Chapter-3

Assessment of Energy Consumption in a Tea Factory in Assam

Among the many energy intensive processes, tea processing is also regarded as one such process. All the operations of tea manufacturing require about (14.4-64.8) MJ/kg of made tea. The energy expenses constitute about 30% of the total tea production costs. The tea manufacturing processes ingest thermal and electrical energy sufficiently. Most of the energy used is thermal energy in the tea factories of Assam [24]. The *SEC* lies between (14.4-144.4) MJ/kg of made product [26,192]. The cultivation and transportation of tea consumes energy as petro-fuels [147]. The poor energy utilities give rise to more environmental problems [168]. Use of non-conventional power sources would be beneficial environmentally in energy consumption in tea processing [145].

A case study was conducted in a tea factory in Chenijan in Jorhat, Assam. The factory manufactures CTC tea. The energy expended in the different processing steps of CTC tea manufacturing was evaluated. Most of the energy used was thermal energy which was mainly required to reduce the moisture level of tea leaves during the wilting and drying operations in the factory under study. Electrical energy on the other hand got utilized in almost all the operations. Energy management was assessed in terms of the cost of energy per unit volume of production. Natural gas was used as the source of thermal energy in the factory. The particulars of the different machinery used and power consumed by them in the various operations are illustrated in the succeeding sections below. All the machines and equipment are assumed to be working in full load conditions. Power factor for electricity consumption is considered as 0.8 from the energy bill. The per unit (kWh) cost of electricity is considered as ₹7.25 and that of per m^3 of gas as ₹11.06 [155]. Fig. 3.1 shows the energy input in the various tea processing stages.

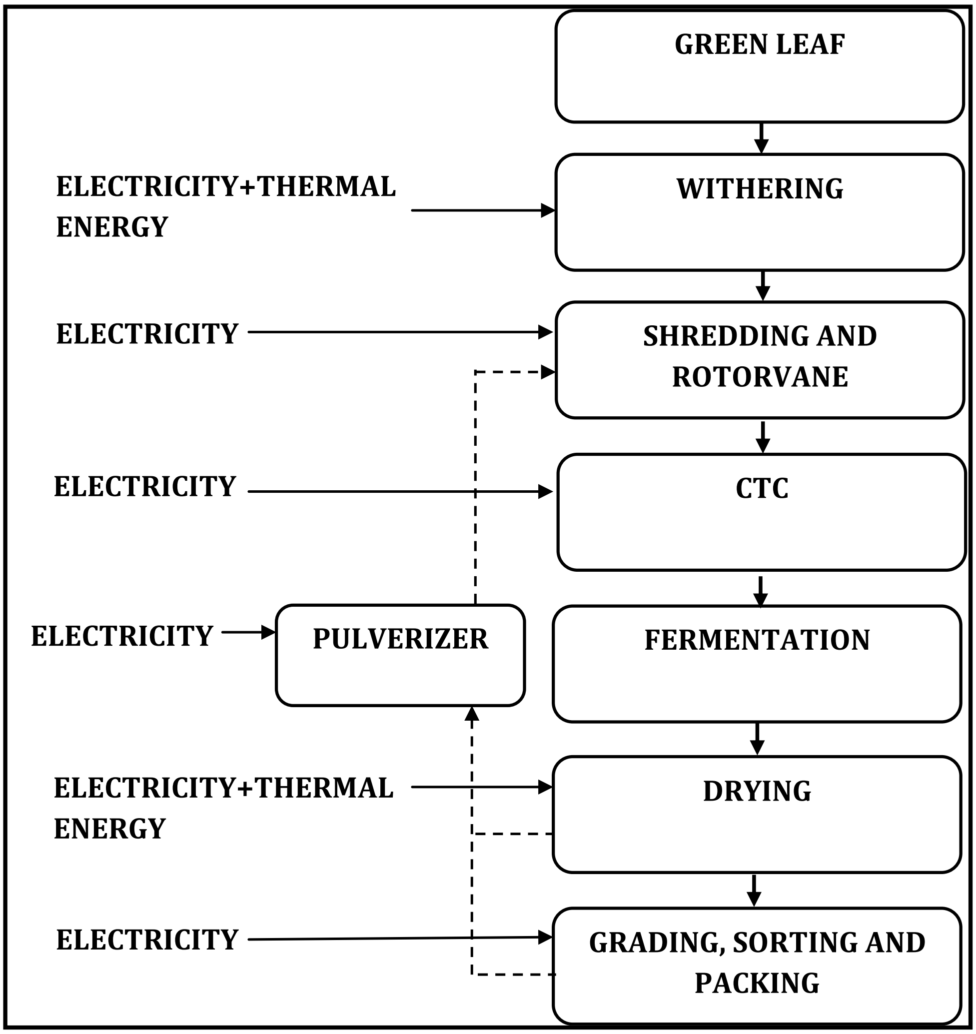

Fig 3.1. Process and energy input for CTC tea manufacturing [192]

