DEVELOPMENT AND PERFORMANCE EVALUATION OF A RUBBER TAPPING MACHINE

By

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THESIS

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DECLARATION

I, hereby declare that this thesis entitled **"DEVELOPMENT AND PERFORMANCE EVALUATION OF A RUBBER TAPPING MACHINE"** is a bonafide record of research work done by me during the course of research and the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title, of any other University or Society.

Place: Tavanur

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Certified that this thesis entitled **"DEVELOPMENT AND PERFORMANCE EVALUATION OF A RUBBER TAPPING MACHINE"** is a bonafide record of research work done independently by Ms. Aswathy M. S. under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to her.

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Aswathy. M. S

Dedicated to My Family

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LIST OF SYMBOLS AND ABBREVATIONS

%	: Per cent
&	: And
/	: Per
°	: Degree
° C	: Degree Celsius
Ah	:Ampere hour
ARTS	: Artificial Rubber Tapping Machine
cm	: Centi metre
DC	: Direct current
DCA	: Double Cut Alternative
DES	: Department of Economic Survey
DRC	: Dry rubber content
et al.	: And others
etc.	: Etcetera
FAO	: Food and Agriculture Organisation of the United Nations
ft	: Feet
g	: Gram
GOK	: Government of Kerala
h	: Hour
ha	: Hectare
hp	: Horse power

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IRRDB	: International Rubber Research and Development Board
IRSG	: International Rubber Study Group
k Da	: kilo Dalton
KAU	: Kerala Agricultural University
KCAET	: Kelappaji College of Agricultural Engineering and Technology
kg	: Kilogram
kg/ha	: Kilogram per hectare
km^2	: square kilometre
l	: Litre
m	: Metre
min	: Minute
ml	: Milli litre
mm	: Milli metre
MSD	: Musculoskeletal Disorder
MSS	: Musculoskeletal Symptoms
n.d	: no date
NE	: North east
nm	: nano metre
No.	: Number
NP	: Neck Pain
NR	: Natural Rubber

PTP	:Phloem Turgor Pressure
rpm	: Revolutions per minute
RSS	: Ribbed smoked rubber
s	: Second
SE	: South East
SW	: South west
TNAU	: Tamil Nadu Agricultural University
TPD	: Tapping Panel Dryness
V	: Volt
W	: Watt
yr	: Year (s)

Introduction

CHAPTER I

INTRODUCTION

Hevea brasiliensis, the Para rubber tree or common rubber tree, is the most important species for the commercial source of natural rubber (NR). It is an important commercial plantation crop which is originated in Amazon basin. In the late 19th century, the rubber cultivation was started in the countries belonging to tropical belts of Asia and South East Africa like Thailand, Indonesia, Malaysia, Vietnam, China and India. Rubber plantation covers over 9.3 million hectares of plantation area in the world, in which 95% belongs to Asia. In 1902, India started to cultivate rubber commercially and the hinterlands of the southwest coast, mainly Kerala and Kanyakumari District of Tamil Nadu are the traditionally cultivating areas of rubber (Rubber Board, 2017a). Thailand is the leading producer of natural rubber with a production of 4.469 million tonnes. Currently, India is in the sixth position in the production of natural rubber with a share of 5% of world production and occupied second position in productivity during the year 2016. In India, 5.59 lakh ha area is under rubber cultivation and the natural rubber production during the year 2016-17 is 0.624 million tonnes (Rubber Board, 2016; Rubber Board, 2017b).

In India, Kerala is the leading producer of natural rubber and accounts 86.5% of the country's total natural rubber production. According to Government of Kerala, the state holds 5.51 lakh ha area under rubber cultivation with a production of 0.54 million tonnes during the year 2016-17 (DES, 2017).

The rubber tree is a quickly growing, perennial tree which grows to 25 to 30 metres height. The rubber tree has fairly sturdy straight trunk with thick bark which is soft and light brownish grey in colour. Rubber trees have an average life of 100 years. But in plantations, it has an economic life period of around 32 years, comprising immature phase of 7 years and productive phase of 25 years. The bark of the rubber tree consists of three distinct layers, soft bast inner layer, hard bast intermediate layer and an outer protective layer of cork cells. The inner layer of bark consists of latex vessels which produce hevea latex. The hevea latex is a hydrosol in which the particles are dispersed and protected by a complex film. The latex present in these vessels contains 30 to 45% natural rubber particles that can be harvested and utilised for various industrial applications (Rubber Board, 2017a).

Natural rubber (chemically, cis-1,4-polyisoprene) is one among the raw materials used for industrial applications such as automobile industry which have beneficial economic and environmental impact. It is used for fabrication of a wide range of industrial and domestic articles like tyres, gloves, rubber band, ball etc., (Diaby *et al.,* 2013). The natural rubber is harvested in the form of latex (a sticky, milky colloid) through the process called tapping. Tapping is the process of making a controlled wound in the bark of rubber tree to cut open the latex vessels, which cause the flow of latex for capturing the latex. For trees tapping for the first time, tapping cut open the latex vessels and for trees under regular tapping, tapping removes the coagulum that blocks the cut ends of the latex vessels (Rubber Board, 2017a).

In India, two types of knives are used commercially for tapping called Michie Golledge knife and Jebong knife. Michie Golledge knife or Gouge knife is widespread and common over the country and is pushed along the tapping cut to shave the bark. Jebong knife which is commonly used in Malaysia become popular due to its more suitability for speedy and easier tapping since the knife is pulled along the cut to remove the bark, but with a slightly higher bark consumption. Various modifications had been done to these knives for better efficiency (Abraham, 1992; Rubber Board, 2017a).

The optimum yield of latex is obtained while tapping in the early morning since the greater turgor pressure cause greater exudation of latex. The number of trees tapped in a day or tapping task by an experienced tapper in India usually varies from 300 to 400 trees per day (Rubber board, 2017a). The tapping task will vary according to the topography of land, tapping system, the position of the tapping cut, stand or number of rubber trees per hectare, the age of trees and skill of the tapper (Abraham, 1992). The depth of cut for obtaining best yield of rubber in tapping is less than 1 mm, a depth close to the cambium. Care should be taken not to injure the cambium at the time of tapping for obtaining optimum yield. The annual rate at which the bark is consumed in tapping or bark consumption of about 20-23 cm is preferable, without rest period, for obtaining optimum yield and it will vary with the skill of the tapper (Rubber Board, 2017a).

The process of rubber tapping poses potential risk of various health problems among rubber workers. It varies from simple musculoskeletal aches to more serious and complicated structural damage to bone, tendons, muscles and nerves of musculoskeletal system. The health problems of rubber workers may be due to the arduous demands of farm labours in the field (Reddy *et al.*, 2012; Shan *et al.*, 2012; Kalubowila and Vidanapathirana. 2015).

The challenges confronting the rubber industry are long immature life of rubber tree, fluctuating prices of rubber, shortage of skilled and trained tappers, competition from other sources of natural rubber and potential threats of devastating diseases. During the tapping process, the labour has to apply a greater force on each tree to get the desired path for the harvesting of rubber which makes the labour tired while tapping nearly 300 trees in a short duration. Low social status, physical strain and need of training are the reasons which lead to the shortage of trained labours in the rubber tapping field (Heng and Joo. 2017).

From past years, a number of researches have been carried out to develop a mechanical rubber tapping equipment. The mechanical method of rubber tapping will reduce fatigue of the tappers and thereby improve the efficiency and yield of rubber tapping. If a rubber tapping machine is developed it can be effectively used by any unskilled person, thus reducing the scarcity of skilled rubber tapping labours and thereby encouraging people to be engaged in rubber cultivation. Also, the damages usually occur in the inner cambium of rubber bark during the manual tapping of the rubber with tapping knives due to lack of control on depth of cut can be reduced which enhances the effective life of rubber trees for the economic harvesting of natural rubber. It is also envisaged that the time required in the manual tapping method can be efficiently reduced by a suitable mechanical tapping method. The tapping task or number of rubber trees tapped daily will be increased thereby increasing the efficiency of tapping labours. The problems like requirement of skilled labour, scarcity of skilled labours and high wages for labour can be reduced by the use of a suitable rubber tapping machine.

Considering the above facts, a study had been undertaken on the topic **"Development and Evaluation of a Rubber Tapping Machine"** with the following objectives:

1. To study the performance of existing rubber tapping methods and tools
2. To develop a rubber tapping machine
3. To evaluate the performance of the developed rubber tapping machine

Review of Literature

CHAPTER II

REVIEW OF LITERATURE

This chapter explains the various rubber tapping methods and different rubber tapping tools and equipments presently in use. The rubber tapping process, efficiency of labours and human drudgery in the rubber tapping field are also described in this chapter.

2.1. RUBBER TREE AND HISTORY

2.1.1. Rubber Trees

Rubber trees are upright growing milky trees that are cultivated mainly for collection of latex, a milky liquid secretion which is utilised in various industrial applications for the making of different rubber products. *Hevea brasiliensis* or Rubber is a plantation tree that grows fast in the regions of tropical low lands below 400 m altitude (a maximum altitude of 700-800 m at the equator and at less altitude away from the equator). *Euphorbiaceae* is a very large family which consists of about 280 genera and 8,000 species and most of the members of this family produce milk or latex in various vegetative parts. *Hevea brasiliensis* or Para rubber tree or simply rubber tree is the major commercially cultivating plant species from the *Euphorbiaceae* family from where the latex can be utilised economically and they contribute about 90% of the total global production of natural rubber (Balsiger *et al*., 2000; Verheye, 2010; Rubber Board, 2018).

Rubber trees have an average life of 100 years. But in plantations, it has an economic life of about 32 years, comprising immature phase of 7 years and productive phase of 25 years. The rubber trees have a height ranges from 25 to 30 m in plantation and have a conical or cylindrical shape trunk that tapers from the base showing periodicity in growth (GOK, n.d; Webster and Paaradkooper, 1989; Verheye, 2010; Rubber Board, 2018).

