being the largest fuelwood consumer in the country, accounts for 33% of the total industrial fuelwood consumption [3]. These figures highlight the importance of fuelwood as an energy source for the tea industry in Sri Lanka.

The tea industry in Sri Lanka is faced with several problems that result in a high production cost relative to other producer countries. One of the contributing factors is the high energy consumption, which stands at 10% of the production cost [4]. In order to reduce the energy cost in the Sri Lankan tea industry, it is necessary to increase the thermal efficiency of the drying plant and to reduce the fuel wood consumption. In a preliminary study to assess the technical feasibility of gasifiers for the Sri Lankan tea industry, de Silva [5] has shown that a thermal efficiency of 83% can be achieved. Moreover the same study reported a fuelwood saving of 0.23 kg/kg tea compared to the conventional wood-fired air heater system.

This study assesses the viability of local gasifiers in technological, practical and financial terms. An overview of the development of local gasifier technology for the tea industry in Sri Lanka is first presented to highlight previous key findings. It is followed by a description of some experimental work designed to evaluate the performance of a local gasifier compared to an imported model. Then a detailed financial analysis of the wood gasifier system and the conventional wood-fired air heater system is presented. Finally, the potential for a successful transfer of the technology to the tea industry is discussed.

2. GASIFIERS FOR THE TEA INDUSTRY

The National Engineering Research and Development (NERD) Centre Sri Lanka is the pioneer research institution conducting research on gasifiers in the country with the aim of introducing this technology to local industries. The first gasifier fabricated for tea drying by the NERD Centre was in 1987 and a second gasifier was commissioned a year later. However these early attempts were not successful. There were several technical problems associated with these early models. These included high heat losses from the gasifier body, gas and air leakage from the system, rapid deterioration of materials used in the hearth zone, clogging of wood chips above the throat and severe corrosion of the inner wall of the body [5].

In 1988, the Tea Research Institute (TRI) of Sri Lanka also began conducting research on wood gasifiers to replace the traditional furnace system. As a result, a system consisting of a downdraft wood gasifier, gas burner and engine-cum-generator, fabricated in the Netherlands was tested between February 1988 and September 1990. The gasifier was designed to convert 190 kg of fuelwood per hour into 440 m^3 of gas. After cleaning, this gas was used in an internal combustion engine for power generation. The unit had a rated thermal and electrical capacity of 500 kW_{th} and 60 kW_e, respectively. The thermal conversion efficiency of the system was found to be 83% for fuelwood at 17% moisture content - wet basis (w.b.). During testing, a fuelwood saving of 0.23 kg/kg of tea was achieved [6].

Since the imported gasifier was too expensive and complicated to operate and maintain, the NERD Centre, in collaboration with the TRI, fabricated a downdraft heat gasifier using local technology and materials [7]. This 400 kW_{th} gasifier was installed in a tea factory in the TRI and testing began in 1994. Although the conversion efficiency and the detailed test data of the system were not reported, a fuelwood saving of 0.30 kg/kg of tea was apparently achieved during testing [7].

3. TEST GASIFIER

In order to further evaluate the NERD design, another locally fabricated gasifier of similar design to the 400 kW_{th} unit, but only 80 kW_{th} in capacity, has been tested (Fig. 1). The main reason for the selection of the smaller capacity gasifier was to reduce running costs. The downdraft test gasifier has an inner reactor diameter of 920 mm and is 1.15 m long. The inner and outer walls of the drum are made from 22 gage mild steel and 1.4 mm thick galvanized iron respectively and there is a small air gap between the walls (Fig. 2). Air is supplied to the combustion zone through 12 air nozzles, 6 mm in diameter, located 100 mm above the throat. The 100 mm diameter throat is lined with high alumina castable and is surrounded by firebricks to withstand the high temperatures in the combustion zone. Below the 220 mm long gasification zone, there is a grate to catch any unreacted char and an ash chamber lies below the grate. A 50 mm diameter galvanized steel pipe is used to extract the gas from the system and deliver it to the load.