3.1 Withering Equipment

The industry uses an enclosed trough tea withering process. In an enclosed withering trough, the leaf bed is set in a closed environment. The rims of the troughs are raised to a certain height and a cover is put on top of the bed to create such an ambience. This design creates a plenum chamber over the leaf bed. In this system of tea withering, the fan always blows air in the forward direction. The airflow can be either from the top to bottom or vice-versa with a provision of damper and shutter control at the entrance and exit respectively. However, the fan direction remains unreversed during the process. Due to less handling of tea leaves in enclosed trough, the chance of damage is much lesser. The leaves in turn also get some seclusion from the rapid changes in the atmospheric conditions. In the factory, 2 kg of green leaf is spread per square feet of the bed area. Usually, the RH is measured using wet and dry bulb thermometers. The Hygrometric Difference or HD is the variance between the readings of wet and dry bulb thermometers. A variance of 4 °C is found to be ideal under typical conditions [6]. If the difference is less than 4 °C, then preheating of the air is required which is carried out by introducing gas flame at the inlet. The HD readings are taken in regular intervals to determine the terminations of withering of the tea leaves after the attainment of a desired degree of wither. Since the temperature of hot air is higher in the entry region of the trough than the exit, usually a heap of leaves is kept at the entry of the trough. Fig. 3.2 shows a schematic diagram of an enclosed tea withering trough.

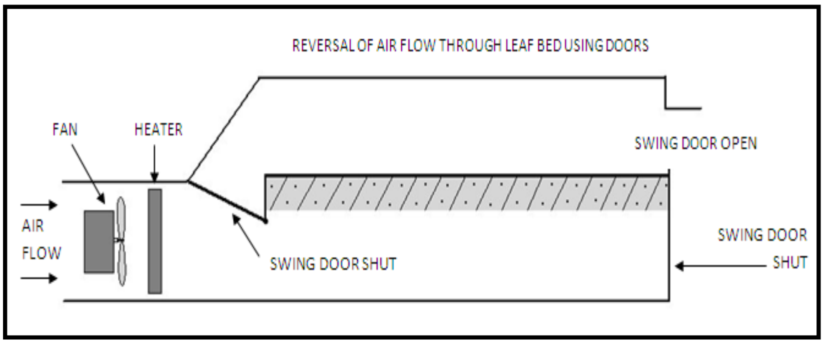

Fig. 3.2. Schematic diagram of an enclosed tea withering trough

Around 2550 kg of green leaf is withered in a single shift of withering. Flame strength in the gas burner is 401.76 kW and its estimation is described in Table-3.1. The volume, density and calorific value (CV) of the natural gas is considered as 1 m^3, 0.714 kg/m^3 and 35538.36 kJ/kg respectively. The combustion efficiency is assumed to be 95%.

Table-3.1. List of withering equipment and power consumption

Flame Strength = (volume of gas/s) × density of gas × CV of gas × Combustion efficiency

= (1 × 0.714 × 35538.36 × 0.95) / 60

= 401.76 kW

All the calculations are made for a single shift of withering:

Weight of green leaves = (Area of the leaf bed × Weight of leaf per m^2)

= (25.91 m × 4.57 m × 21.53 kg)

= 2550 kg

Equipment	Specification	Hours of Operation	Energy Consumed (kWh) (1HP=0.7355 kW) [Formula: Power in kW × Time in h × cosϕ]	Avg. Cost per unit (₹)	Total Cost (₹)

Blower Fan	10 HP, 3ϕ	Rainy days: 12 h	2 × (10 × 0.7355 × 12 × 0.8) = 141.22 kWh	7.25	1023.85
		Sunny days: 10 h	2 × (10 × 0.7355 × 10 × 0.8) = 117.68 kWh	7.25	853.18
Gas Burner	Natural gas, Pressure: 0.5 kgf/cm^2 Type: 3A burner Avg. flow rate: 1 m^3/min	Rainy days: 3 h	(1 m^3/min × 3 × 60) = 180 m^3 (or) 401.76 × 3 = 1205.28 kWh	11.06	1990.8
		Sunny days: nil	---	---	---

3.2 Maceration Equipment

The CTC maceration equipment can be further divided into:

- Rotorvane
- CTC

3.2.1 The Rotorvane

The Rotorvane usually preconditions the tea leaves by providing twist to the already withered leaves. This aids the CTC rollers to give proper treatment. It is a cylinder with one end closed and the other open. A feed hopper is installed near the closed end. Resistors are fitted inside the processing zone. A rotor is fitted concentrically inside the cylinder. It consists of a feed worm, with vanes disposed at small angle and at right angles to the next one. An end device, which is generally an Iris plate in case of Rotorvane is present here. A 3ϕ motor transmits the power to the rotor vane shaft with the help of v-belt drive. The withered tea leaves are fed through the hopper and carried to the processing zone where these are worked upon mechanically. Inside the cylinder there are 12 steel blades having width of 0.08 m and length 0.12 m. The blades rub against a set of fixed blades on the internal circumference of the cylinder. The leaves are injured sufficiently because of the continuous feeding by the feed worm and rubbing action of the blades. This is very much necessary for the subsequent CTC operation. Fig. 3.3 shows a typical rotorvane.