2.1.2. Climatic and Soil Conditions for Rubber Tree

The rubber tree is mostly growing in the areas of latitude between 15°N and 10°S where a permanent hot and humid climate is observed. The rubber trees are cultivated in areas having rainfall ranges from 180 to 250 cm which is evenly distributed throughout the year with at least 100 rainy days. There should not be a marked dry season in the area. The latex production yield and quality is seriously affected during dry spells or dry seasons of more than 2 to 3 months, but not the vegetative growth is specifically damaged. The required climatic conditions also include a stable high temperature which ranges from 20 to 34°C with an average monthly temperature of about 25 to 28°C and a relative atmospheric humidity of 60-80%. Rubber trees can tolerate temperature below 15°C without much damage for longer periods especially during the initial growth stage but sometimes result in lower latex production and retarded growth. It is recommended to cultivate the rubber trees in areas free from strong winds with sunshine hours ranges from about 1500 to 2000 hours/year at a rate of 6 hours/day throughout the year. To obtain the optimum growth of rubber trees, a weathered, well-drained deep soil is required which consist of laterite, sedimentary types, lateritic types, alluvial soils or non-lateritic red. Loamy or sandy clay texture soil where clay content is more than 20% is highly recommended since sandy soils have a low water-holding capacity and nutrient content. The optimum soil pH is in the range of 4.5 and 6.0 and the higher pH of soil will results in early coagulation of latex on the excised bark which in turn reduces the time of latex flow. High slope (more than 25%) topography of the plantation area is not recommended since it makes the work more difficult during tapping and other estate maintenance. And there is a high chance of erosion risk in a sloping field and contour cultivation is recommended in areas having slope above 5% (Pushparajah, 1977; Yew, 1982; Watson, 1989; Ong *et al.*, 1998; Balsiger *et al.*, 2000; Testado, 2001; Verheye, 2010; IRRDB, 2018; Rubber Board, 2018).

2.1.3. History of Rubber Cultivation

The *Hevea* genus is originated in the Amazon and Orinoco valleys and is native to South America. During nineteenth century, Brazil was the main producer. During the second part of nineteenth century, the *Hevea brasiliensis* species became popular and started to cultivate commercially for the latex production. H. Ridley was identified *Hevea brasiliennsis* as the superior among all rubber producing plant species in a study conducted in Singapore Botanical Garden. From the pre-Columbian time, rubber was used for the production of rubber ball and other products like bottles, crude footwear, waterproofing fabric etc. (Watson, 1998; Verheye, 2010).

In 1495, Columbus first reported about latex and in 1775, a French explorer Fusee Aubelt studied about rubber tree. Priestly reported the first use of rubber, for rubbing pencil marks and after that the name rubber is came to the product. Mac Intosh dissolved rubber in naphtha and coated with fabric for making waterproof cloths in 1823 and used in the American Civil war. The discovery of the process vulcanisation of rubber where rubber is heated with sulphur to form different shapes without losing their physical properties, by Charles Goodyear and Hancock in 1839 made a revolution in the use of rubber. In 1845, pneumatic tyres of motor cars were made from latex rubber by Thomson and it was the most successful application of rubber. In 1876, Henry Wickman taken 70000 seeds to Royal Botanical Garden in London and later it started to cultivate industrially in Malaysia and other East Asian countries. Malaysia established first rubber plantation in 1890 and during the beginning of twentieth century, Africa also started rubber plantation (Goldthorpe, 1993; Watson, 1998; Killmann and Hong, 2000; Verheye, 2010; IRRDB, 2018). In 1902, the first large rubber estate was started at Sumatra's East Coast (Priyadarshan *et al.,* 2005).

Rubber cultivation in India was initiated in 1902 by Dutch since Kerala and other places have similar tropical climate suitable for rubber plantation. Before the commercial cultivation of *H. brasiliensis* started, the major contribution was from *Ficus elastica* (Assam rubber) in India (Thomas and Panikkar, 2000). The hinterlands of the southwest coast, mainly Kanyakumari District of Tamil Nadu and Kerala are the traditionally rubber cultivating areas in India. The non-traditional areas of rubber cultivation are hinterlands of coastal Karnataka, Konkan Region of Maharashtra, Goa, hinterlands of coastal Orissa and Andhra Pradesh, Andaman and Nicobar Islands and the north-eastern states (Vinayaka *et al.*, 2017; Rubber Board, 2018).

2.2. SOURCES OF NATURAL RUBBER

Natural rubber is produced in the latex of around 8 botanical families (Asclepiadaceae, Euphorbiaceae, Apocynaceae, Asteraceae, Papaveraceae, Moraceae and Sapotaceae), 300 genera and 2500 species plants (Cornish *et al.*, 1993). Rubber tree (*Hevea brasiliensis* or Muell. Arg. or Willd. ex A. Juss.) is commonly known as the Brazilian rubber tree. It is the major source for commercial production of natural rubber. A shrub called Guayule (*Parthenium argentatum* Gray, Asteraceae) and the Russian dandelion (*Taraxacum koksaghyz*) are the two species of plants that produce rubber in large quanity with high molecular weight. The natural rubber produced from the rubber trees are of superior quality, even though guayule and Russian dandelion are promising alternative rubber sources (Schmidt *et al.*, 2010; Venkatachalam *et al.,* 2013). Ceara rubber (*Manihot glaziovii*), Panama rubber (*Castilla elastica* Cerv.), India rubber (*Ficus elastica* Roxb.), Lagos rubber (*Funtimia elastica* Stapf.), Lettuce (*Lactuca serriola*), Madagascar rubber (*Cryptostegia grandiflora* R. Br.), Fig tree (*Ficus bengalensis*) and *Lactarius chrysorrheus* are the other alternative rubber sources which are not used commercially (Mekkriengkrai *et al.*, 2004).

Table.2.1. Sources and properties of natural rubber producing plants

Natural rubber producing plants	Property	Source of rubber	Mw (kDa)	Production (tonnes/yr)	Content of rubber (%)
Hevea brasiliensis	*Hevea*, white or yellow latex	Bark	1,310	9,000,000	30-40
Guayule shrub *P. argentatum* Gray	Brown/ green color	Root	1,280	10,000	3-12
Russian dandelion *Taraxacum (koksaghyz)*	High-quality rubber	Root	2,180	3,000	15
Fig tree (*Ficus carica*)	Pale grey in colour	Bark, leaf	190	---	4

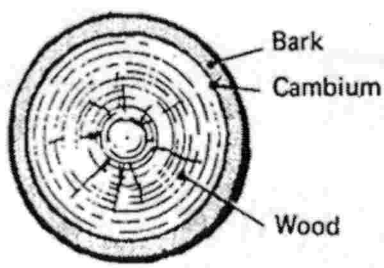
(Source: Venkatachalam *et al.*, 2013)

Guayule is an industrial crop, native to North Mexico and Chihuahuan desert of Texas, and contributes a minor portion of the global production of natural rubber. The latex from Guayule is used for the production of medical products and gloves since it does not cause allergic reactions. The average yield of latex is 600 to 900 kg/ha (Estilai and Ray, 1991). Latex from Guayule is used for hypoallergenic products. The use of Gauyule latex is limited due to the low abundance of natural rubber particles and the slow volume growth of the plant (Cornish and Siler, 1996). Russian dandelion (*Taraxacum koksaghyz*) seen in Sinkiang, China is mainly used for tyre manufacturing (Cheng, 1963).

2.3. STRUCTURE OF RUBBER TREE

2.3.1. Trunk and Bark of Rubber Tree

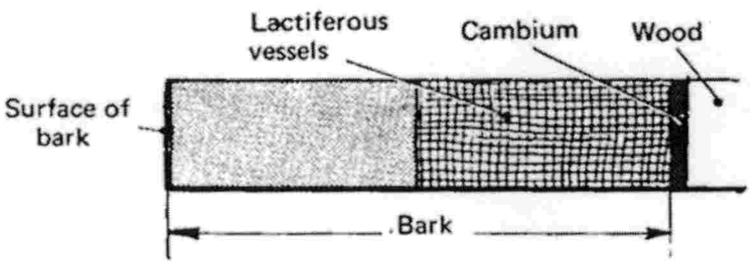
The rubber trees have a soft wood of white creamy colour with a straight grain and pinkish tinge. There is no distinguishable heart wood and sap wood. The fresh wood has 60 to 80% initial moisture content, 1 to 2.3% free sugar content and 7.5 to 10.2% starch content (Killmann and Hong, 2000). The trunk of the rubber tree contains inner pith, surrounding the wood and cortex. The wood and cortex is separated by a layer of cambium tissue which have the regenerative capacity. The cortex is distinguished by 3 distinct concentric layers. The outer periderm is called corky layer, inner layer of phloem with latex vessels and a layer of parenchyma with a large number of stone cells in between the inner and outer layers (Verheye, 2010; Rubber Board, 2018).



(FAO, 2018)

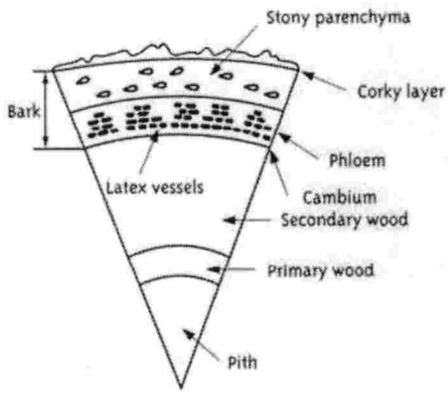
Fig.2.1. Cross section of trunk of a matured rubber tree

The bark or cortex of the rubber tree is the most important part which contains a network of interconnected tissues called latex vessels in their soft bark. Latex vessels are modified sieve tubes which are developed from coalescing and cambium during disintegration of cell wall and are spread in anti-clockwise direction in the concentric trunk at an angle of about 30° with the vertical axis of the trunk. The latex vessels contain a milky fluid which is a colloid of an aqueous serum and suspended rubber particles and it is called as latex. The percentage of rubber particles in latex usually varies from 25 to 40% with an average value of about 30%. The presence of latex in the bark of rubber trees help the tree to free from pest attack since the latex give an unpleasant, odd taste to all parts of tree and also reduces the chances of penetration of aggressors into the plant through the wounds by sealing the wounds with latex. The yield of latex will depend on the age of the tree, variety of the tree, thickness of bark and proportion of the latex tissue (Verheye, 2010; Rubber Board, 2018).