4. EXPERIMENTAL WORK

The experimental test rig consisted of the test gasifier, fan, air flow meter, data logger, computer, orifice plate, manometer, cooling system, gas sample collector, thermocouples and scales (Fig. 3). Six *k*-type thermocouples in a high temperature resistant ceramic sheath were used to measure the temperatures at various intervals along the central axis of the gasification zone. Data such as moisture content and bulk density of wood chips were measured at the start of each of the 13 test runs of the gasifier. Three samples selected randomly were tested for each run and the average value was taken. The range of moisture contents of the samples varied from 11.1% to 15.6% (w.b.). The range of bulk density of the samples varied from 314-330 kg/m^3. The weight of wood used for each operation of the gasifier was also

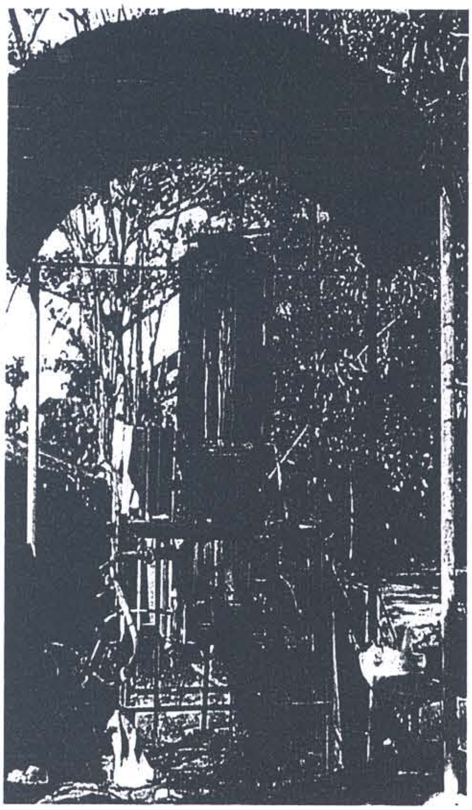

Fig. 1. Test gasifier.

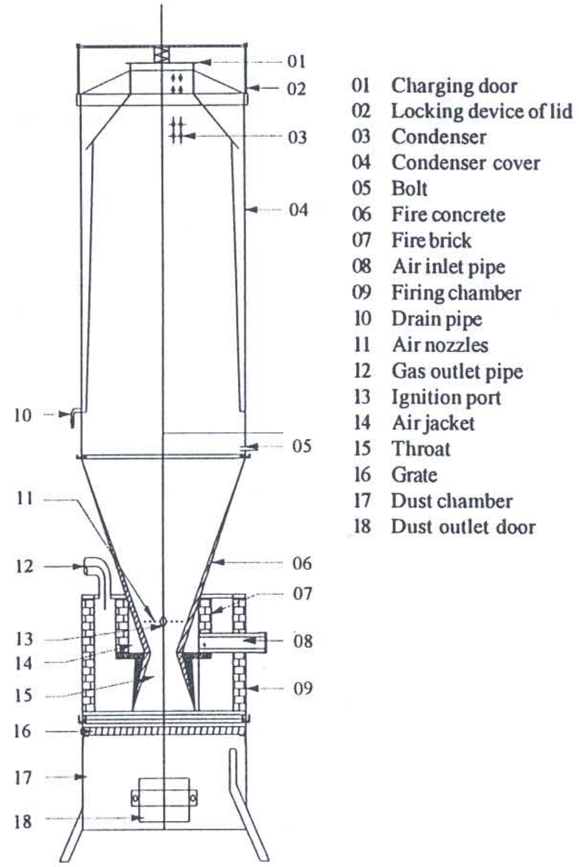

Fig. 2. Schematic diagram of the test gasifier [14].

