1

Introduction

1.1 History of Tea

Tea has a very fascinating story. Tea is included in the large family of camellias within which about 90 species are known. Camellias are well known for the beauty of their flowers and shiny dark green leaves. These species are primarily distributed on the mainland of south-east Asia. The commercially important tea plant, Camellia sinensis (L.) O. Kuntze, has been known to Chinese people for certainly more than 2000 years, and is consumed as a beverage throughout the world. In C. sinensis, two varieties are found - var. sinensis, characterized by a small leaf and a bush-type habit, and var. assamica, which has a large leaf and a tall, tree-type habit. Generally, green tea is produced from var. sinensis, while black tea is manufactured from var. assamica.
1.1 History of Tea

The Chinese had discovered that the infusion of tea leaves, if carefully processed, produce a very appetizing drink. The people in Siam (now Thailand) and Shan States of Burma (now Myanmar) had also been using the leaves of the tea plant for as long as the Chinese. At first, they used it for medicinal purposes and later on as a beverage. Although tea plants have been found growing near to all the caravan routes between China and India, in the late 18th century, Europeans reported tea plants growing wild at Kathmandu. In Assam, indigenous plant had been found extended eastwards through the Naga Hills and into Burma. Also in the whole region between upper Assam and Manipur to the south, connecting up with the Chinese provinces of Sze-chuan and Yu-nan tea had been grown. So, it is seen that the tea camellia, C. sinensis and its many var., is indigenous throughout the forests of south-east Asia where, in its natural state, it grows into a tree between 30 and 40 feet tall.

It is known that the Chinese were drinking tea in the 5th century AD. The Turkish traders carried it westwards first and later on reached the Mongolian border to barter goods for Chinese produce. By the end of the 6th century tea had been begun to be regarded not just as a medicinal drink, but as a refreshing beverage. The famous book, Cha Ching (tea book) written by Lo-Yu in the year 780 AD, describes the preparation of the leaf and manufacture of tea.

Methods of cultivation on small plots of land in China had remained unchanged for centuries. The new "plantation" way of growing tea was started in British India, which was incompatible for older Chinese method. China lost most of great leaf trade with Britain and the British Empire, but continued to supply Russia, mainly in the form of brick-teas. China had been exporting brick-tea since the early 17th century that was carried by porters over the
high mountains into Tibet, Siberia and Mongolia for hundreds of years and this trade also remained unaffected by the new Indian and Ceylonese (Sri Lankan) teas.

By the year 1900 China’s exports of tea had dropped catastrophically due to the result of linking of tea drinkers worldwide with new Indian and Ceylon teas. One million acres of tropical jungle had been felled in India and Ceylon for tea plantation by the same year. This was the achievement of the British commercial Empire, unforgettable courage and determination to succeed under terrible conditions of a new breed of man, the pioneer planters [1].

1.1.1  The Discovery of the Tea Plant in North-East India

In 1823, Singpho chief informed Major Robert Bruce, who was in the province of Assam, about the existence of tea plants near Sadiya in north-east Assam. The natives had the habit of drinking an infusion of dried leaves from the plants that were growing wild in the forests. Robert Bruce and his brother Charles Alexander Bruce, commanding HM gunboats on the North-East Frontier, sent samples of these plants to the Botanical Gardens in Calcutta for identification. Upon close examination it was found to be of the same family, camellia, but not the same species, from which the Chinese tea is manufactured. But this startling discovery went largely unrecognized; no official action was taken at that time [1].

In 1832, Lieutenant Charlton of the Assam Light Infantry at Sadiya found similar wild tea plants growing in the jungle close to his garrison. Like Bruce, he also sent seeds and
1.1 History of Tea

leaf samples of the camellia to the Botanical Gardens at Calcutta. Finally his report set the
wheels in motion within the East India Company.

1.1.2 Introduction of Indian Tea as Market Product

The very first samples of tea, made from indigenous plants of Assam, were sent to Calcutta
in December 1837. This historical consignment of Indian tea left Calcutta on the sailing ship
towards the end of May 1838 and which arrived London docks in November of the same year.
On the 10th January 1839, the auction of eight chests of Indian tea was held at the London
Commercial Sale Rooms in Mincing Lane.