(FAO, 2018)

Fig.2.2. Transverse view of bark of a matured rubber tree



(Verheye, 2010)

Fig.2.3. Cross sectional view of bark of a matured rubber tree

2.3.2. Latex

Hevea latex was first discovered by an American scientist and subsequently turned to a major economically important product (Balsiger *et al.*, 2000). Hevea latex obtained from the rubber tree is a sticky, milky colloidal suspension of rubber particles and acts like a hydrosol where the particles are dispersed and protected in a complex film. The latex is a colloid of four major components and they are Rubber particles, Lutoids, Frey wyssling particles and other elements like resins, proteins, sugars, tannins, glycosides, mineral salts, alkaloids and secondary metabolites. Rubber particles have varying shapes like pear shape or spherical with a diameter of 6 nm to 5 micron and contain 25 to 40% of the total latex volume. Lutoids are responsible for latex vessel plugging, by which the latex flow is controlled or stopped after tapping and contain 10 to 20% of the total volume of latex with 0.5 nm to 3 micron size. The Frey wyssling particles constitute about 5% of the total latex volume and have impact on coagulation and oxido-reduction processes (Delabarre and Serrier, 2000; Verheye, 2010; Bauer *et al.*, 2013; Rubber board, 2018).

2.4. PRODUCTION AND USES OF NATURAL RUBBER

2.4.1. Production of Natural Rubber

According to the IRSG (2018), the world natural rubber production was 12.40 million tonnes during the year 2016. Thailand, Indonesia, Vietnam, China, Malaysia and India are the major natural rubber producers in the world. Rubber plantation covers over 9.3 million hectares of plantation area in the world, in which 95% belongs to Asia. Thailand is the leading producer of natural rubber with a production of 4.469 million tonnes (Rubber Board, 2016; Rubber Board, 2017b).

Currently, India is in sixth position with a share of 5% of world natural rubber production and second position in productivity. During the year 2016, India produced 0.624 million tonnes of natural rubber from an area of 5.59 lakh ha. The world consumption of natural rubber is 12.6 million tonnes in 2016 and India is in second position with an annual consumption of 1.03 million tonnes (Rubber Board, 2016; Rubber Board, 2017b).

Table.2.2. Country wise production of natural rubber

Country	**Production of natural rubber (in '000 Metric tonnes)**
Thailand	4469.0
Indonesia	3208.1
Vietnam	1032.1
China	774.0
Malaysia	673.5
India	624.0
Others	1620.3
World total	**12401**

(Source: Rubber Board, 2017b)

In India, rubber is cultivated predominantly as a small holder's crop and contributes more than 87% to the total natural rubber production. In India, Kerala is the leading producer of natural rubber and accounts 86.5% of the country's total natural rubber production. In Kerala, rubber is an important plantation crop cultivated in the state and 80.96% of the total area under plantations is cultivated with rubber. In the year 2016-17, rubber is cultivated in an area of 5,51,050 ha. The total production of natural rubber was 5,40,400 tonnes during the year 2016-17 in the state. Kottayam is the leading producer of natural rubber in the state with a production of 1,10,000 tonnes and area of 20.76% of total rubber cultivated area (DES, 2017).

2.4.2. Uses of Natural Rubber

Natural rubber, chemically cis-1,4-polyisoprene with molecular weight ranging from 200 to 8000 kDa have viscoelastic properties (GOK, n.d). Natural rubber is one among the very few raw materials and has a wide range of applications in different industries in which the natural rubber is used as the raw material for different products. Directly or indirectly, about 50,000 products are produced from natural rubber. The various applications include insulating blankets, footwear, treads of vehicle tyres, rubberized fabrics, washer and gaskets, transmission and conveyor belts, hospital and household supplies, sports goods, paints etc. From the total produced natural rubber, about 70% is consumed by the automobile industries for manufacturing tyres, tubes and other parts in association with automotive transport. About 4% of the total rubber is used for making wire and cable isolation and about 6% is used for making footwear, shoes, boots, heals or soles. The resistance to abrasion property is utilised for making vehicle tyres. The vibrations of heavy machinery can be reduced by using different shock absorbers and mountings which are made from natural rubber due to its elasticity. Because of the water resistant property, natural rubber is used for making rainwear, diving and underwater equipment, and lining for chemical and water tanks. Rubber is used for making insulating material since it is a bad conductor. Sponge rubber made by foaming latex is utilised for making upholstery and mattresses etc. Vulcanised rubber is used as protective lining of chemical plants in electrical and radio engineering. Powdered rubber mixed with bitumen is used as a surface finishing material for road (Verheye, 2010; Diaby *et al.,* 2013; Vinayaka *et al*., 2017).

2.5. HARVESTING OF NATURAL RUBBER

2.5.1. Rubber Tapping

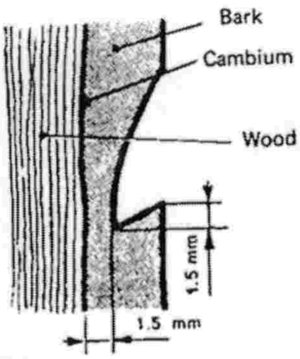
The natural rubber is harvested from the rubber tree in the form of latex through a process called rubber tapping. In the research conducted by H. Ridley in Singapore Botanic Gardens, *Hevea brasiliensis* is identified as the superior latex producing species. The institute developed technology for harvesting of rubber tree called rubber tapping. They studied about the wound response (excision method of tapping in which the same cut is opening up for increasing the latex flow), the most appropriate time for tapping and bark regeneration which is required for re-tapping (Verheye, 2010).

Tapping is the process of making a controlled wound in the bark of rubber tree to cut and open the latex vessels which cause a flow of latex for capturing the latex. In rubber tapping, a cut is made in the bark, which cuts the phloem tissue along with the laticifer rings in which the latex is stored. The method of excision tapping is developed by Railey in 1899. During tapping, a thin layer of bark is removed in descending half spiral using a knife with V shaped cutting edge to cut the latex vessels in a sloping cut. While tapping the rubber tree, the cut made in the vessels cause the release of pressure and exudation of the viscous latex at the location of cut. As a results of this exudation of latex in which a strong forces of cohesion is existing while in the liquid phase, the latex will flow along the length of the latex vessel and laterally. The latex gets more diluted due to absorption of moisture from the surrounding tissues as a result of the fall in pressure in the vessels. The dilution with water would make the latex less viscous and forcing the latex to flow along the grooved channel to harvest the latex from the rubber tree. The latex vessels are arranged at an angle of 30° to the vertical axis of the trunk of rubber tree in anti-clockwise direction in concentric cylinders. Tapping is usually done from the top left to the bottom right at an angle about 25 to 30° for cutting the latex vessels at a right angle and obtaining 7 to 8% more yield. The overflowing can be avoided by cutting in a slope and the latex flowing in a vertical guide line can be collected in a cup where a metallic spout drives the flow into the cup. The milk coloured latex sap collected is refined into usable rubber (Boedt, 2001; Verheye, 2010; Vinayaka *et al.*, 2017).

Hydrostatic or turgor pressure is the force responsible for the flow of latex from the latex vessels. The turgor pressure is high in the time of night and morning and is reduced in the day time. It is recommended to perform the tapping operation in early morning where temperature and evaporation is less and turgor pressure is more for obtaining optimum latex yield. The flow will last for about 5 to 8 hours. The number of trees tapped in a day or tapping task by an experienced tapper in India usually varies from 300 to 400. The depth of cut for obtaining best yield of rubber in tapping is less than 1 mm, a depth near to the cambium. To obtain optimum yield, at the time of tapping, care should be taken not to injure the cambium. The rate at which the bark is consumed in tapping will depend much on the skill of the tapper. The annual bark consumption of about 20-23 cm is preferable to for obtaining optimum yield. It consumes only 1.5 to 2 mm thick shaving per tapping on virgin barks. From renewed bark stage of basal panel, virgin bark above 25 cm height is tapped employing Controlled Upward Tapping (CUT). The normally recommended tapping system is half spiral tapping once in three days and low frequency systems are useful for cost reduction as well as long-term harvesting. (GOK, n.d; Verheye, 2010; Heng and Joo. 2017; Rubber Board, 2018).

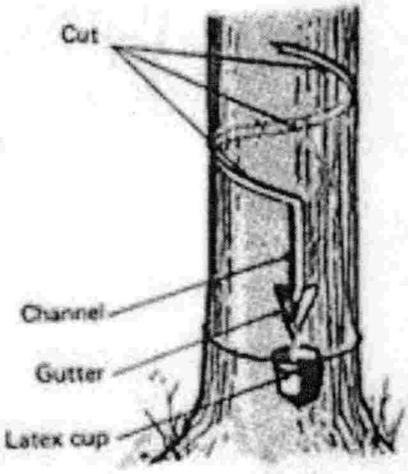
The tapping process starts when the 60% of the stand or number of trees per hectare in the plantation achieve a minimum of 50 cm girth at a height of 1 m from the bottom and it is normally reached in 5 to 6 years after planting. The first tapping in a newly established plantation is normally started during rainy season. The rubber tree is productive for 25 to 30 years.

Once the tapping process started, tapping can be continued throughout the year except some weeks during which the tree is under vegetative rest. In a year, tapping is performed for about 85 to 140 days. The yield of latex declines after 30 years of tapping and then the trees are removed and replanted since further tapping is uneconomical (Balsiger *et al.*, 2000; Verheye, 2010; Vinayaka *et al.*, 2017).