Fig. 3.3. A Rotorvane [213]

3.2.2 The CTC

The process of Crushing-Tearing-Curling (CTC) is carried out by the teeth present on the two stainless steel rollers. The rollers are machined with circumferential and helical grooves meshed properly and rotated in contrasting directions at a 1:10 speed ratio. The roller diameter fluctuates between (0.203-0.2095) m. The pre-conditioned leaves from the rotorvane are brought to the rollers with the help of a conveyer belt made from hygienic rubber sheet. Two cylindrical rollers with diameter 0.17 m and length 1m provide the required tension to the rubber sheet. For avoiding buckling of the sheet, a third roller is positioned at a distance of 0.75 m from the top roller. The conveyor gets the required motion from the top roller. A chain and sprocket drive system from the CTC cutter shaft provides the power to the top roller, which in turn acquires the power from a 25 HP motor. A v-belt drive is used to transfer the power from the motor to the CTC cutter gear box. This gear box delivers the needed speed ratio of 1:10. In order to recompense the minor transverse motion of the CTC rollers during their operation, some universal joints with toothed ends are added between the CTC cutter end and the gear box shaft. A magnetic bar over the conveyor sheet eradicates the metallic bits in the macerated leafs occurring from the cutter teeth rupture or some other factors. Three to four CTC machines are connected to one another by means of conveyors which carry the leaves to the next cutting units.

The withered tea leaves of weight 600 kg (approx.) go through the maceration process. The time taken for the completion of maceration stage is 1 h. Table-3.2 shows the energy consumed during the maceration operation.

Table-3.2. List of maceration equipment and power consumption

Weight of withered leaf: 600 kg   Time taken: 1 h

Equipment	Specification	Hours of Operation	Energy Consumed (kWh) (1HP=0.7355 kW) [Formula: Power in kW × Time in h × cosϕ]	Avg. Cost per kWh (₹)	Total Cost (₹)
Rotorvane	20 HP, 3ϕ, 1440 rpm	1 h	(20 × 0.7355 × 1× 0.8) = 11.77 kWh	7.25	85.33
	Roller no-1: 25 HP, 3ϕ, 1450 rpm	1 h	(25 × 0.7355 × 1 × 0.8) = 14.71 kWh	7.25	106.65
CTC	Roller no-2: 20 HP, 3ϕ, 1450 rpm	1 h	(20 × 0.7355 × 1 × 0.8) = 11.77 kWh	7.25	85.33
	Roller no-3: 20 HP, 3ϕ, 1450 rpm	1 h	(20 × 0.7355 × 1 × 0.8) = 11.77 kWh	7.25	85.33
Ghoogi	3 HP, 3ϕ, 950 rpm	1 h	(3 × 0.7355 × 1 × 0.8) = 1.77 kWh	7.25	12.83

3.3 Fermentation equipment

Energy is required during the natural tea fermentation process only if humidifiers are used. Electrical energy is consumed for rotating the drum in drum fermentation as well as in continuous fermentation to run the blowers. The humidity of the ambient air decides about the use of humidifiers. Hence, it becomes quite tough to estimate the power consumption and in turn, the cost incurred during fermentation. On the other hand, the cost incurred is very small in comparison to the other costs of production. The industry uses the natural fermentation process and therefore, the fermentation cost is neglected here.

3.4 Drying equipment

As described earlier, drying is the most energy-intensive tea processing operation. Mainly, two varieties of dryers are used- conventional pressure chamber type and the fluidized bed type (FBD). The factory under study uses the conventional pressure chamber type dryer. It consists of a rectangular compartment having conveyors which carry the fermented leaves through it and hot air is blown through the chamber. The conveyors run usually at a speed ratio of 10:14:18 and they are positioned to resemble three tray circuits. These values are the speed ratios (speed of driver to speed of driven) of conveyor sprockets of ECP (Endless Chain Pressure) tea dryer. To support the proper loading (drying) time of fermented tea leaves for drying, these consecutive enhanced speed ratios are maintained as per the manufacturer's specification of the ECP type tray dryer. The fermented tea is put from the top in a filling tray placed over the dryer. The filling tray is installed at an angle of about 20° and above it, a metallic conveyor takes the tea to the dryer tray circuits. The material is spread evenly along the conveyor width with the help of a scrapper. This provides a uniformity in the thickness of the tea which is essential for uniform drying. The required driving power to the tray circuit is given by a 3 HP motor. The motor is connected to a step cone pulley which helps in varying the speed of the circuit, thus varying the drying time. The hot air intake duct is the only open side of the drying chamber, rest all the sides remain closed. Chain guides and sprockets are fitted to the side walls of the chamber. To prevent air leakage, air baffles are fitted at the ends. The floor gets scrapped continuously by a scrapper circuit fitted at the bottom to avoid accumulation. There is a furnace at the other end of the dryer where natural gas is burnt in an insulated cylindrical chamber. An overhead fan brings the heat produced by the flame to the main dryer chamber. The time required for tea drying varies with the degree of wither, temperature, volume of air and thickness of spread. Fig. 3.4 shows the schematic diagram of a conventional tea dryer.

