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Research Article

Experimental Assessment of Energy Potentials from Tea Wastes as a Source of Energy: A Case of Itona Tea Factory in Tanzania

Andrew Stephen Mwampulo[1, *], Arthur Mngoma Omari[1], Duncan Mwakipesile[2]

[1]Department of Electrical and Power Engineering, Mbeya University of Science and Technology, Mbeya, Tanzania
[2]Department Mechanical and Industrial Engineering, Mbeya University of Science and Technology, Mbeya, Tanzania

Abstract

Tea processing is an energy-intensive process. However, high agricultural productivity and subsequently the growth of the green revolution have been made possible only by a large amount of energy inputs, especially those from fossil fuels, wood fuels, and electricity. With recent price rise and scarcity of these fuels there has been a trend towards use of alternative energy sources such as waste (agricultural waste) to energy that could solve both energy and environment issues. Moreover, these energy resources have not been able to provide an economically viable solution for agricultural applications so long as they seem to contain amount of energy which can be source of energy to be used in various factories in rural areas through gasification process. A gasifier is normally fuel specific system and it is tailored around a fuel rather than the other way round. Hence, this paper presents an experimental assessment of energy potentials from tea wastes available at Itonaa Tea Factory for tea drying processes as important data for agricultural wastes. The experimental measurement of energy potential from tea wastes was done using bomb calorimeter, muffle furnace and energy balances to determine calorific value moisture content and energy potentials of tea waste respectively. The findings indicate that the combined energy potential of factory and garden tea waste was found to be $2.78x10^8$kWh, and corresponding electrical energy was estimated to be $2.78x10^7$kWh which is enough for tea drying process in tea manufacturing plant. The total energy used in the production of tea was discovered to be equal 3.5 - 7.5 kWh/kg of made tea. Thus, total energy consumption (4.5 kWh/kg of made tea) for processing of 9.6×10^6 kg of tea from 4.5×10^3 hectares of tea plantation in Mufindi for the period of 2021-2022 was $4.32x10^7$ kWh. Thus, with the proper utilization of energy conversion technology of tea waste, part of the energy requirement in processing of tea could be met reducing environmental challenges associated with both wood fuel burning and tea waste disposal.

Keywords

Factory Tea Waste, Potential Energy, Calorific Value, Garden Tea Waste

1. Introduction

Tea is undoubtedly the most popular beverage in the world [1-3], and due to its therapeutic benefits, including its anti-oxidative, anti-tumor, and anti-carcinogenic characteristics, it has gained more popularity recently [4].

*Corresponding author: amwampulo28@gmail.com (Andrew Stephen Mwampulo)

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Both consumers and scientists have recognized and arouse interest in the numerous health benefits of tea as a result tea processing receives special attention because it has a direct impact on tea quality [5, 6]. The balanced flavor of made tea is achieved upon drying [7, 8] because moisture is eliminated thus inhibiting fermentation and extending tea's storage life [9].

Tea processing includes a number of energy-intensive unit activities, including plucking, withering, rolling, maceration, fermentation, drying, grading, and packing [9]. Processing tea is a higher energy process that uses a ratio of 15:85 of electrical and thermal energy [10]. Thermal energy is extensively used during withering and drying processes, whereas electrical energy is used to power motors, fans, humidifiers, and lighting.

Itona tea factory is located at Itona Mufindi, Mafinga – Tanzania to which both forest and tea plantations are found at large. As per Tanzania Forest Agency (TFS) pine trees cover a big land as compared to other species of trees. Itona tea factories had to switch from oil furnaces to firewood-based boilers due to the rise in global oil prices and unstable, low – quality power supplied by TANESCO. The specific energy consumption varies from 4 -10.4 kWh/kg of made tea [11]. This transition is fraught with challenges, including the loss of forest cover and large quantities of money spent on buying firewood. The consequences of climate change have been amplified by the loss of trees, which has had an impact on tea production, resulting in lower yield [12, 13].