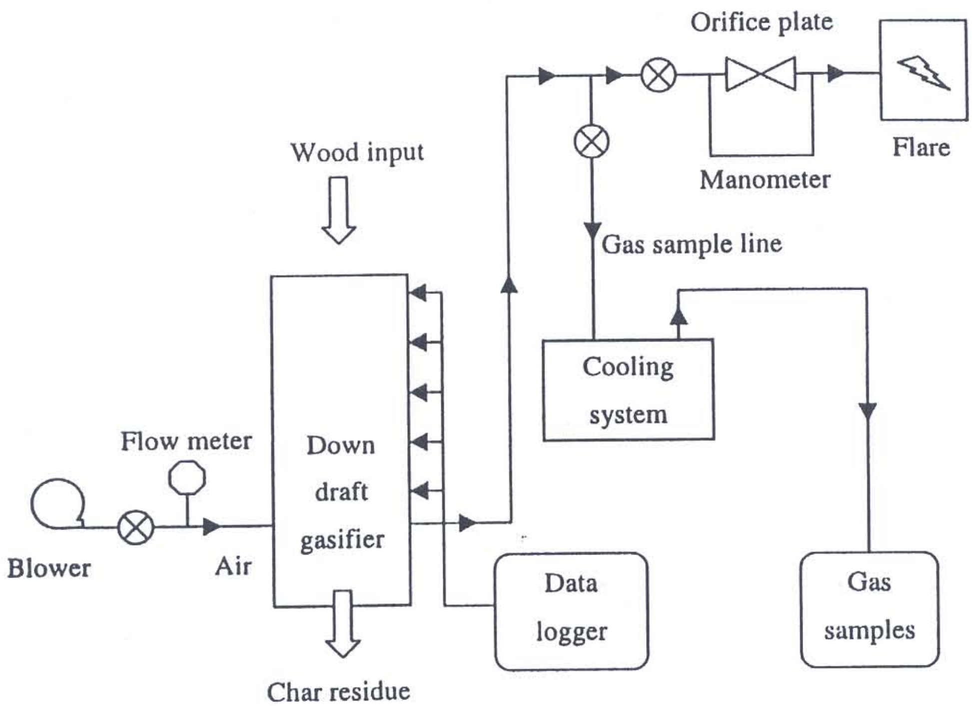

Fig. 3. Schematic diagram of the experimental system.

recorded. After ignition, as gas production started, the airflow rate, temperatures and pressure were recorded and a sample of the gas was collected for analysis. The experiments were conducted for three chip sizes (3.3, 4.4 and 5.5 cm) and for four air-fuel ratios.

4. PERFORMANCE EVALUATION

The aim of the experiments was to collect data to compare the performance of the local and imported gasifiers, to determine key parameters of the local design and to provide data to use in further improvement of performance and reliability. Three specific areas were investigated.

4.1. Gas Analysis and Conversion Efficiency

An example of the analysis of the gas produced by the test gasifier is given in Table 1. This composition is compared with that measured and reported for the imported gasifier for a moisture content of 17% (w.b.) [5]. A gas yield of 2.3 m³/kg of wood and lower heating value of 14.4 MJ/kg for wood have been used to determine the conversion efficiency of the imported gasifier, which is only marginally higher than the local unit.

4.2. Heat Losses

As stated above, the early NERD gasifiers had high heat losses. The heat loss, which is largely a function of the insulation type and thickness, has a significant effect on gasifier performance, particularly thermal efficiency. The heat loss of the test gasifier was therefore quantified in order to compare it with heat losses reported by other authors. Energy and material balances for the test gasifier were carried out using data recorded during two of the experimental runs and the heat loss was found to be between 11.5% and 14% of the input energy. Chern [8] stated that a level of 10% of input energy is acceptable for a commercial gasifier and Milligan [9] found by experiment that the heat loss in the various gasifiers ranged between 6% and 16% of input energy. It was also found that approximately 50% of the total heat loss occur in the gasification zone of the test gasifier. Despite this, the level of heat loss of the NERD test gasifier is comparable with other gasifiers and any change in insulation type or thickness in the gasification zone area should be fully evaluated to ensure that additional investment is justified.

4.3. Operating Temperatures

In order to avoid the premature deterioration of lining materials experienced in the early gasifiers, some knowledge of the typical throat and gasification zone temperatures and their relationship to key

Table 1 Typical Composition of the Product Gas
[3.3 cm chips @ 13.8% m.c. (w.b.) and air-fuel ratio of 2.2]

Parameter	Imported Gasifier	Test Gasifier
Gas composition (% by volume)		
CO	16.8	20.2
H_2	21.0	18.3
CH_4	1.8	1.1
CO_2	13.4	9.7
N_2	46.2	50.7
O_2	0.8	0.0
Conversion efficiency (%)	83.5	80.7

operating parameters is desirable. Temperatures were therefore measured at 4 cm intervals along the central axis down from the throat of the test gasifier. The highest temperatures in each test run consistently occurred 8 cm from the throat and ranged between 1252 K and 1493 K. In general, the higher temperatures occurred when the largest chips were used. Increasing the air-fuel ratio also increased gasification zone temperatures, presumably because of the increased oxidation of volatiles. High heat losses will reduce operating temperatures and it was determined that every one percent increase in heat loss would produce a drop in reactor temperature of 40 K.