Early in 1840 two-thirds of the East India Company’s tea lands were handed over to the
newly formed Assam Company free of rent for a period of ten years. Over the next 15 years
the tea produced in Assam was only by the Assam Company. During the early 1850s there
were many new private planters who took up land on their own account for tea plantation and
most notable among the new-comers was the Jorehaut Tea Company in 1859.

In the mid 1850s the first *baries* (houses) were formed and the first tea garden was opened
in 1857. Tea cultivation was first started in an area below the town of Darjeeling in the
early 1850s. Although Chinese *jat* (breed) was unsuccessful in its trials down on the plains
of Assam, the Chinese plant was known to be very suitable for growing at cooler, higher
elevations. The tea growing area gradually spread eastwards and reached the boundary of
Assam. The small-leafed frost-resistant China plant was well suited to the *Kangra* valley and
the surrounding hill districts [1].
1.1 History of Tea

1.1.3 Present Day Scenario of Tea

Tea is grown in more than 35 countries spread over all the continents except North America. According to the report of Tea Board of India, in 2015 total global production and consumption were 5305 million Kg and 4999 Kg respectively. China had highest production among the tea producing countries with a total production of 2278 million Kg. Production shares of tea producing countries are shown in fig.1.1.

In 15 states of India tea is cultivated. Among them, Assam, West Bengal, Tamil Nadu and Kerala are the major tea growing states. 97% of total production of Indian tea is accounted from these states. The other states where tea is grown are Tripura, Himachal Pradesh, Uttarakhand, Bihar and Karnataka. The states that have started growing tea are Arunachal Pradesh, Manipur, Meghalaya, Mizoram, Nagaland and Sikkim.

India is the second largest producer of tea. In India during 2015-16, total area of tea cultivation was 566.66 thousand hectors where Assam has the highest tea cultivation of
307.08 thousand hectares. Total production of Indian tea was 1233.14 million Kg out of which 1121.35 million Kg were CTC (Crush/Cut, Tear and Curl) and 111.79 million Kg were orthodox (Darjeeling+Green) (fig. 1.2). Out of the tea producing states, Assam had the highest production of 652.95 million Kg [2]. CTC is the most widely produced and consumed tea type in Assam.

The tea gardens of India sell their teas generally in three modes, viz.

1. Through auction,

2. Export under forward contact,

3. Private sell.

46% of the total production is sold through public auction and the remaining through other modes. Domestic retention of tea in India is shown in fig.1.3 and all India tea auction prices are shown in fig.1.4.
1.1 History of Tea

Fig. 1.3 Domestic retention (Tea Board of India report 2015-2016)

Fig. 1.4 Auction price (Tea Board of India report 2015-2016)
1.2 Tea Processing

In order to preserve for a longer period of time or for transportation to distant markets, the drying of agricultural crops is a traditional method of treatment. The tea crop decomposes in a relatively short time since at the moment of harvesting it has a high moisture level. The basic need of tea processing is to achieve the optimum flavour and quality so that a clean attractive product is produced [1]. Teas have different types and they are characterised by their physical appearances and quality attributes. The processing techniques involved for different types of teas are different [3]. Tea is generally classified into six different types, viz. white tea, green tea, yellow tea, Oolong tea, black tea and post-fermented tea [4].

Basically, tea processing consists of a series of operations in the following order:

1. Partial removal of moisture (withering);
2. Leaf disintegration into small pieces (cutting, rolling);
3. Quality development by exposure to air (oxidation or fermentation);
4. Completion of moisture removal (drying or firing);
5. Sieving into size fractions with fibre removal (sorting).

The most important physical functions are water removal and particle size determination, while the most important chemical aspects occur in withering, fermenting and drying [1].

Withering is the foundation for achieving good quality in produced tea. It is a common process for the manufacture of all types of tea except green and yellow tea. Both physical and chemical processes are involved in withering. Freshly plucked leaves are conditioned
physically and also chemically for subsequent processing stages. The physical withering reduces the moisture content (MC) of the fresh leaf. It also makes the leaf ‘flaccid’ or ‘rubbery’ which is essential for the subsequent processing stages. Chemical withering starts immediately after plucking of tea leaves which involves several biochemical processes like release of carbon dioxide and water, which is, due to fragmentation of larger molecules. The biochemical changes contribute to the very important quality attributes of tea like the ‘body’ and the ‘flavour’ [5].