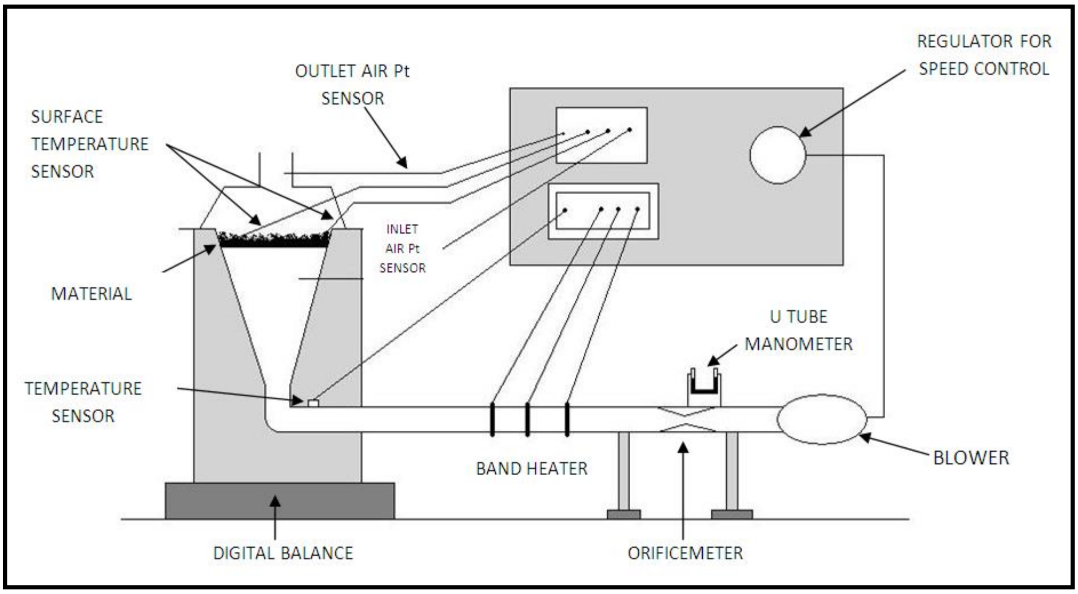

Fig. 3.4. Schematic diagram of a conventional tea dryer

Table-3.3 shows the drying equipment and the energy consumed by them. The total weight of the leaves after fermentation comes down to 170 kg. The drying time required is 1 h. The flame strength in drying is 803.52 kW and is estimated as shown in Table-3.3. The volume, density and calorific value (CV) of the natural gas is considered as 1 m^3, 0.714 kg/m^3 and 35538.36 kJ/kg respectively. The combustion efficiency is assumed to be 95%.

Table-3.3. List of drying equipment and power consumption

Flame Strength = (volume of gas/sec) × density of gas × CV of gas

= (2 × 0.714 × 35538.36 × 0.95) / 60

= 803.52 kW

Weight of fermented leaf: 170 kg   Time taken: 1 h

Equipment	**Specification**	**Hours of Operation**	**Energy Consumed (kWh) (1HP = 0.7355 kW) [Formula: Power in kW × Time in h × cosϕ]**	**Avg. Cost per unit (₹)**	**Total Cost (₹)**
Fan motor	15 HP, 3ϕ, 1440 rpm	1 h	(15 × 0.7355 × 1 × 0.8) = 8.83 kWh	7.25	64.02
Tray motor	3 HP, 3ϕ, 950 rpm	1 h	(3 × 0.7355 × 1 × 0.8) = 1.77 kWh	7.25	12.83
Gas flame	Natural gas, Pressure: 1 kgf/cm^2 Type: 4A burner Avg. flow rate: 2 m^3/min		(2 m^3 /min × 1 × 60) = 120 m^3 (or) 803.52 × 1 = 803.52 kWh	11.06	1327.20

3.5 Grading equipment

The dried tea initially is full of different particles like stalks, fibers, leaf portions, etc. It is passed over mechanically oscillated sieves to sort into various grades. Generally, the method of fiber extraction varies from estate to estate. In CTC process, tea is first sent through an electrostatic fiber extractor (EFE). The principle of static electricity is used in this machine to extract fiber and stalk. The machine is generally (10-12) ft long with a width of (3-4) ft. In the EFE, there are two stages with three and four PVC rollers each. Each one having about 4 inch diameter rotates at speed of around (2000-2500) rpm on strong bearings mounted in plumber blocks. Dried tea comes into contact with the PVC rollers after being fed into the machine through a conveyor system. This gives rise to friction between them which results in generation of static electricity. The fiber and rollers develop opposite charges and hence the particles get attracted towards the rollers. However, the fiber is turned over by means of centrifugal force and gets gathered in boxes of aluminum installed over the conveyors in between the rollers. It is then relocated to different trays and collected in different containers according to their size.

Table-3.4 shows the equipment used for fiber extraction and the energy consumed by them. The weight of the dried leaves is now 120 kg and the time needed for fiber extraction is 1 h.