4.4. Limitations

A more detailed comparison with the imported gasifier was not possible due to lack of input and performance data such as air-fuel ratio, chip size and heat loss for this unit. Despite this shortcoming, from a technical standpoint the local gasifier design appears to be comparable with other gasifiers. The data collected from the test gasifier have also been used to calibrate a gasifier model to investigate the optimum set of operating parameters for the local design and this work is reported in detail elsewhere [10].

5. FINANCIAL EVALUATION

In the past, another shortcoming in the successful development of local gasifiers has been the lack of a detailed cost and benefit analysis. The acceptance of gasifier technology by the tea industry in Sri Lanka will ultimately depend on the financial viability of the system. A preliminary financial analysis reported in a previous paper [11] was based on assumptions made because of the lack of practical data. The more comprehensive analysis below is based on an increased fuelwood consumption and includes fuel wood preparation cost and more accurate data of efficiency and operating hours. The present financial analysis should therefore represent a more realistic picture of the cost effectiveness of the technology.

6. COST AND BENEFIT ANALYSIS

In 1998, there were 594 tea factories operating in Sri Lanka [7]. Assuming an annual national tea production of 280,000 tons, an average factory will produce around 472 tons per year. If 250 working days a year is assumed, then the average daily production will be around 1900 kg. Over a ten-hour day, a drier with a capacity of 200 kg of tea per hour is required. It is shown in the Appendix that to meet these requirements, a gasifier with a fuelwood consumption rate of 180 kg/hr would be required, resulting in a fuelwood consumption of 0.90 kg/kg of tea at a moisture content of 17% (w.b.).

6.1. Wood-Fired Air Heater System

According to Tariq and Purvis [12], the combustion efficiency of the furnaces used in the tea industry is around 50%. The moisture content of wood logs used for tea drying in Sri Lanka is in the range of 25-45% (w.b.) [5]. An average moisture content of 35% corresponds to a lower heating value of 10.4 MJ/kg and a fuelwood consumption of 1.38 kg of wood per kg of tea. The initial investment cost of a locally fabricated wood-fired air heater with a 15-year life expectancy for a 200 kg/hr capacity drier is approximately US$15,400 [7]. If an operating and maintenance cost of 10% of the capital cost, inflation rates of 10% for operation and maintenance and 5% for fuel, and a market discount rate of 12% are assumed, then this results in a life cycle energy cost of US$3.25/GJ (see Appendix for details). Externalities such as effects on the environment and forest cover are not included in this calculation. Any new technology needs to be competitive with this life cycle energy cost.

6.2. Gasifier System

The price of fuelwood including preparation cost in the tea growing areas is about US$38/ton [7]. The initial investment of a locally fabricated gasifier with a capacity of 2.5 GJ/hr (700 kW_{th}) and a lifetime of 15 years is approximately US$23,000 [7]. If the same level of maintenance cost, inflation and discount rates used for the wood-fired air heater system are assumed, then this will result in a life cycle energy cost of US$3.00/GJ (see Appendix for details). A summary of the life cycle energy cost and estimated fuelwood consumption for the two systems is given in Table 2. The fuelwood consumption of the gasifier is adjusted to a moisture content of 35% (w.b.) to compare it with the wood-fired air heater system.

7. TECHNOLOGY TRANSFER

Although all the recent experimental work and the financial analysis above indicate that the local gasifiers can be technically and financially viable, their acceptance by the tea industry will also depend on the reliability of the system. Most of the early NERD gasifiers failed to attract the attention of the local industry because they did not perform consistently at their rated capacity. However, in the last 20 years, some 75 gasifiers of various capacities and types have been designed, fabricated and commissioned [6]. Most of these have been the downdraft type. The gasifiers have been used to provide energy for a variety of end uses including electricity generation, vehicles, foundry work and crematoria. They have been successfully adopted by the crematorium industry where a total of 32 gasifiers have been installed and commissioned. The uptake of gasifier technology by this industry is a promising sign for further transfer to other industries. It proves that local personnel can operate the technology reliably in a commercial setting, rather than merely in a research environment.