The cutting operations require optimum leaf moisture levels. Sometimes when the leaves are not fine, rolling operation is employed before cutting. Proper cutting operation results in production of main grade percentage. The most popular cutting machine, the CTC, is capable of producing higher main grade percentages over a wider range of withered leaf moistures. A moisture level of 68–70 % is preferred. For orthodox tea, rollers generally utilizes withered leaf of 60 % moisture or lower. In this method generally dust and small particles produced is less, but has some other operational disadvantages. Depending on the design of withering and drying system, the operational optimum moisture level in cutting or rolling system is determined. If the withering system can remove less water, it means final drying capacity needed will be more and vice versa [1].

The fermentation process in tea manufacturing implies to how much extent tea is allowed to undergo enzymatic oxidation. The process objective of oxidation is to provide close interaction of the catechins with the respective enzymes for oxidizing the catechins in presence of oxygen. In these oxidation reactions, the temperature and relative humidity (RH) have a major role. These two parameters should be maintained at such a levels so that
the enzyme activity is at the peak. Adequate supply of oxygen is necessary for oxidation, insufficiency of which leads to dull liquors. Irrespective of orthodox or CTC, processed leaf should immediately be subjected to oxidation on the floor or continuous fermenting machine (CFM). This has profound effect on the liquors of final product. Various liquor qualities of tea are formed depending on to what extent the catechins have been oxidized to individual theaflavins (TF), particularly the theaflavin gallates, as well as, on to what extent conversion of TFs to thearubigins (TR) take place. Quality, briskness, strength and colour change with temperature and time. Each desired character reaches its peak at different times [6].

Drying is necessary to arrest enzymic reaction and stop oxidation process. It is also necessary to remove moisture from the fermented leaf particles so as to produce a stable product with durable quality. Drying is influenced by temperature of inlet and exhaust air, volume of air, quantity of leaf fed (i.e. thickness of spread) and period of drying (throughput time). In the process of drying, the moisture is reduced from around 70 % to 3 % [7]. Tea processing stages are shown in fig.1.5.

1.3 Process Parameters in Tea Manufacturing

The important parameters in tea processing are -

1. Temperature,

2. Relative humidity and

1.3 Process Parameters in Tea Manufacturing

Fig. 1.5 Block diagram of tea processing
1.3 Process Parameters in Tea Manufacturing

Proper control of these three parameters in each and every processing stages is the key for achieving good quality of product.

To get the desired effects of the above parameters air is utilised widely in tea manufacturing process. Uses of air in tea processing are as follows-

1. To remove moisture during withering at relatively low temperature,

2. To control the temperature of leaf during fermentation,

3. To supply oxygen to the leaf during fermentation,

4. To supply heat to the fermented tea for enzyme inactivation and to remove moisture during drying, at relatively higher temperature.

To carry out these various tasks air is supplied in appropriate conditions of temperature and moisture handling capability as well as in the correct quantity.

The moisture removal process in withering is highly dependent on ambient condition. If the RH level in ambient is very high (suppose 100 %), the air is already saturated, the only way it can be made to carry more moisture is by heating it. On the other hand if air is at around 70 % RH it is capable of carrying moisture without an increase in temperature. In both cases latent heat of evaporation is achieved from the temperature of incoming air.

Air supplied during fermentation ensures

1. Adequate supply of oxygen necessary for the biochemical and chemical reactions and

2. Control of leaf temperature.
Failure to maintain these leads to degradation in quality of final product. Ambient RH determines the required time duration of fermentation. Sometimes additional supply of moisture becomes necessary in fermentation room.

Temperature plays profound role in drying stage compared to other parameters although moisture in produced tea is a critical issue. Heated air approximately 100 °C or higher is passed through the fermented tea. Even after passing through tea particles, the exhaust temperature is much higher than the ambient which is generally 49-54 °C. The other influencing parameters in drying are volume of air, quantity of leaf fed (i.e. thickness of spread) and period of drying (throughput time).

## 1.4 Grading and Quality Parameters of Produced Tea

Along with the quantity, quality is a major concern for tea manufacturing. Quality of produced tea determines its value in the market. Tea quality is determined from various aspects such as the body, texture or aroma and appearance; although the quality of the final product is highly influenced by cultural practice, soil, geographical location and climate.