Table-3.4. List of fiber extraction equipment and power consumption

Weight of dried tea leaf: 125 kg   Time taken: 1 h

Equipment	**Specification**	**Hours of Operation**	**Energy Consumed (kWh) (1h HP = 0.7355 kW) [Formula: Power in kW × Time in h × cosϕ]**	**Avg. Cost per kWh (₹)**	**Total Cost (₹)**
Conveyor 1	1 HP, 3ϕ, 950 rpm	1 h	(1 × 0.7355 × 1 × 0.8) = 0.6 kWh	7.25	4.35
Conveyor 2	1 HP, 3ϕ, 950 rpm	1 h	(1 × 0.7355 × 1 × 0.8) = 0.6 kWh	7.25	4.35

Pre Sorter	3 HP, 3ϕ , 950 rpm	1 h	(3 × 0.7355 × 1 × 0.8) = 1.77 kWh	7.25	12.83
Main Sorter	3 HP, 3ϕ, 950 rpm	1 h	(3 × 0.7355 × 1 × 0.8) = 1.77 kWh	7.25	12.83

3.6 Energy consumption

Fig. 3.5 illustrates the amount of energy or power consumed during the different stages of tea processing. Both thermal and electrical energy consumed in kWh is computed for 100 kg weight of tea. It is clear from the calculation that drying is the most energy intensive tea processing operation followed by withering compared to the other processes. Drying 100 kg of fermented tea consumes 497.53 kWh of thermal and 6.23 kWh of electrical energy. In SI units, the values are 1791.11 MJ and 22.43 MJ respectively. Similarly, the thermal energy consumed to wither 100 kg tea leaves is estimated to be 49.75 kWh and the electrical energy ingested for the same is 10.15 kWh. The values are 179.10 MJ and 19.94 MJ respectively in SI units. Though the electrical energy consumption in maceration is higher, the overall consumption is less due to no thermal usage in this stage.

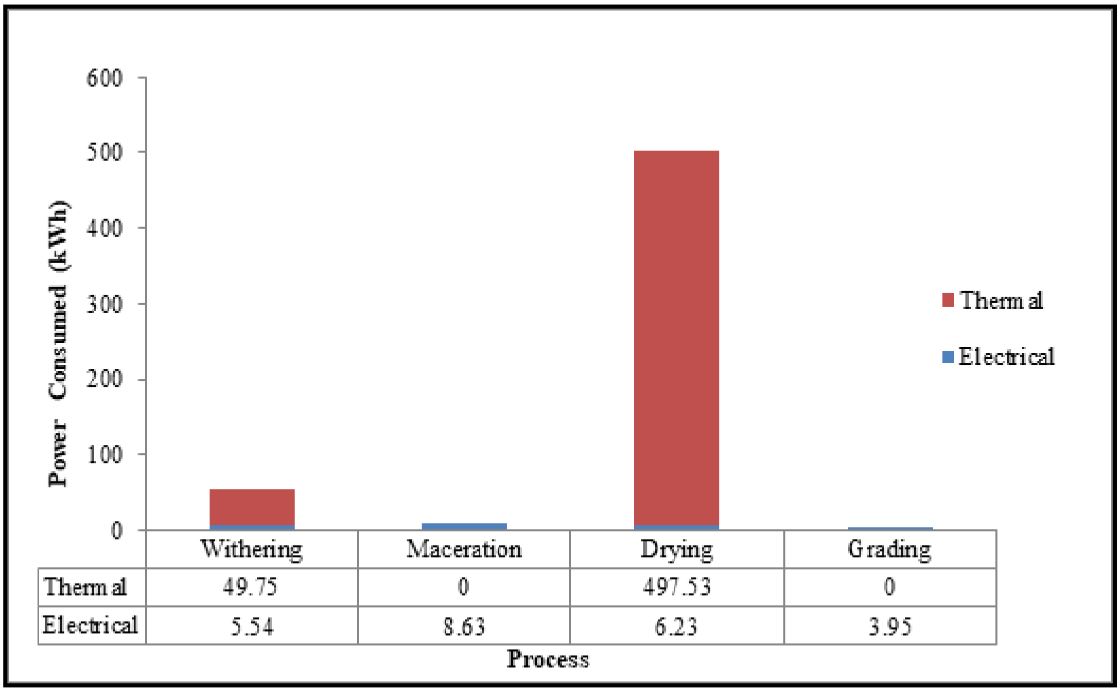

Fig. 3.5. Power consumption versus process

3.6.1 Energy costs

Fig. 3.6 depicts the energy costs incurred per kg of tea leaves during tea processing in different production stages. It is evident that drying being the most energy exhaustive process, the cost of drying constitutes the maximum portion of the total production cost and it is about ₹8.26 per kg. This is again followed by withering with a cost of around ₹1.18 per kg. Fig. 3.7 shows the specific energy cost for the industry under study. The specific gas cost is ₹8.6 whereas the specific electricity cost turns out to be ₹1.76.