Stassen [13] in a UN-World Bank funded global review of gasifier technology stated that "building local capacity is a slow process, but it is the only one that will lead to successful projects that benefit rural communities". The 20 years of research, design and development activities in Sri Lanka seems to bear out this observation. According to Stassen, the "most effective gasification programs have resulted from the formation of strong and experienced local organisations that enable the training of local personnnel ..." The role of the NERD centre in developing a locally manufactured gasifier seems to have been pivotal in the successes, albeit limited to date, of this technology in Sri Lanka.

8. CONCLUSIONS

A locally fabricated gasifier appears to have a comparable performance to a more expensive imported unit. The gasifier offers the possibility of reducing fuelwood use in the tea industry by 0.17 kg of wood per kg of tea, i.e., a 12% saving in the drying process compared to the conventional wood-fired air-heating system. The life cycle cost of energy produced by the gasifier is 8% lower than that from a conventional system. With the advantages of a lower fuelwood consumption and energy cost, gasifier

Table 2 Energy Cost and Fuel Consumption for Wood Heater and Gasifier

System	Energy cost (US$/GJ)	Wood consumption at 35% m.c. (w.b.) (kg/kg of tea)
Wood fired air heater	3.25	1.38
Wood gasifier	3.00	1.21

systems appear to be a realistic option for the Sri Lankan tea industry to decrease production costs. Maintaining a gasifier requires the skills of trained operators and the successful uptake of the technology by the crematoria industry in Sri Lanka indicates that the technology can be operated and maintained by local personnel, supported by a core group of professionals at the NERD centre.

9. ACKNOWLEDGEMENTS

The authors wish to thank Mr. Victor Mendis, former Chairman, National Engineering Research and Development Centre, Sri Lanka for the information about the gasifiers. The financial support from the Asian Development Bank-Japanese Scholarship Programme is also acknowledged.

10. REFERENCES

[1] Ekono. 1985. '*Sri Lanka peat study*', quoted in Wijesinghe, L.C.A. de S. 1988. Biomass fuel and its utilization in Sri Lanka. *RERIC International Energy Journal* 10 (1): 67-80.

[2] Kumaradasa, M.A.; Bhattacharya, S.C.; Abdul Salam, P.; and Ghulam Qambar Amur. 1999. A study of biomass as a source of energy in Sri Lanka. *RERIC International Energy Journal* 21 (1): 55-68.

[3] Haskoning. 1989. *Energy Conservation in the Tea Industry in Sri Lanka, Conclusive Results*. The Netherlands-Sri Lanka Energy Programme, Sri Lanka.

[4] Sivaram, B. and Herath, D.P.B. 1996. *Labour Economics in Tea*. TRI, Sri Lanka.

[5] de Silva, W.C.A. 1994. Some energy saving achievements of the tea industry in Sri Lanka. *Sri Lanka Journal of Tea Science*, TRI Publication, 63 (2): 59-69.

[6] Weerarathna, M.D.S. 1999. *Development of Gasification Technology at NERDC*, 25th Anniversary Souvenir, NERD Centre, Sri Lanka, pp. 145-150

[7] Ziyad Mohamed, M.T. 1998. Personal communication, Deputy Director Research (Technology), Tea Research Institute, Sri Lanka.

[8] Chern, S.M. 1989. Equilibrium and kinetic modelling of co-current downdraft moving-bed gasifier. Ph.D. Thesis, Kansas State University, Kansas, U.S.A.

[9] Milligan, J.B. 1994. Downdraft gasification of biomass. Ph.D. Thesis, Aston University, Birmingham, U.K.

[10] Jayah, T.H. 2002. Evaluation of a downdraft wood gasifier for tea manufacturing in Sri Lanka. M.Eng.Sc. Thesis, Department of Civil and Environmental Engineering, University of Melbourne, Australia.

[11] Jayah, T.H.; Fuller, R.J.; and Lu Aye. 1998. Renewable energy options for the tea industry in Sri Lanka. In *Proceedings of the 36th Annual Conference of the Australia and New Zealand Solar Energy Society,* Christchurch, New Zealand, 25-27 November, pp 15-21.

[12] Tariq, A.S. and Purvis, M.R.I. 1997. Industrial biomass use in Sri Lanka. *International Journal of Energy Research* 21: 447-464.