(FAO, 2018)

Fig.2.4. Schematic view of tapping cut on rubber tree



(FAO, 2018)

Fig.2.5. Main trunk of a mature tree showing the tapping panel and latex harvest

The tapping process requires care and precision to avoid damages to the cambium layer lying under the latex vessels since the damages in cambium cells causes bulges in the bark which is susceptible to microbial attack and uneven surface healing. The cambium cells helps in regeneration of the bark in the rubber tree after tapping so that the renewed bark which have more functional latex vessels can be used again for the harvesting of latex more economically. The tapping is usually done by using special knives (Abraham, 1992; Verheye, 2010).

The yield of rubber will increase steeply year by year and after 14 years of planting it reaches to maximum. In South India, annually an average yield of 375 kg/ha from seedlings trees is obtained and the budded plants gives an average yield of 800 - 1000 kg/ha (TNAU Agri-tech Portal, 2018). The yield of latex from rubber plantation will vary according to the age of rubber tree, quality of the rubber variety, topography of land, tapping system, the position of the tapping cut, stand or number of rubber trees per hectare and also the skill of labours. The intensity of latex flow, capacity of the tree to replace the latex between various tapping sessions and the percentage rubber content in the latex will vary depending on the age of rubber tree, climatic and soil conditions, clone type and plant management (Abraham, 1992; Verheye, 2010).

2.5.2. Processing of Latex

The tapped latex can be collected by two methods either as fresh latex or as coagulated latex from the collecting cup. Collecting as fresh latex is mostly practiced and in this method the latex is collected in a 500 to 1000 ml capacity cups which are fixed to the rubber trees. After cutting the bark of a fixed number of rubber trees, the latex is allowed to flow for 5 to 6 hours and later the latex are collected from the cups. An anticoagulant ammonium hydroxide can be used for preventing coagulation and the density of latex is measured using a density metre. The collected latex is filtered and stored in aluminium or galvanised iron tanks (Verheye, 2010).

Prior to the processing of latex, initially the latex is diluted with water to get the constant dry rubber content (DRC) and homogenised in 5000 to 20000 l capacity containers. The maximum rubber content in the concentrated latex is normally about 60%. The latex is centrifuged to remove serum or aqueous substances for making concentrated liquid latex and is stabilised by adding ammonia (Verheye, 2010).

In the making of ribbed smoked rubber (RSS), initially the collected latex is filtered through finer screener after diluting with water to 12-15% DRC. The diluted filtered latex is coagulated by mixing thoroughly after adding acidic or formic acid at a concentration of 3 to 5 g per kg of latex. The mixing should be quick, thorough and the froth is removed to avoid bubble formation in the coagulated rubber. The latex is coagulated into a curd like thick sponge like sheets. The sheets are passed through a roller for 6 to 8 times to make it 2 to 5 mm minimum thickness. Finally passed through a grooved roller to produce ribbed sheets and dried in a smoking house at 50°C for 4 days. The ribbed smoked rubber has a uniform golden yellow colour (Delabarre and Serrier. 2000; Boedt, 2001; Verheye, 2010).

For obtaining granulated rubber, the coagulated sheets are first squeezed between two crushers for removing the coagulum serum remaining in the coagulated sheets and further squeezed by two grooved rollers which are rotating in opposite directions. The second squeezing gives homogenised coagulum after washing out the serum and results in fragments. The fragmented rubber is crushed in a shedder to obtain granules of 5 mm size and is dried at high temperature of 120-130°C for around 3 hours subsequently. The lower-grade rubber is first soaked in water before being passed to a slab cutter and a pre-breaker since it has many impurities. The slab cutter and pre-breaker breaks the chunks of agglomerated coagulum into small size pieces of 3-4 cm in diameter (Delabarre and Serrier. 2000; Boedt, 2001; Verheye, 2010).

2.5.3. Rubber Tapping Systems

Obouayeba *et al.* (2009) conducted an experiment to study the combined effect of tapping systems and height of opening in southeast of Cote d'Ivoire. They studied agronomic parameters and susceptibility to tapping panel dryness on clone PB 235 of 510 trees/ha plant density for deciding the best exploitation system. The study compared two tapping systems (high tapping intensity and low tapping intensity) at two opening heights (1.20 m and 0.75 m above ground level) and split-plot lay out was used. Growth rate of tapping panel dryness (TPD), yield, sucrose contents and dry rubber were measured. Results revealed that at 0.75 m mainly with high tapping intensity yield is reduced with higher rates of TPD but the growth is not affected. A decrease in sucrose content and significant increase in the rate of TPD was observed in intensive tapping. The yield of clone PB 235 had significant effect on opening height but not on its growth. The exploitation system where the trees are opened at 0.75 m height above the ground was practically difficult. Combination of high intensity of stimulation and lower tapping frequency improves and enhances a better carbohydrates supply and better sucrose availability. The best exploitation which can be applied on clone PB 235 was the low tapping intensity at 1.20 m above ground level.

Chantuma *et al.* (2011) carried out a study conducted to test a new tapping system which is called the double cut alternative tapping system (DCA) as opposed to the currently used single cutting system. The object is to give the trees the ability for more latex production with the DCA due to a more favorable metabolic activity during the first 10 years of tapping. DCA increased overall rubber production by 9% and resulted in a higher rate of tapping panel dryness.

Sayan *et al*. (2012) tested the Double Cut Alternative method under different conditions which attempted to increase the lifespan of the tree, thereby increasing the latex yields. The method of DCA involves two separate, alternating cuts instead of just one. The high tapping frequency remains the same. The method was tested during the first three years of tapping in the Songkhla province. The results revealed an increase in yield (kg/tree) of 22% in the DCA treatment T2 compared with its control (T1) and an increase of 16% in the DCA treatment T4 compared with its control (T3). An increase in bark consumption of 13-19% was observed in two DCA tapping systems.

2.5.4. Rubber Tapping Tools

2.5.4.1. Rubber tapping knives

In India, two types of knives are used commercially for tapping called Michie Golledge knife and Jebong knife. Michie Golledge knife or gouge knife is widespread and common over the country and is pushed along the tapping cut to shave the bark. Jebong knife which is commonly used in Malaysia become popular due to its more suitability for speedy and easier tapping since the knife is pulled along the cut to remove the bark, but with a slightly higher bark consumption. Various modifications had been done to these knives for better efficiency (Abraham, 1992; Rubber Board, 2018).

Huang *et al.* (2011) experimented on several measures to improve the mechanical properties of hand-pushing tapping knife. The knife was metallographically investigated through hardness tests and chemical treatments.

Mannayi Rahu, a para-rubber gardener in Wang district of Narathiwas Province developed the Hornbill knife to maximize the product outcome and prolong the age of the rubber tree. It is an application between

Jebong knife, razer blade, and traditional spoke shave. The Knife weights 0.27 kg and one blade can cut up to 1,000 to 2,000 trees with a cutting depth of 1 mm (Anon, 2018a).

2.5.4.2. Rubber tapping machines

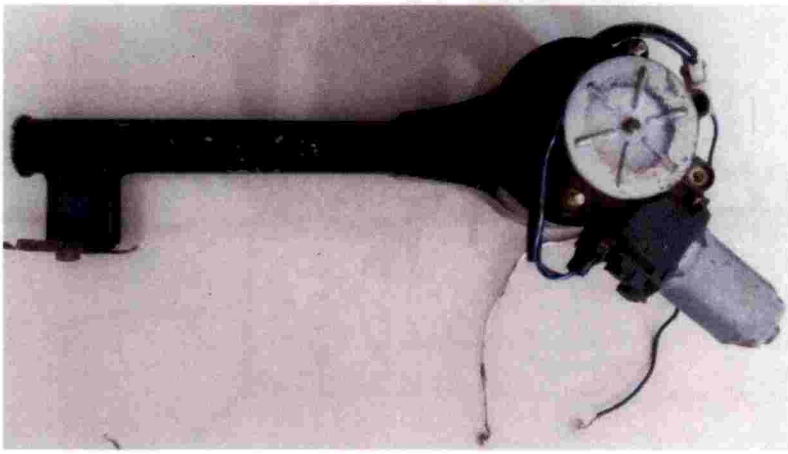
Zakariahs (2010) developed a motorized rubber tapping machine comprising a hollow body, a shaft, a motor, a pair of cams and a plurality of bearings.

Joseph (2012) developed an automatic rubber tapping machine-auto taper. The machine consists of a wheeled moving platform which is placed at the front for supporting the cutting parts, rotatable circular saw blades. The planes of all saw blades are held laterally and parallel beyond the sides of the platform. The cutting blades are powered by an internal combustion motor which is mounted at the rear side of machine. The motor drives the vehicle glider wheels. A 5000 mAh, 12 V battery is used. Guard rollers and dust guards are provided for protecting the device and the cutting blades. For the easy handling of the machine, a belt or the handle is provided at both sides of the machine. The author reports that the machine has a capacity of 400 trees/day.

(Anon, 2018b)

Fig.2.6. Autotaper

Aswathy *et al.* (2016) developed a power operated rubber tapping machine at K. C. A. E. T, Tavanur. A connecting rod linking the shaft and the gear assembly converts the rotary motion of motor into reciprocating motion of the shaft. The developed machine was heavy and operation was difficult.



(Aswathy *et al*, 2016)

Fig.2.7. Power operated rubber tapping machine developed at KCAET

Malaysian Rubber Board reported about an Automatic Rubber Tapping Machine or ARTS, an automatic latex harvester which is attached to the tree for bark incision. According to the programmed time, the machine automatically performs the tapping task. The continuous supply of power for the system is provided by a power supply unit that uses the solar energy to charge the battery. The developed machine promotes a greener and more sustainable operation (Malaysian Rubber Board, 2017).

Anon (2018b) reported an automated rubber tapping machine called Dextra rubber tapping machine. It is an electric operated rubber tapping machine of 350 g weight. A 2000 mAh battery which can be used continuously for 4 hours is used. The tapping efficiency can be increased by 15% -20%. The main components of the machine can be used for 3-5 years.