Most of the tea producers use “grading terms” for identification of the appearance of black tea. These terms do not have any universal standard. China teas are generally graded by number based on quality of raw material and manufacturing. Highest grade starts from 1 and the grade ends at 9. The grading terms used in Japan and Taiwan are: Extra Choicest, Choicest, Choice, Finest, Fine, Good Medium, Medium, Good Common, Common, Nubs, Dust and Fanning. Extra Choicest is the best quality product.
The most common grading terms are used in Europe, Sri Lanka, India, Africa, Indonesia, Argentina and Malaysia. Some of them are tabulated in table 1.1 [8].

Table 1.1 Tea grading acronyms [8]

<table>
<thead>
<tr>
<th>SL. No.</th>
<th>Acronyms</th>
<th>Full form</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>OP</td>
<td>Orange Pekoe</td>
</tr>
<tr>
<td>2</td>
<td>FOP</td>
<td>Flowery Orange Pekoe</td>
</tr>
<tr>
<td>3</td>
<td>GFOP</td>
<td>Golden Flowery Orange Pekoe</td>
</tr>
<tr>
<td>4</td>
<td>TGFOP</td>
<td>Tippy Golden Flowery Orange Pekoe</td>
</tr>
<tr>
<td>5</td>
<td>TGFOP-1</td>
<td>Tippy Golden Flowery Orange Pekoe One</td>
</tr>
<tr>
<td>6</td>
<td>FTGFOP</td>
<td>Finest Tippy Golden Flowery Orange Pekoe</td>
</tr>
<tr>
<td>7</td>
<td>FTGFOP-1</td>
<td>Finest Tippy Golden Flowery Orange Pekoe One</td>
</tr>
<tr>
<td>8</td>
<td>SFTGFOP</td>
<td>Special Finest Tippy Golden Flowery Orange Pekoe</td>
</tr>
<tr>
<td>9</td>
<td>SFTGFOP-1</td>
<td>Special Finest Tippy Golden Flowery Orange Pekoe One</td>
</tr>
</tbody>
</table>

The letter “B” is added to the name for broken leaves, as in BOP (Broken Orange Pekoe), FBOP, GBOP, TGBOP, etc.

Fanning and dust grades are used for smaller grades such as OF, OPF, FBOPF, FD, GD.

Tea grades are marked by the producer, so sometimes there may be variations.

Based on taste of the liquor, a taster describes and values tea. Taste is a very complex property which is difficult to be assessed chemically. Based on his previous knowledge and
experience of the outturn of a particular estate, a taster makes evaluation of the product to
gives his conclusions.

The taster’s infusion is prepared in a mug fitted with a lid. To make the infusion, 6 grams of tea is placed in the mug first. Boiling water is poured into the mug, the lid is removed and
the infusion is left to settle down for five minutes. The infusion and the infused leaves are
separated by gradually pouring the liquor into a bigger cup than the mug. The infused leaf is
placed on to the inverted lid and placed on top of the mug. The term, “infused” leaf refers to
the wet leaf that is left over after the liquor is drained out and “infusion” refers to the liquor.

With a loud sucking noise, the tea taster takes the tea into his mouth. In tea tasting,
besides the tongue which experiences taste, other surfaces of the mouth also play a major
role. Therefore, the tea taster swirls the liquor round his tongue and gums. Draws the aroma
back into the mouth and up into the olfactory nerves. The taster, thus, tastes, feels and smells
the liquid.

There are four kinds of tastes -

1. Salty,

2. Sour,

3. Sweet and


Different tastes are experienced by different parts of the tongue. The tip of the tongue
experiences the sweetness and saltiness whereas the back experiences bitterness. Saltiness is
also tasted at the sides of the front of the tongue. At the back edges, sourness is experienced.
On the gums and part of the cheek, stringency or pungency is felt. When the tea taster swirls the liquor, round the mouth, he also feels and judges the thickness and body or viscosity.

Tea tasting is a precise skill, which can be well performed only with a good natural palate and active olfactory nerve. Besides tasting and describing tea, the ability to decide the value, reflects experience and knowledge of a tea tester. Tea tasting terms and describing characteristics are given in table 1.2.