In order to produce tea in a sustainable manner, it is vital to pay close attention to energy consumption trends in the tea industry [14]. As a result, a good use of tea waste could fulfill a portion of the energy necessary in tea processing. Tea waste includes both processing (factory) waste and garden waste. During the sorting or grading of manufactured tea, processing waste is generated. The fibers are removed from the primary tea during this process. Garden waste, on the other hand, is generated during the off-season when tea bushes are pruned. The tea waste from bush varies from 2-2.5 kg for wet matter basis per bush per year in a 4-year pruning cycle. According to a study the tea waste generation is about 2% of the total tea production [15]. Therefore, utilizing tea waste in a productive way could provide some of the energy needed for the tea-processing process. Tea waste is a biomass in which energy can be generated through gasification and pyrolysis.

2. Methods and Materials

During the assessment, samples and amount of tea bush were collected from Itona Tea factory in Mfindi Tanzania. Both processing (factory) waste and garden waste were collected as samples for assessment of moisture content, calorific value and their total available energy as follows:

2.1. Determination of the Moisture Content (MC)

The samples were broken up into tiny pieces and kept at 105 ℃ for a full day in a muffle furnace. The moisture content of factory waste, garden waste leaves and branches were calculated by using Equation 1.

$$MC = \frac{W_{ws} - W_{ds}}{W_w} x100 \quad (1)$$

Where,
W_{ws} = Weight of wet sample
W_{ds} = Weight of dry sample

2.2. Calorific Value

A bomb calorimeter was used to measure the calorific value of the sample. A bomb-calorimeter measures the amount of heat produced when a sample is burned under controlled conditions in a closed vessel that is submerged in water and has an oxygen atmosphere. A calorimeter is used to measure the increase in temperature caused by the heat released into the surrounding water during the burning process, which is dictated by the burning process. The calorific value of the sample is determined using the formula as shown in Equation 2.

$$Calorific\ Value\ \left(\frac{kWh}{kg}\right) = \frac{W_w\ x\ (T_1 - T_0)}{W_s}\ x\ C \quad (2)$$

Where,
W_w = Weight of water equivalent to calorimeter (g)
T_0 = Temperature before firing (℃)
T_1 = Maximum temperature after firing (℃)
W_s = Weight of sample (g)
C = 0.00116 (Constant).

2.3. Energy Potential Estimation from Tea Waste

Energy balances was applied to calculate energy potentials of tea waste from two sources namely factory and garden source.

2.3.1. Factory tea waste (FTW)

The energy potential of factory tea waste was determined by Eq. 3,

$$E_p(kWh) = P(Kg)x0.02F_{cv}(kWh/kg) \quad (3)$$

Where,
E_p = Total energy (kWh)
P = Tea production (kg)
F_{cv} = Calorific value of tea waste from the factory (kWh/kg)
0.02 = Constant, percentage of tea waste generated

2.3.2. Garden Waste

The energy potential of tea bush waste and shade tree waste was calculated by using Eq. (4).

$$E_p(kWh) = B_w(Kg)xNxA(h_a)G_{cv}(kWh/kg) \quad (4)$$

Where,
E_p = Total energy (kWh)
B_w = Waste from tea bush (kg)
N = Total number of tea bush/hectare
A = Plantation area of the tea bush (ha)
G_{cv} = calorific value of the waste's tea bush (kWh/kg)

3. Results and Discussions

This section presents findings and briefly explains its implications in the context of the study. The main objective of the study was to estimate the energy potentials of tea waste as a source of energy for Itona tea factory.