The maintenance cost of this machine is much less than the conventional rubber tapping method. It is very easy to operate and no skill is required to work with this machine.

(Anon, 2018b)

Fig.2.8. Dextra rubber tapping machine

2.6. YIELD AND EFFICIENCY OF RUBBER TAPPING

2.6.1. Study on Yield from Rubber

Pujade-renaud *et al.* (1994) conducted a study on increase in the mRNA levels and glutamine synthetase activity in ethylene induced *Hevea brasiliensis* latex cells. The result of the study shown that, the regenerating metabolism was activated significantly within the laticiferous cells. After ethylene treatment, a specific and significant cytosolic glutamine synthetase (CS) activation parallels the increase of latex yield in the laticiferous cells. Ammonia mediates the CS response to ethylene which increases in latex cytosol after ethylene treatment.

Schroth *et al.* (2004) studied different methods to increase productivity of rubber trees, which included the application of a chemical ethephon which increased rubber production by up to 38% per week. The study also conducted tests on the two different knives used in the region as well as the different methods of tapping, the Amazonian method as opposed to the Asian method of rubber tapping.

Rodrigo *et al.* (2005) demonstrated the intensive intercropping in young rubber plantations. The intercropping of banana with rubber tree in the younger stage results a reduction in the unproductive immature phase length. A sustainable increase in the growth and yield of rubber trees was observed. A significant additional income was obtained on intercropping the rubber trees with short-term crops during the long immature period of rubber tree growth when no latex is produced.

Tungngoen *et al.* (2009) studied the stimulation of latex yield by ethylene application and the involvement of HbPIP2; 1 and HbTIP1; 1 aquaporins through the regulation of water exchanges between latex cells and inner liber. They verified the higher efficiency of HbPIP2;1 than HbTIP1;1 in increasing plasma lemma water conductance in xenopus laevis oocytes. The required prolongation of latex flow and increase in the yield of latex with the application of ethylene was linked to the water circulation between the laticifers and their surrounding tissues along with the probable maintenance of turgor pressure in the liber cells.

Zhu and Zhang (2009) conducted a study on the mechanism of ethylene action, as a stimulant in *H. brasiliensis* for increased latex production, especially in molecular aspect. The results revealed that the rubber biosynthesis was accelerated as the direct effect of ethylene application. The stimulation of latex yield by the ethylene application is due to the prolonged latex flow and accelerated of sucrose metabolism.

The plugging of latex vessels can be prevented by the application of a stimulant called 2-4D,copper salt or the synthetic ethephon which is commercialized as Hevetex 5% PA and Ehtrel and results in an increase in the yield of latex. At the end of the day, the stimulant is applied to the tapping cut using a brush. The other methods of application include the application of stimulant to the renewed tapping panel or to the bark after it has been scraped off (Verheye, 2010).

She *et al.* (2013) investigated an innovative rubber yield stimulation technology that involves the application of ultrasound on the tapping cut surface as a pre-treatment for the rubber trees. The field trial results on an average of 50 replications shown that, a 23% and 14% increase in the latex and dry rubber yields was obtained in a 4 min ultrasound treatment. But the thiol content was decreased in ultrasound treatment.

An *et al.* (2014) investigated variation in PTP (Phloem Turgor Pressure) with rubber tree yield potential, clone and age along with commonly used Ethrel stimulation. In the study they examined the relationships between these factors and the possible use of PTP as an index for tapping system optimization and rubber tree clone assessment. The results revealed that in the foliation season a daily change of PTP was observed and the high PTP in the plant cells cause a high latex yield. The yield potential of rubber tree clones is positively related to the PTP, but the Ethrel stimulation observed as non-significant in increasing the initial PTP of a rubber tree where the ethrel stimulation delays the recovery of PTP after tapping. For the tapping system optimization and rubber tree latex yield, PTP can be used as an indicator.

2.6.2. Efficiency of Rubber Tapping

Vo *et al.* (1993) conducted a study regarding the evaluation of the technical natural rubber production efficiency state farms in Vietnam. The study was conducted in 33 farms using a time-varying stochastic frontier production function model which is used for unbalanced data. Individual bimodal distribution of technical efficiency indices and the farm technical efficiencies were calculated. A few farms operated near the production frontier while the bulk operates well away from the frontier.

Ali and Davis (2003) conducted a survey to study the rubber tappers and the effects of their sex, age and tenure on their job performance during the rubber tapping. The study revealed that the experience of the tapper is a greater indicator in determining job performance while comparing with age. Female tappers were found to have greater latex output, potentially due to greater generalized hand dexterity.

Hashim and Musthapha (2011) applied stochastic frontier analysis to investigate the relative performance of rubber smallholders in Besut District. In the study they identified and measured the performance of rubber smallholders under the supervision of the RISDA personnel. A total of 35 rubber smallholders were investigated and 23% of the total cultivators achieved 0.95-1.00 technical efficiency score. The highest number of cultivators (25.7%) was in the category of 0.80-0.85 technical efficiency score. About 8.6% of the total cultivators were with 0.60-0.65 technical efficiency score of the lowest category. Variations in tangible and intangible factors like husbandry practice, quantity of fertilizer application, skill, species of the rubber trees, management competence of the supervisors, motivation and experience of operators, weather conditions and soil fertility were studied.

Kittilertpaisan *et al.* (2016) conducted a study on technical efficiency of smallholding rubber farmers in Changwat Sakon Nakhon using stochastic frontier analysis. In the analysis, 375 rubber farmers of smallholdings were sampled. Age of plantation, labour and cultivated area were the three inputs and with an output of 69% technical efficiency. Age and gender of smallholding farmers, education and training were the factors which influence efficiency.

Aliyu *et al.* (2017) analysed the technical efficiency of smallholder's rubber production in Negeri Sembilan, Malaysia. The descriptive statistics results shown that the mean rubber yield was 5465 kg where the seven inputs used for farm size, task, farm tools, fertilizer, herbicides, labour and rubber clones were 1.2 ha, 602.7, 2.33, 363.6 kg, 13.0 l, 13.2 man days and 2.47 respectively. The inferential statistics revealed that, the mean technical efficiency obtained was 0.73 with a standard deviation of 0.089. Nine farms were very near the frontier with efficiency score range between 0.90-0.99 and 20 firms have range 0.80-0.90. Tapping experience, race, extension agent's visits and household number are the critical factors which determines the technical efficiency of rubber smallholders in Negeri Sembilan, Malaysia.

2.7. SOCIAL AND ENVIRONMENTAL FACTORS IN RUBBER TAPPING

2.7.1. Environmental Factors in Rubber Cultivation

In Northeast India, a study was conducted on the ecological impact of rubber plantations on soils degradation and has demonstrated an improvement of soil properties by shifting cultivation. By adopting proper agroforestry management practices like silt pitting and bunding, terracing and the growth of leguminous cover plants between the rows to assist with nitrogen fixation in rubber plantations, were found to help in the enrichment of organic matter, which in turn improved the soil physical properties, such as soil porosity, bulk density, infiltration and moisture retention. An increase in organic matter was also noticed in the study. (Krishnakumar *et al.,* 1990).

Chandrasekhar *et al.* (1994) conducted a study on monthly pattern of growth and its duration in rubber trees in the traditional rubber growing areas of India. The rubber clone J3 was selected and evaluated from 1992 to 1994 on the basis of data collected on the girth growth of trees. The growth curve obtained using Euclidian distances shows that from July to August peak growth occurs and from May to November active growth occurs. In traditional rubber growing areas the growth is reduced during dry periods.

Priyadarshan *et al.* (2005) conducted a study on the yielding potential of natural rubber in sub-optimal environments. It is observed that during late 1970s, the rubber production has been spread in many sub-optimal environments like southern plateau of Brazil, highlands and coastal areas of Vietnam, northeast India and southern China. A number of clones were evaluated for adapting the clone for the sub-optimal areas which are stressed under low temperature, higher altitude, diseases and wind. In Tripura (NE India),. the yield shows a negative relationship with wind velocity, minimum temperature and evaporation for all clones. In India, RRII 208, PB 235, HAIKEN 1and RRII 203 were adopted. RRIM 600 is the clone which can be adapted universally in all sub-optimal environments with moderate yield.

Wigboldus *et al.* (2017) conducted a study on scaling green rubber cultivation in Southwest China- an integrative analysis of stakeholder perspectives. In Asia, monoculture pattern cause a negative impact on environment in biophysical, hydrological, climatic, socio-economic and cultural aspects. The study explored the integrative perspectives on green rubber using stakeholders in SW China. The main challenge in conserving natural resources was maintaining the incomes. The green transformation requires social innovation complimented to technologies.

2.7.2. Social Factors in Rubber Cultivation

Brown and Rosendo (2000) examined the effects of extractive reserves on the political and economic empowerment of local communities. The study shows a theoretically informed analysis of the interactions between rubber tappers and environmental organizations in the establishment and implementation of extractive reserves in Brazil. The

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analysis proposed that the alliances have been more successful in allowing political empowerment compared with economic empowerment, though they have not resulted a better livelihood condition of the poor forest dwellers.

Ahrends *et al*. (2015) studied the current trends of rubber plantation expansion which may threaten biodiversity and livelihoods. Since 2000, in continental SE Asia, the quick and widespread conversion of land to monoculture rubber plantations due to higher rubber price was observed where the natural rubber production has increased more than 50%. He analysed the subsequent spread of rubber from 2005 to 2010 in combination with reports on rubber plantation performance and environmental data and found that in sub-optimal environments, cultivation of rubber was accelerated. New rubber plantations which are important for ecological functions and biodiversity conservation are frequently formed. More than 610 km^2 of protected areas and 2500 km^2 of natural tree cover were converted to plantations from 2005 to 2010 in SE Asia.