**Table 1.2 Tea tasting terms and characteristics [9]**

<table>
<thead>
<tr>
<th>SL. No.</th>
<th>Tea quality term</th>
<th>Characteristic</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Autumnal</td>
<td>Tea manufactured in the period of autumn is known as autumnal tea. In that period, the leaf obtained after drying is reddish in colour, but with various degrees of flavour and aroma, for which it is preferred by a lot of customers.</td>
</tr>
<tr>
<td>2</td>
<td>Bakey</td>
<td>Due to high temperatures during drying this undesirable characteristic is developed in manufactured tea.</td>
</tr>
<tr>
<td>3</td>
<td>Black</td>
<td>This is a desirable characteristic of tea. This indicates the black colour of tea instead of brown, red or green. Only fine plucking and careful manufacture process can produced this grade.</td>
</tr>
<tr>
<td>4</td>
<td>Bloom</td>
<td>Outward look of the particles is indicated by bloom. This characteristic is found if development of a varnish-like film occurs on individual particles during manufacture.</td>
</tr>
</tbody>
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<th>Characteristic</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>Bold</td>
<td>It indicates particle size of tea. If leaf particles are larger than standard size, they are known as bold.</td>
</tr>
<tr>
<td>6</td>
<td>Bright</td>
<td>Brightness indicates that the manufacture is free from bacterial infection and has been carried out carefully. It appears on both liquor and infused leaf are called as bright.</td>
</tr>
<tr>
<td>7</td>
<td>Brisk</td>
<td>It is a character of liquor. Briskness means liquor is not soft or flat.</td>
</tr>
<tr>
<td>9</td>
<td>Brown</td>
<td>This describes the colour of dry leaf. Although, valuable second flush tea is brownish in colour, generally, under withered leaf gives brown tea. But</td>
</tr>
<tr>
<td>10</td>
<td>Burnt</td>
<td>Extreme high temperatures during drying produces burnt tea. It is an undesirable characteristic.</td>
</tr>
<tr>
<td>11</td>
<td>Chesty</td>
<td>Due to inferior quality packing chests, an undesirable resinous smell is developed in both dry leaf and liquor.</td>
</tr>
<tr>
<td>12</td>
<td>Clean</td>
<td>Free from stalk and fibre, a clean and uniform product of classified tea.</td>
</tr>
<tr>
<td>13</td>
<td>Coarse</td>
<td>A tea having harsh liquor. Probably develops through coarse plucking and this is undesirable.</td>
</tr>
</tbody>
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### 1.4 Grading and Quality Parameters of Produced Tea

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<tbody>
<tr>
<td>14</td>
<td>Cream</td>
<td>Hot water soluble compounds and caffeine separates out as ‘cream’ on cooling. Bright indicates good quality and dull or muddy indicates inferior liquor.</td>
</tr>
<tr>
<td>15</td>
<td>Dull</td>
<td>It describes infused leaf, liquor and the appearance of made tea. Dullness of the infused liquor indicates a poor quality tea. It is developed from bacterial infection or over-fermentation.</td>
</tr>
<tr>
<td>16</td>
<td>Even</td>
<td>It describes the condition of the infused leaf. Normally used in combination with ‘bright’ or ‘coppery’ as qualifying adjectives.</td>
</tr>
<tr>
<td>17</td>
<td>Fibrous</td>
<td>Particularly in fanning and dusts, the term denotes the presence of fibre. Due to coarse plucking or application of heavy pressure in rolling gives fibrous tea.</td>
</tr>
<tr>
<td>18</td>
<td>Flakey</td>
<td>In orthodox manufacture, if produced tea is not properly twisted it is termed as ‘flakey’. Insufficient withering or rolling causes flakiness.</td>
</tr>
<tr>
<td>19</td>
<td>Flavour</td>
<td>One of the most desirable characteristics of liquor. A pleasing aroma of the made tea indicates the grade.</td>
</tr>
<tr>
<td>20</td>
<td>Fruity</td>
<td>A defective taste in liquor. Excessive fermentation and subsequent bacterial infection causes fruity grade.</td>
</tr>
</tbody>
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<tbody>
<tr>
<td>21</td>
<td>Green</td>
<td>A defective colour in infused leaf. Coarse plucking, insufficient fermentation, inadequate rolling or insufficient withering are responsible for green grade.</td>
</tr>
<tr>
<td>22</td>
<td>Grey</td>
<td>Highly undesirable grade. Faulty sorting and breaking procedures are main cause of producing this grade.</td>
</tr>
<tr>
<td>23</td>
<td>High fired</td>
<td>This describes liquor of produced tea with prolonged drying process.</td>
</tr>
<tr>
<td>24</td>
<td>Irregular</td>
<td>Uneven size of particles in a batch is called irregular. Improper sorting is the cause of this grade.</td>
</tr>
<tr>
<td>25</td>
<td>Leafy</td>
<td>Grade with larger leaves.</td>
</tr>
<tr>
<td>26</td>
<td>Light</td>
<td>Although the tea may have desirable flavour, it lacks in the depth of liquor colour.</td>
</tr>
<tr>
<td>27</td>
<td>Mixed</td>
<td>This term describes infused leaf with varying colour. This indicates improper manufacturing process.</td>
</tr>
<tr>
<td>28</td>
<td>Plain</td>
<td>Poor quality tea produced during the monsoons. Soft withering, excessive heating or moisture in the leaf in withering results plain grade.</td>
</tr>
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<tbody>
<tr>
<td>29</td>
<td>Pungent</td>
<td>It is a desirable characteristic of the liquor. It shows an extreme briskness. Also produces an astringent effect on the palate.</td>
</tr>
<tr>
<td>30</td>
<td>Quality</td>
<td>It is the most desirable characteristic of tea liquor. It indicates efficient and correct manufacture.</td>
</tr>
<tr>
<td>31</td>
<td>Raw</td>
<td>Insufficiently fermented leaf produces a raw tea.</td>
</tr>
<tr>
<td>32</td>
<td>Smokey</td>
<td>This is a defect of tea liquor. A faulty direct heater or leakage in the pipes of an indirect heater causes this.</td>
</tr>
<tr>
<td>33</td>
<td>Soft</td>
<td>Lacking in briskness and brightness is indicated by this term. Bacterial infection and over-fermentation causes softness.</td>
</tr>
<tr>
<td>34</td>
<td>Stalky</td>
<td>Tea with a high concentration of stalks.</td>
</tr>
<tr>
<td>35</td>
<td>Stewed</td>
<td>Faulty frying procedures develop this defect. Low exhaust temperature and prolonged fermentation produces ‘stewed’ tea.</td>
</tr>
<tr>
<td>36</td>
<td>Strength</td>
<td>This is a desirable characteristic of Assam tea. Adequate ‘substance’ in the liquor is denoted by this term.</td>
</tr>
<tr>
<td>37</td>
<td>Tippy</td>
<td>The tea containing large number of tips is termed as tippy.</td>
</tr>
<tr>
<td>38</td>
<td>Twist</td>
<td>This term indicates the style of the leaf created in rolling process.</td>
</tr>
</tbody>
</table>