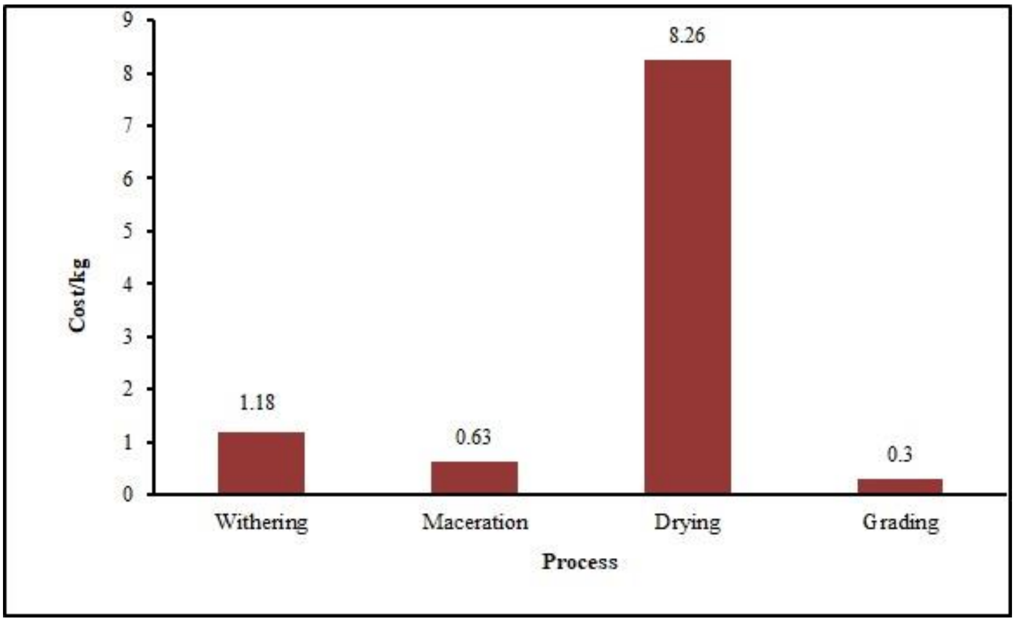

Fig. 3.6. Cost incurred per kg versus Process

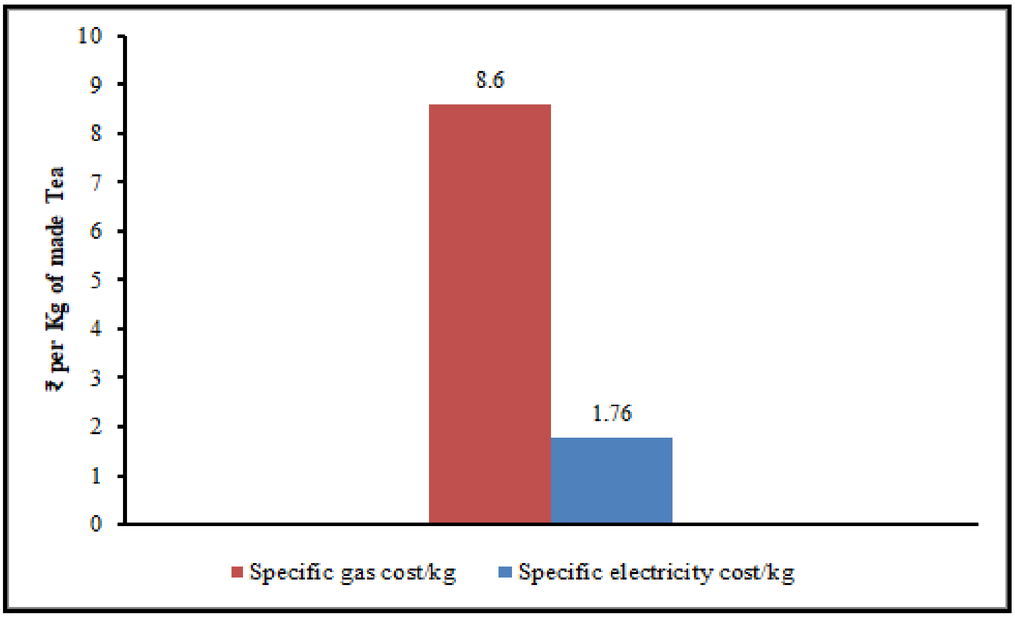

Fig. 3.7. Specific energy cost for the industry

3.6.2 Comparison with the South Indian tea industries

An attempt has been made to compare the energy consumption patterns in some tea factories with those of some South Indian tea manufacturing industries from literature available [24, 225]. Fig. 3.8 and Fig. 3.9 shows the energy consumption in tea processing in Assam and South India respectively. It is found that the thermal and electrical energy consumption is around 20% and 69% higher in Assam than those in South India respectively. This evidently shows that ample opportunity is there to upgrade the tea manufacturing procedure in the local tea factories of Assam, be it in terms of machinery, technique or management.