[13] Stassen, H.E. 1995. Small-scale biomass gasifiers for heat and power - a global review. World Bank Technical Paper (Energy Series) No 296, Washington, D.C.

[14] Adhikarinayake, T.B. 1999. Personal communication. Head, Department of Agriculture Engineering, National Engineering Research and Development Centre, Sri Lanka.

11. APPENDIX: COST BENEFIT ANALYSIS DETAILS

General Assumptions and Nomenclature

• Overhead and maintenance costs	=	10% of capital costs
• Fuel price inflation(i_1)	=	5% pa
• Overhead and maintenance inflation(i_2)	=	10% pa
• Market discount (d)	=	12% pa
• Life time (N)	=	15 years
• Drier capacity	=	200 kg tea/hr
• Number of operating hours per day	=	10 hr
• Number of working days per year	=	250 days

Wood Fired Air Heater System

Energy Cost

Thermal efficiency of the plant	=	50%
Wood preparation cost	=	US$3.00/ton
Wood price	=	US$30.00/ton
Wood price including preparation cost	=	US$33.00/ton
Wood consumption by air heater system	=	1.38 kg/kg tea
Fuelwood requirement	=	200 x 1.38 kg/hr
		276 kg/hr
Thus, annual fuelwood cost	=	276 x 10 x 250 x 33/1000
		US$ 22,770
Energy production over lifetime	=	276 x 10 x 250 x 15x 14.0 x 0.50 MJ
	=	72,450 GJ
Initial cost of air heater	=	US$ 15,400
PWF (N=15, i_2=10, d=12)	=	13.64
PWF (N=15, i_1=5, d=12)	=	10.09
Life cycle cost	=	15400 + 1540 x PWF (N=15, i_2=10, d=12) + 22770 x PWF (N=15, i_1=5, d=12)
	=	US$ 235,379
Thus, energy cost	=	235,379 / 72,450
	=	**US$ 3.25/GJ**

Gasifier System

Wood Consumption

Assumptions

• Drier efficiency	=	50%
• Efficiency of burner and heat exchanger	=	85%
• Heating value of gas	=	5 MJ/Nm^3
• Gas yield per kg of wood	=	2.3 Nm^3
• Latent heat of water	=	2.4 MJ/kg

Initial moisture content of tea entering the drier	=	66% (w.b.)
Final moisture content of tea leaving the drier	=	3% (w.b.)

For one hour operation:

Weight of water to be removed	=	200 x (0.66 - 0.03)/(1.00 - 0.66)
	=	370.6 kg

Therefore, energy required	=	370.6 x 2.4 MJ
	=	889 MJ
Then energy input to the drier	=	889 / 0.50
	=	1778 MJ
Energy input to the burner and heat exchanger	=	1778 / 0.85
	=	2092 MJ
Gas requirement	=	2092 / 5
	=	418 Nm^3
Thus, wood consumption	=	418/2.3
	=	180 kg
Wood consumption per kg of tea	=	180 / 200
at m/c of 17% (w.b.)	=	**0.90 kg**

Energy Cost

Assumptions

• Conversion efficiency of the gasifier	=	80%
• H.V. of wood at m/c of 17% (w. b.)	=	14 MJ/kg

Wood Preparation Cost

Average labor cost for wood preparation	=	US$ 7.15/ton
Cost of power for sawing	=	US$ 0.86/ton
Thus, total wood preparation cost	=	US$ 8/ton
Wood price	=	US$ 30/ton
Wood price including preparation cost	=	US$ 38/ton
Wood consumption	=	180 kg/hr
Number of operating hours a day	=	10 hr
Number of working days a year	=	250 days
Thus, annual wood cost	=	180 x 10 x 250 x 38 / 1000
	=	US$ 17,100
Energy production over lifetime	=	180 x 10 x 250 x 15 x 14 x 0.80 MJ
	=	75,600 GJ
Initial cost of the gasifier	=	US$ 23,000
Life cycle cost	=	23,000 + 2,300 x PWF (N=15, i_2=10, d=12) + 17,100 x PWF (N=15, i_1=5, d=12)
	=	US$ 225,902
Thus, energy cost	=	226,911 / 75,600
	=	**US$3.00/GJ**