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<tr>
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<th>Characteristic</th>
</tr>
</thead>
<tbody>
<tr>
<td>39</td>
<td>Wiry</td>
<td>This term describes the orange pekoe grade which is well-twisted and thin.</td>
</tr>
<tr>
<td>40</td>
<td>Woody</td>
<td>This term describes liquor of tea manufactured late in the autumn.</td>
</tr>
</tbody>
</table>

Based on the tasting terms as tabulated (table 1.2) tea tasters give a rating for quality to a produced tea called overall liquor rating (OLR) [10].

The chemically tested major quality parameters are:

1. Theaflavins (TF),

2. Thearubigins (TR),

3. Highly polymerized substances (HPS),

4. Total liquor color (TLC) and

5. Total soluble solids (Water extract)(TSS).

Briskness and brightness of tea liquor are contributed by TF. During fermentation, TF progressively increases and reaches maximum value when highest quality of fermentation is achieved. TR is complex condensation products of oxidized catechins with TF. To obtain better quality, proper balancing of liquor parameters is necessary. TR is an indication of fermentation process. Very high levels of TR indicates over fermentation and low levels
Caffeine and catechin play a vital role on the quality of tea. Caffeine act as a direct stimulant of the Central Nervous System. Its level increases during processing. A higher level of caffeine indicates a good leaf standard (with the maturity of the crop shoots caffeine decreases). A higher values of Water extract or TSS indicate a better quality of the raw material [11].

1.5 Role of Moisture in Tea Manufacturing

Moisture plays a very important role in tea manufacturing process. To avoid operational difficulties during manufacturing and for achieving better quality of product, maintaining proper level of moisture is necessary. In tea manufacturing, withering is the first process where moisture from fresh tea leaf is partially removed. This process is called physical withering. Correct level of withering is essential for quality of produced tea. Determining the end point of wither is a difficult task. The involved biochemical processes in withering are generally termed as chemical withering. The required amount of moisture reduction can be achieved in a faster rate, but to achieve the chemical withering it requires around 12 to 16 hours of withering time. Therefore physical withering is conducted in a regulated manner by passing air through the leaves so as to achieve the required level of moisture loss after the end of same time required for chemical withering. Proper withering of tea leaves is an important
and critical issue. Under withering damages the leaf in the rolling process resulting in a low quality product. The cutting and tearing of under withered leaf results in lumps during fermentation. It also causes non desirable bacterial growth above 25 °C. Maintaining proper level of moisture is also related to the production cost. Excess of moisture in withering increases load in dryer and hence the cost. Over withering of tea leaves produces low quality product. In withering for CTC, moisture is around 68 - 70 %. On the other hand for orthodox it is around 60 % or lower.