The specific gas and electricity costs per kg of made tea are critical parameters for determining thermal energy costs. However, per kg gas or per unit electricity cost over India is not a critical parameter since these costs may vary slightly across different regions in India. However, variations in these costs could somewhat impact the overall thermal energy cost of the tea manufacturing process across different locations. The major contributing factors for energy cost per kg of made tea are overall efficiency of fuel burner (combustion efficiency, excess air used, mechanical/electrical efficiency of drive, control system of combustion devices) etc.

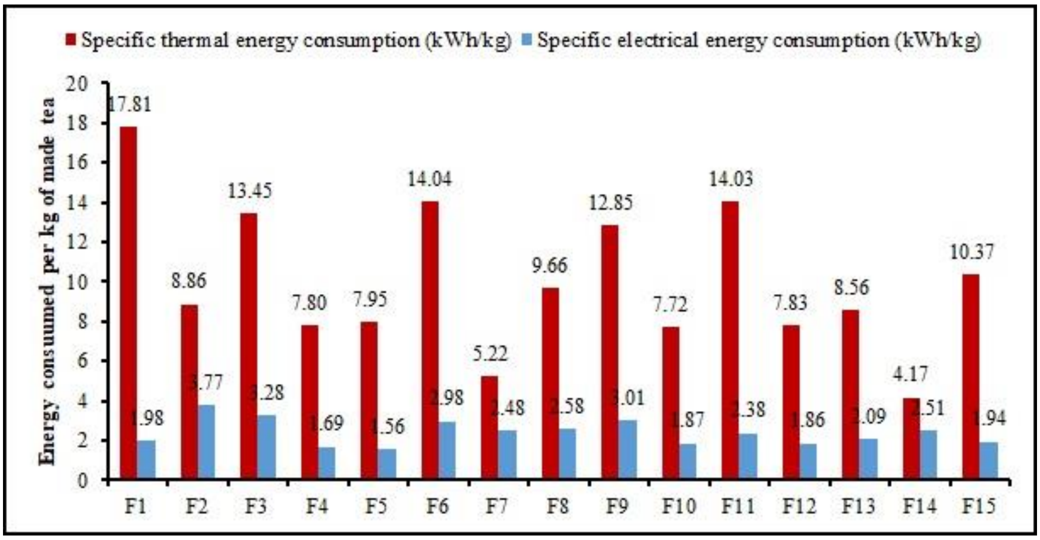

Fig. 3.8. Energy consumption in different tea factories of Assam [24]

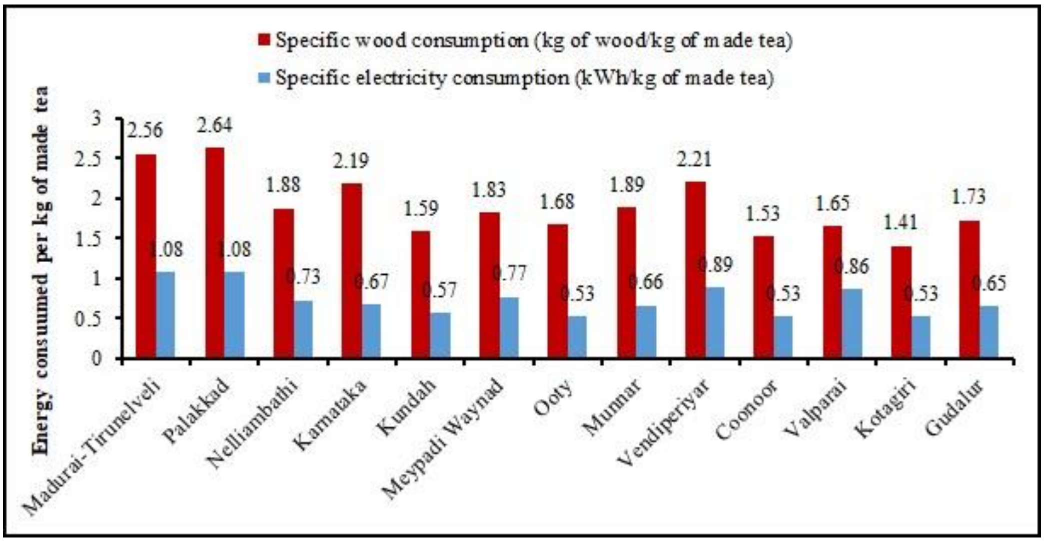

Fig. 3.9. Energy consumption in South Indian tea industries [225]

3.7 Measures for energy management

Energy management is a tactic to manage the use of energy and lessen the energy costs. The analysis done here pinpoints the areas of high energy ingestion, and thereby taking precautionary actions to reduce the same. On the basis of this analysis and taking the help of literature survey, some energy effluent technologies may be embraced by the tea industry which will reduce the production cost to a considerable amount.

3.7.1 Improvements in the electrical energy utilization

By making a few changes to the various processes, the consumption of electrical energy may be greatly decreased. A tea industry uses around 20% of the total electrical energy for the wilting operation. The majority of trough fans are found to be large, and neither the motor speed nor the air flow can be adjusted. Process conditions are not well monitored, and this frequently results in higher electricity usage. Following are the methods by which considerable amount of electrical energy can be saved.