2.8. HUMAN DRUDGERY IN RUBBER TAPPING

In rubber industry, farming and agriculture tasks are highly physical demanding. The farm workers are at potential risk of health problems due to the requirement of arduous and extremely high energy for performing the tasks at field. Chemical hazards, physical hazards, ergonomic hazards and biological hazards are the main health problems faced by the workers. The Ergonomic hazards include variety of musculoskeletal symptoms (MSS) encompasses low back pain, the neck, osteoarthritis of the upper limb, hip and knee complaints, and hand-arm vibration syndrome (Walker-bone and Palmer, 2002). The rubber tappers are exposed to the ergonomics risk factors such as awkward postures, repetitiveness, forceful exertion and static muscle loading while doing the overall rubber tapping tasks (Reddy *et al.*, 2012). Height of tapping areas, age of the trees, uneven ground, number of area being tapped and technique of performing the tapping are the ergonomic factors present in rubber tapping process. In rubber tapping twisted head, neck extension, awkward postures, flexion of neck and repetitive moving of the head are the main risk factors for NP. Various lung function abnormalities and inflammation are caused due to the use of acids for the coagulation of the latex (Danwanichakul *et al.*, 2011). In Kerala, a wide range of occupational related diseases among agriculture workers especially among rubber plantation population are caused by the ergonomic risk factors and there is a need for extensive exploration in the field (Reddy *et al.,* 2012).

Kalubowila and Vidanapathirana (2015) conducted a study on the health problems of rubber tappers in Welikala, Sri Lanka. They studied 100 tappers and found that the most common musculoskeletal problem was backache (54%). The health hazards included cuts (44%), chemical injuries (26%), eye injuries (32%) and snake bites (8%). Knowledge regarding safety measures had been gained by 30% tappers. The most common hazard was cut injuries. There was no significant relationship of musculoskeletal problems with carrying method of latex, age or gender of the tappers but with number of tapped trees.

Meksawi *et al.* (2012) evaluated the prevalence of musculoskeletal disorders and ergonomic risk levels, and identified ergonomic factors related to low back pain in rubber tappers in Chumporn Province, Southern Thailand. Over half (52.9%) of the participants had low back pain during the previous 3 months, while the prevalence of pain in the legs, upper arms, neck, wrists, and lower arms were 14.8%, 8.9%, 3.0%, 2.3%, and 2.1%, respectively. The tapping levels and tapping postures including high frequencies of twisting, bending, and extension of trunk were significantly associated with low back pain. Other independent risk factors included a high frequency of weight lifting, high perceived fatigue from work, and lower levels of social support, education and income. Rubber tapping is regarded as an occupational risk for musculoskeletal disorders (MSDs).

Reddy *et al.* (2012) conducted a study in 343 (among 246 subjects with same socio economic status and equivalent physical activity) rubber tapping workers in two districts of Kerala. The results shown that the workers are affected with neck pain (NP) (72.2%), low back pain (66.2%), shoulders pain (44.9%), knee pain (55.8%), ankles/feet pain (34.4%), elbow pain (33.2%), upper back pain (30.8%), wrists pain (50.1%) and hip/thighs pain (15.3%). The study revealed that the workers were in potential risk of neck pain and various other musculo skeletal diseases (MSD) and lung function abnormalities due to exposure to acids, which are being used for the coagulation of latex.

Shan *et al.* (2012) conducted a study to determine the prevalence of neck pain (NP) and musculoskeletal symptoms (MSS) and its association with personal characteristics, physical workloads and psychosocial factors among rubber workers. Data was collected from 419 rubber workers in FELDA's scheme Malaysia. The results revealed the prevalence of NP was 59.9% and all physical workloads (neck flexion or rotation, awkward postures, repetitive motion and static postures) had significant weak to moderate positive correlation with NP. This study showed that high prevalence of NP was associated with neck flexion or rotation, awkward and static postures.

Materials and Methods

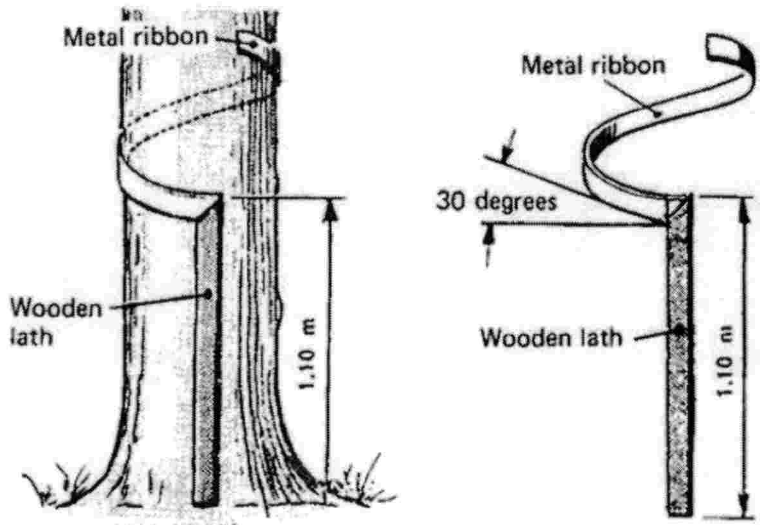
CHAPTER III

MATERIALS AND METHODS

The methodology of fabrication and evaluation procedures for the rubber tapping machine are described in this chapter. This chapter also explains the various requirements to develop the rubber tapping machine and evaluation of existing rubber tapping devices in Kerala.

3.1. STUDY ON RUBBER TAPPING PROCESS

A detailed study was conducted on how the tapping process is carried out to understand the design requirements that should be considered during the development of a rubber tapping machine.



(FAO, 2018)

Fig.3.1. Initial marking of tapping process

The tapping process was starts when a rubber tree reaches 50 cm in circumference, at a height of 1 metre from the ground. Normally the tapping process is initiated at 5th year after it had been raised in the plantation. To start tapping, a metal ribbon attached to a wooden lath 1.10 m long was taken. The metal ribbon may be at an angle of 30 degrees to the horizontal.

The metal ribbon was rolled around the tree. With an awl (an iron point), a cut was made along the ribbon. The cut ends when one round was completed, and the beginning of the cut and the end of the cut were on the same vertical line. With the awl a vertical channel was cut from the lower edge. The cut and the channel were then deepened.

3.2. STUDY ON EXISTING RUBBER TAPPING KNIVES

Prior to the development of rubber tapping machine, a study was conducted on the traditional gouge knife which is commonly used in Kerala. The performance of the knife was evaluated in terms of time for pre tapping operations, depth of cut, thickness of cut, time for tapping and weight of the knife as prescribed in 3.2.1.1 and 3.4.2 -3.4.6 respectively.

3.2.1. Traditional Gouge Knife

The blade of the knife shall be manufactured from carbon steel or alloy steel or tool steel. The chemical composition of the carbon steel shall be as follows:

a) Carbon 0.7 to 0.9%;

b) Silicon 0.1 to 0.4%;

c) Manganese 0.5 to 1.0%;

d) Sulphur 0.05%;

e) Phosphorus 0.05%.

Handle was made of wood and ferrule with mild steel or brass. The blade of the knife is heat-treated to give hardness within the range of 450 HV to 500 HV. The dimensions of the knife were:

The width of the cutting edge was 25.0 ± 0.5 mm

The length of the blade was 100 ± 3 mm

The length of the tang was 110 ± 3 mm

The length of the handle was 140 ± 3 mm

The minimum thickness of the blade was 6.0 mm

The angle of cutting edge was 105 ± 3°

Plate 3.1 Traditional gouge knife

3.2.1.1. Time for pre tapping operations

Time for pre tapping operations is the time taken by the tapper to perform all the necessary operations which were required prior to tapping. The pre tapping operations include removal of coagulated latex in the cutting path, fixing of latex collecting accessories, keeping the height of tapping, if the tapping is high level tapping etc. Time taken by the tapper for moving from a tree to next was also considered to calculate the total time between two successive tapping. A stopwatch was used to record the time.

3.3. DEVELOPMENT OF RUBBER TAPPING MACHINE

Rubber tapping machine was developed and fabricated at K. C. A. E. T., workshop. It consists of the following parts.

a. Cutting blade

b. Shaft

c. Connecting rod

d. Crank

e. Gear assembly

f. Bearing

g. Coupling

h. Frame

i. Casing

j. Motor

k. Battery

3.3.1. Cutting Blade

Cutting blade was the main component of the rubber tapping machine, which helps to cut the bark of rubber tree during tapping. The blade was made of 0.5 mm thick high carbon steel sheet. The blade was replaceable and has a cutting width of 1 cm and a supporting edge of 4 cm length. A bolt was used to connect the cutting blade to the shaft. A M8×50 mm bolt was used and is fixed at the center of the cutting blade.

3.3.2. Shaft

The shaft or push rod was made of mild steel. The shaft was cylindrical in shape and has dimensions of 175 mm length and 10 mm diameter. A hole of diameter 8 mm was provided at one end of the shaft for connecting the replaceable cutting blade. On the other end, the rod was flattened in a length of 15 mm to a thickness of 3 mm. A hole of 6 mm diameter was drilled in the flat end of shaft to connect the shaft with the connecting rod. The shaft was solid in the end where the cutting blade was connected and hollow in the other half to reduce the weight of the machine.

3.3.3. Connecting Rod

Connecting rod was the part which connects the shaft with the gear assembly. It converts the rotary motion of the gear assembly to reciprocating motion in the shaft. The connecting rod was made up of 2 mm thick mild steel sheet of rectangular shape. It had a dimension of 65 mm length and 18 mm width. Both ends of the connecting rod were rounded with a radius 9mm. Two holes of 6 mm diameter were provided in both ends for connecting the rod with shaft and gear assembly. The holes were provided at a distance of 9 mm from the edge.

3.3.4. Crank

A crank made of mild steel was attached to the gear assembly. The crank had a diameter of 50 mm, thickness of 7 mm and weighs about 200 g. The crank connects the shaft and the gear assembly. A hole of 6 mm diameter was provided to connect the connecting rod at an eccentricity of 15 mm.