In fermentation, proper development of flavour characteristics and other biochemical changes occur suitably at the level of moisture in the range 60 - 70 %.

In dryer typical leaf input has moisture in the range around 60 - 70 %. After completion of drying process moisture is around 3.5 % for rolled tea and 2.5 % for CTC tea. Proper drying ensures the durability of produced tea. Because of over-drying, essential volatiles of flavour characteristics are driven off and a bakey flavour is developed.

### 1.6 Instrumentation in Tea Factory

In India, present day tea manufacturing process is mainly dependent on manual control. Required optimum conditions of process parameters are determined mostly based on subjective assessment. The productivity and quality of produced tea depends upon the experience of the factory supervisor. There is no worthwhile electronic instruments support available for monitoring and control in tea manufacturing. With increasing international demands of tea and competition for producing better quality it is essential to improve productivity and
quality. From the current scenario of tea manufacturing process, particularly in India, it is observed that tea industry can be highly benefitted by using electronic instruments even with the existing conventional manufacturing setup.

The manufacturing process of tea depends upon a number of inter-related parameters. There are no well established analytical relationship between the outputs of different stages and its affecting parameters. In such a case, artificial neural network (ANN) based instrumentation, can be employed to study these relationships and based on these relationships ANN based process models can be used in tea manufacturing process.

### 1.7 Artificial Neural Network in Dynamic Process Modeling

ANN have been applied in solving a wide variety of problems that are not well suited for ordinary classical methods of analysis. ANN is a data driven model [12] and it can be used in extremely complex nonlinear problems [13]. Due to the ability of realization for complex nonlinear mapping of multidimensional interrelated input and output parameters ANN provides excellent prediction model compared to expert systems or its statistical counterpart [14]. Different structures of ANNs are used depending on the type of applications including the food and agriculture industry [15, 16]. Application of ANN in prediction or forecasting of time series is widely presented in the literature [17] - [21]. For nonlinear system identification or modeling, generally the nonlinear autoregressive model with exogenous input (NARX)
1.8 Overview of the Research Work

The research work focuses on the development of an online technique for monitoring and measurement of moisture loss in withering process of tea manufacturing. It involves detailed study of the existing techniques and methods for moisture measurement in withering. Various techniques are reported in literature although most of the techniques are not commonly used in tea factories due to some inherent difficulties in those techniques.

Different aspects of withering process of tea manufacturing is studied precisely in detail from related literature and field observation. Despite the various biochemical processes involved in withering, the end point of withering of tea leaves are determined mostly from the estimation of moisture in tea leaves. Involved biochemical processes are termed as chemical withering which generally takes 12-16 hours [1, 5]. On the other hand the moisture removal process, called physical withering, is basis for determining end pont of withering. Physical withering is regulated by passing air through the leaves so as to achieve the desired chemical withering [5].

Since moisture plays the main role in withering, in this study, it is closely observed what are the parameters that affects the moisture release process and how the process is effected by those parameters. Moisture release from tea leaves in withering mostly depends upon the level of RH and temperature of incoming air in trough [1]. In this research a novel
1.9 Organisation of the Thesis

The thesis is divided into six chapters.

Chapter 1 describes general introduction of tea, tea processing and objectives of the research work.

Chapter 2 presents withering process and its different aspects in tea manufacturing.

In chapter 3, sensors, signal conditioning and calibrations are described. Design and development of a network based data acquisition system is also presented in this chapter.

Chapter 4 describes the design and development of a scaled down version of enclosed type trough. Testing and validation of ANN (Artificial neural Network) based prediction method for moisture loss in withering is presented in this chapter.

In chapter 5, implementation of ANN based withering level estimation technique in actual trough is presented in detail.
In chapter 6, conclusion of the research work and suggested future improvement have been presented.