3.7.1a Dual speed withering

The energy consumption in tea withering may be reduced to around 0.08 units/kg of made tea by using fiber reinforced plastic (FRP) fans and an aerofoil bladed flexible pitch fan having dual speed. The main advantages of FRP fans over conventional fans are-

- Low power consumption due to lighter blades.
- FRP fans are corrosion free.
- The longevity of the mechanical drive system is extended due to the less overall weight of the fan.

- Lesser flow noise than conventional metallic fans.
- Longer life due to better mechanical strength.

3.7.1b Automatic rollers

Manually operated rollers work at a very low efficiency of 40% leading to the loss of energy. By replacing these manually operated rollers by automatic ones, the motor efficiency may be improved to around 75%. This will reduce the energy loss. It also increases the quality of the made tea and reduces the time for rolling process.

3.7.1c Implementing solar energy

Solar energy utilization is expanding and is even being used commercially. According to a research done at a South Indian tea factory, using a solar air preheater reduced the fuel use by 15-20%. For the whole Indian tea industry, this amounted to almost 168 M coal equivalent savings with a specific thermal energy range between (4.5-6) kWh. Additionally, it was able to cut the withering time by around 3 h, conserving electricity [135].

3.7.1d Other methods

A few other methods for saving electrical energy are-

- Use of flat belt in CTC machine: Flat belts seem to be more efficient because of their large contact area and being less prone to bending and wedging over the V- belts.
- Use of proper starter: The electricity consumption of star connected starter is less than delta connected starter.
- Improvement of the power factor.
- Elimination of leakage and loss of current.
- Use of CFL bulbs for lightening purpose.
- Use of energy star rating equipment.
- Use of electronic control system.

3.7.2 Improvements in the thermal energy utilization

A significant portion of the overall energy used in tea factories is thermal energy. By recovering waste heat from the dryers, thermal energy usage might be significantly improved. Following are some of the methods of by which significant amount of thermal energy can be saved-

3.7.2a Waste heat recovery

The flue gas and dryer exhaust can be used to recover a sizable quantity of heat energy. Economizers, which can pre-heat air intake to air heaters, can recover the heat from the flue gas. Commercial machines are available for both preheating the outside air and, in the case of boiler systems, preheating the water.

3.7.2b Direct fired heaters

Indirect heaters, which are essentially tubular heat exchangers using coal or firewood, are used by the majority of the tea industry. Direct-fired heaters, in which flue gas is delivered directly to the dryer, have recently become popular in various tea-related sectors. Both the fluidized bed and the traditional dryers are excellent candidates for this system. Temperature uniformity and fuel efficiency are guaranteed. However, this is only feasible if a clean fuel is accessible, like low sulphur LPG or oil.

3.7.2c Recirculation of exhaust air from the dryer

It has been noted that the dryer's exhaust air is not completely saturated and can still take in moisture from the tea leaves. As a result, some of the exhaust can be recycled. Other industries' dryers employ this technique as well. Adopting this in tea dryers presents challenges because the exhaust air contains tea particles that could clog the air pipes. However, this might be avoided by offering effective filters. On a case-by-case basis, the economics are also beneficial, and the investment needed is minimal.

3.7.2d Fuel efficient air heaters

Dryers with ineffective heat transmission utilize a lot of fuel, which results in a lot of thermal energy being used during the drying process. Some firms also employ a separate heater for the withering procedure. Older heaters, inadequate thermal insulation, blocked air tubes, air leaks, etc. are to blame for this. It also results from human feeding of fuel and incomplete combustion brought on by wet and uncut firewood. Thus, it becomes essential to switch over to air heaters with better efficacies.

3.7.2e Other methods

A few other methods for saving thermal energy are-

- Use of proper insulation to reduce the heat loss.
- Use of electronic temperature control measures to prevent overheating and energy loss.

3.8 Summary of the chapter

The present study shows the possibility of energy management in a tea processing industry. On the basis of the analysis done, a few points can be abridged which may benefit the industry management to pick out their flaws as far as energy utilization is concerned and guide them towards the enhancement of productivity in terms of energy cost and production. The following are the salient points drawn-

- The thermal energy consumed in the local tea factories is around 20% higher than that in the South Indian tea industries.
- The requirement of natural gas for thermal energy adds a large portion to the production cost.
- The maximum expense is in the drying process at about ₹8.26 per kg of made tea followed by withering at ₹1.18.
- The thermal energy consumed while drying 100 kg of fermented tea is 1791.11 MJ whereas that consumed to wither 100 kg tea leaves is estimated to be 179.10 MJ for the factory under consideration.

The limited resources of conventional fuels are making the tea production process costly day by day. However, availability of the non-conventional energy sources in abundance brings a ray of hope and their use in the tea sector may help in mending from this energy crisis condition. Therefore, an attempt has been made to find out the possibility of implementing solar thermal energy in the tea withering process in this research work. The elaborate analyses and discussion on the endeavor are discussed in the chapters to follow in this thesis.