3.3.5. Gear Assembly

The gear assembly consists of two gears and was provided to increase the speed of the cutting blade. The gears were made in mild steel. In the gear assembly, one small gear with 12 teeth and one large gear with 48 teeth were meshed with each other to obtain a speed ratio of 4. The gears were rested in a bearing seat. Gear with 12 teeth was connected to the crank and the gear with 48 teeth was connected to the motor shaft.

3.3.6. Bearing

Two types of bearings were used in the rubber tapping machine. Two bush bearings of fibre materials were used in the two ends of the reciprocating shaft. The bush bearings had dimensions of 35 mm length, 12 mm inner diameter and 25 mm outer diameter.

Two double shielded deep groove ball bearings made of high carbon chromium bearing steel were used for making bearing seat. The bearing seat was made by welding the two bearings by side to side. A 6005 and 6002 model bearings were used.

Plate.3.2. Bearings

3.3.7. Coupling

A coupling made of mild steel was used. The coupling had dimensions of 40 mm length and 15 mm width. The coupling connects motor shaft and gear shaft.

3.3.8. Frame

A frame of mild steel was provided for mounting the crank, gear assembly and bearing seat.

3.3.9. Casing

Outer casing made of cast iron was provided for encompassing the gear assembly, fly wheel, connecting rod, coupling, reciprocating shaft and bolt of cutting blade. The outer casing helps to protect the tapper from all moving parts.

3.3.10. Motor

The motor used in the rubber tapping machine was a DC shunt wound motor which was usually used as wiper motor in cars. A 12 V, 185 W motor was used. The motor had a rotational speed of 72 rpm. . The motor was connected to the battery through electric cables which provide electric power.

Plate.3.3. DC Motor

3.3.11. Battery

A 12 V battery of 5 Ah capacity was used. Electrical cables were used to connect the battery with the motor. A switch was used for on/off the connection between the battery and the rubber tapping machine.

Plate.3.4. Battery with connection cables and switch

3.4. PERFORMANCE EVALUATION OF THE RUBBER TAPPING MACHINE

The performance of the developed rubber tapping machine was evaluated by field trials. The performance parameters were measured from the field. Procedure for field trial is described in 3.4.1. Performance of the rubber tapping machine was evaluated in terms of capacity, depth of cut, thickness of cut, time for tapping operations and weight of the machine.

3.4.1. Field Trial of the Developed Rubber Tapping Machine

The field evaluation of the developed rubber tapping machine was done by three tappers at two rubber field. The performance of the developed rubber tapping machine was evaluated in terms of its capacity, depth of cut of bark, bark consumption or thickness of cut of bark, time for tapping operations, weight of the machine etc. The capacity, depth of cut of bark, bark consumption or thickness of cut of bark, time for tapping operations and weight of the machine was calculated as mentioned in the sections 3.4.2 to 3.4.6.

A farmer's field at Kodanad, Ernakulam was selected which was a 2 acre land with a stand of 210 trees/acre. The rubber trees were planted with a plant to plant and row to row spacing of 4.5×4.5 m (15×15 ft). The field was flat in most area with some gender sloppy area. The rubber trees in the field had a life of 13 years and are continuously tapping for past 8 years.

A farmer's field at Malayattoor, Ernakulam was selected which was a 5 acre land with a stand of 190 trees/acre. The rubber trees were planted with a plant to plant and row to row spacing of 6×3 m (20×10 ft). The field was sloppy in most area and the land was terraced. The rubber trees in the field had a life of 8 years and are continuously tapping for the past 2 years.

Three tappers were selected for the field evaluation of the developed rubber tapping machine. The tappers performed the tapping operation using developed rubber tapping machine in both field. The performance of the developed rubber tapping machine was compared with traditional gouge knife.

Tapper 1 was a 45 year old male worker and had an experience of 25 years. Tapper 2 was a 54 year old male worker with an experience of 36 years. Tapper 3 was a 59 year old male worker with an experience of 32 years and was trained from Rubber Board.

3.4.2. Depth of Cut of Bark

It is the depth at which the cutting blade will penetrate through the bark during tapping. It was measured using a steel rule (Least count= 1 mm). As per the recommendations of Rubber Board, the depth of cut should be in the range of 6-8 mm for optimum latex yield, without injuring the cambium.

3.4.3. Bark Consumption or Thickness of Cut of Bark

It is the thickness of the bark removed during tapping with the rubber tapping knife or machine. It was measured using Vernier calipers (Least count= 0.01 mm). The Rubber Board recommends to shave the bark of rubber tree in a thickness of 1-2 mm for getting a long harvesting life.

3.4.4. Time for Tapping Operations

It is the time taken to perform all the tapping processes in a single tree. A stopwatch was used to record the time.

3.4.5. Capacity of the Machine

Capacity of the rubber tapping machine can be defined as the number of rubber trees tapped per hour. The capacity of the rubber tapping machine was calculated using the following equation:

$$\text{Capacity (trees/h)} = \frac{3600}{\text{Time for tapping a single tree (seconds)}}$$

....(3.1)

3.4.6. Weight of the Machine

The weight of the traditional rubber tapping machine with and without power source (battery) were measured. The weight was measured using a digital weighing balance (Least count= 0.001 g).

3.5. COST ECONOMICS

The cost for development of the rubber tapping machine was estimated by considering the fixed and operating cost as per the standard procedure for the analysis of cost economics and is compared with manual tapping. Suitable assumptions are made and the variable cost of unit was calculated by considering electricity charges, repairs and maintenance and cost of labour. Cost analysis is given in appendix A.

Results and Discussion

CHAPTER IV

RESULTS AND DISCUSSION

This chapter deals with results obtained from the development of the rubber tapping machine and from various experiments conducted in the field to evaluate the performance of the developed rubber tapping machine.

4.1 STUDY ON EXISTING RUBBER TAPPING KNIVES

The traditional gouge knife uses the pushing action to cut the bark of the rubber tree. The efforts required for tapping by the knife is more and it is the main disadvantage of the knife. The blade is easy to handle and the life of the blade is more when compared with Jebong knife. The performance of the traditional gouge knife was evaluated and discussed in 4.1.1 – 4.1.6.

4.1.1. Time for Pre Tapping Operations

The time took by the three tappers to perform all the necessary operations in field 1 and 2 which were required prior to tapping was measured and tabulated in table.4.1 and 4.2 as time for pre tapping operations by using a stopwatch.

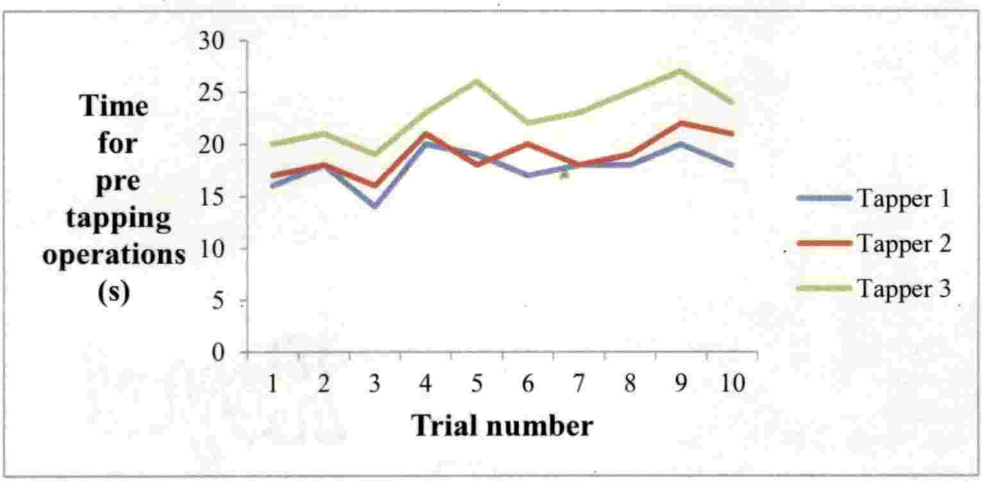


Fig.4.1. Time for pre tapping operations in field 1

Table.4.1. Time for pre tapping operations in field 1

Trial No.	Time for pre tapping operations (s)		
	Tapper 1	Tapper 2	Tapper 3
1	16	17	20
2	18	18	21
3	14	16	19
4	20	21	23
5	19	18	26
6	17	20	22
7	18	18	23
8	18	19	25
9	20	22	27
10	18	21	24
Mean	**17.8**	**19**	**23**
SD	**1.814**	**1.944**	**2.582**

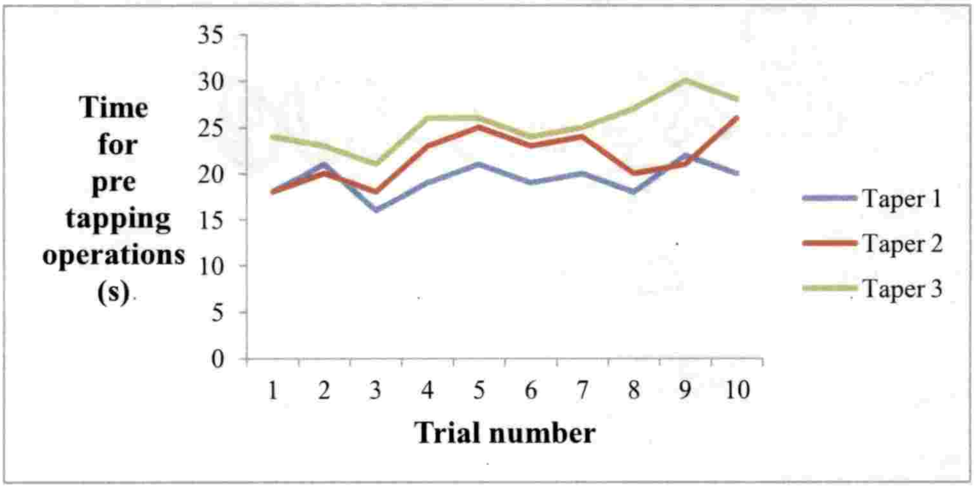


Fig.4.2. Time for pre tapping operations in field 2

Table.4.2. Time for pre tapping operations in field 2

Trial No.	Time for pre tapping operations (s)		
	Tapper 1	**Tapper 2**	**Tapper 3**
1	18	18	24
2	21	20	23
3	16	18	21
4	19	23	26
5	21	25	26
6	19	23	24
7	20	24	25
8	18	20	27
9	22	21	30
10	20	26	28
Mean	**19.4**	**21.8**	**25.4**
SD	**1.776**	**2.821**	**2.591**

The average time for pre tapping operations took by the three tappers in the two fields was 21 seconds. The time required for performing the operations prior to the tapping will be same for a tapper in manual tapping and tapping with the developed rubber tapping machine since the time was recorded prior to the tapping.