About 2% of the total tea produced was wasted during the sorting process. Withering (35%), crush tear curl (CTC) (6%), fermentation (0.7%), drying (57%), sorting (0.6%), packaging (0.1%), and auxiliary activities (0.6%) were shown to use the most energy among the many unit operations in the manufacture of tea. It was discovered that the overall energy used in the processing tea was between 3.5 and 7.5 kWh/kg of produced tea. The average pruned tea leaves and branches obtained were recorded as 10 kg/tea bush/pruning cycle. Thus, the average annual pruned material obtained in a pruning cycle of 4 year was 2.5 kg/tea bush. The average moisture content of processing (tea factory) waste, tea bush pruned leaves, tea bush pruned branches were determined as 2%, 80 %, 58 %, for wet basis, respectively.

3.1. Computation of Energy in Tea Waste

Using a bomb calorimeter, the calorific value of tea waste samples was determined, and it was found that the average calorific value of processed tea waste was 5.056 kWh/kg. As demonstrated in Table 1, the average calorific value of the garden waste samples (tea leaves and branches) that were gathered and examined was determined to be 4.303 kWh/kg.

Table 1. *Calorific value of tea bush waste.*

Garden waste	Calorific value (kWh/kg)	Average calorific value(kWh/kg)
Tea leaves	4.282	4.303
Branch of tea bush	4.324	

3.2. Energy Potential of Tea Waste

The energy potential from processing tea waste (approximately 1.91 x 10^5 kg) in Itona tea factory during the year 2021-2022 was calculated as 1.062 x 10^6 kWh as represented in Table 2. On the other hand, the energy obtainable from the garden tea bush pruned materials (leaves and branches) was estimated as 3.25 x 108 kWh as shown in Table 3.

Table 2. *Energy potential of factory tea waste.*

Parameters	Value
Annual tea production around Itona (kg)	9.550531 x 106
Tea waste (kg)	1.91 x 105
Calorific value (kWh/kg)	5.056
Energy potential (kWh)	1.062 x 106

Table 3. *Energy potential of garden tea bush wate.*

Parameters	Value
Tea plantation area around Itona tea factory (hectare)	4500
Spacing between rows (m)	1.05
Spacing between bushes (m)	0.70
Bush/area (m^2)	1.05 x 0.70 = 0.735
Bush/area (hectare)	10000/0.735 = 13605
Total number of bushes	13605 x 4500 = 6.12 x 107
Garden tea waste/bush/year (wet matter basis) (kg)	2.5
Garden tea waste/bush/ per year (dry matter basis) (kg)	1.05
Total garden tea waste (dry matter basis) (kg)	6.12 x 107 x 1.05 = 6.43 x 107

3.3. Energy Consumption in Tea Factory

The total energy consumption in tea manufacturing was found to be 3.5 - 7.5 kWh/kg of made tea. Hence, the total energy consumption (4.5 kWh/kg of made tea) for processing 9.6 x 10^6 kg of tea from 4500 hectares tea plantation in Mfindi district during the year 2021 - 2022 was 4.32x10^7 kWh from which the thermal energy consumption per kg of tea produced was around 5.67 times that of electrical energy as compared to data by Mwenda, (2016).

3.4. Energy Saving Using Tea Waste

Mufindi District tea estate waste produced 2.78x10^{8}kWh of usable energy. Energy conversion efficiency of calorific value to electrical energy was assumed to be 10%. The total amount of energy in terms of electrical energy that can be obtained from wastes in tea estates was estimated to be 2.78 x 10^7 kWh. Hence, the total energy available from tea waste compared with total energy consumption annually during manufacturing of tea (4.32x10^7 kWh, 4.5 kWh/kg of made tea) shows that 64.4% amount of energy required in tea processing could be saved with the utilization such as gasification technology of tea waste generated from tea industries.

4. Conclusion

The total energy potential of tea waste (factory and garden waste) was estimated as 2.78x10^{8}kWh. Thus, with the positive utilization of tea waste, part of the energy requirement in processing of tea could be met. It could replace the use of wood fuel for tea drying and therefore minimizing environmental challenges associated with both wood fuel burning and tea waste disposal.

Conflicts of Interest

The authors declare no conflicts of interest.

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