The time required for performing the pre tapping operations will vary according to topography of land, age of tree, height of tapping, age and health of tapper and plant density.

4.1.2. Depth of cut

The depth of cut or depth at which the cutting blade will penetrate through the bark during tapping was measured using a steel rule. The depth of cut by using the traditional gouge knife by tapper 1, 2 and 3 were tabulated in the Table.4.3 and 4.4 separately for field 1 and 2.

Table.4.3. Depth of cut of manual tapping in field 1

Trial No.	Depth of cut (mm)		
	Tapper 1	**Tapper 2**	**Tapper 3**
1	6	7	6
2	8	6	6
3	8	6	7
4	7	7	6
5	6	7	6
6	6	6	7
7	7	8	6
8	7	6	7
9	6	7	6
10	9	7	7
Mean	**7.0**	**6.7**	**6.4**
SD	**1.054**	**0.675**	**0.516**

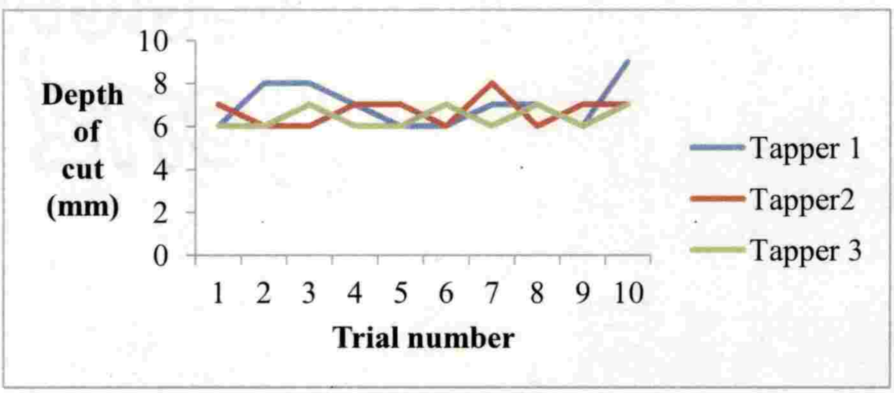


Fig.4.3. Depth of cut of manual tapping in field 1

Table.4.4. Depth of cut of manual tapping in field 2

Trial No.	Depth of cut (mm)		
	Tapper 1	Tapper 2	Tapper 3
1	6	7	6
2	8	6	6
3	8	6	7
4	7	7	7
5	6	7	6
6	6	6	7
7	7	8	6
8	7	6	7
9	6	7	6
10	8	6	8
Mean	**6.9**	**6.6**	**6.6**
SD	**0.876**	**0.699**	**0.699**

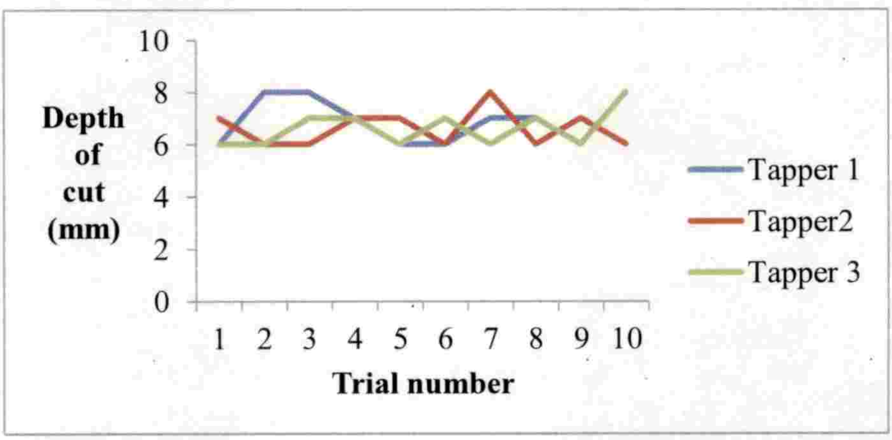


Fig.4.4. Depth of cut of manual tapping in field 2

The average depth of cut took by the three tappers in the two fields was 6.7 mm. The depth of cut obtained in tapping by traditional gouge knife was within the range of 6-8 mm that is recommended by Rubber Board. The experience, health and skill of tapper, variety and age of trees may affect the depth of cut.

4.1.3. Thickness of cut

The thickness of the bark removed during tapping with the rubber tapping machine was measured using Vernier calipers. The thickness of cut using traditional gouge knife by tapper 1, 2 and 3 were tabulated in the table 4.5 and 4.6 separately for field 1 and 2.

Table.4.5. Thickness of cut of manual tapping in field 1

Trial No.	Thickness of cut (mm)		
	Tapper 1	**Tapper 2**	**Tapper 3**
1	2.2	2.0	1.7
2	2.1	1.8	2.0
3	1.6	1.4	1.4
4	1.1	1.2	1.3
5	1.4	1.3	1.1
6	1.5	1.6	1.3
7	1.8	1.3	1.4
8	1.7	1.2	1.1
9	1.8	1.2	1.0
10	2.1	1.0	1.2
Mean	**1.73**	**1.4**	**1.35**
SD	**0.3466**	**0.3091**	**0.3028**

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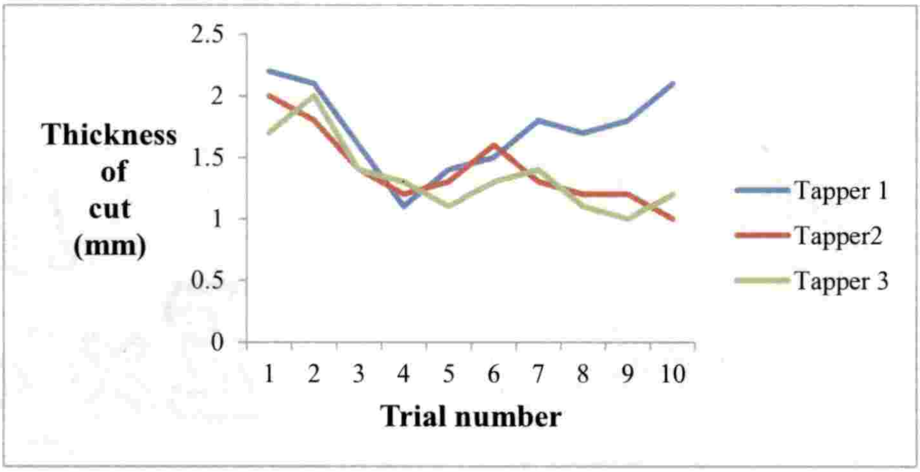


Fig.4.5. Thickness of cut of manual tapping in field 1

Table.4.6. Thickness of cut manual tapping in field 2

Trial No.	Thickness of cut (mm)		
	Tapper 1	**Tapper 2**	**Tapper 3**
1	2.0	1.8	1.8
2	2.1	1.7	1.8
3	1.5	1.5	1.1
4	1.3	1.4	1.3
5	1.3	1.3	1.2
6	1.5	1.5	1.4
7	1.7	1.4	1.0
8	1.6	1.3	1.3
9	1.9	1.5	1.1
10	2.1	1.8	1.2
Mean	**1.7**	**1.52**	**1.32**
SD	**0.3091**	**0.1874**	**0.2781**

70

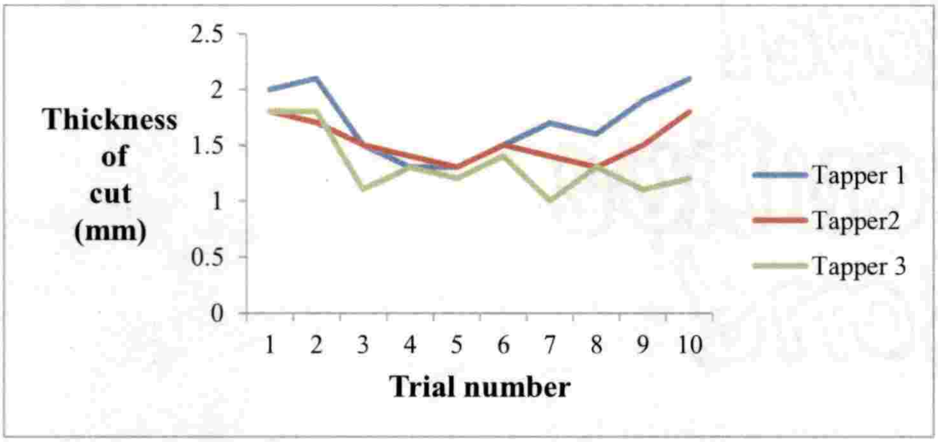


Fig.4.6. Thickness of cut of manual tapping in field 2

The average thickness of cut took by the three tappers in the two fields was 1.5 mm. The thickness of cut obtained in tapping by traditional gouge knife was within the range of 1-2 mm that is recommended by Rubber Board. The experience, health and skill of tapper, variety and age of trees may affect the thickness of cut.

4.1.4. Time for Tapping Operations

The time required for performing tapping operation in a single tree was measured using a stopwatch. The time for tapping while using traditional gouge knife by tapper 1, 2 and 3 were tabulated in the table 4.7 and 4.8 separately for field 1 and 2.

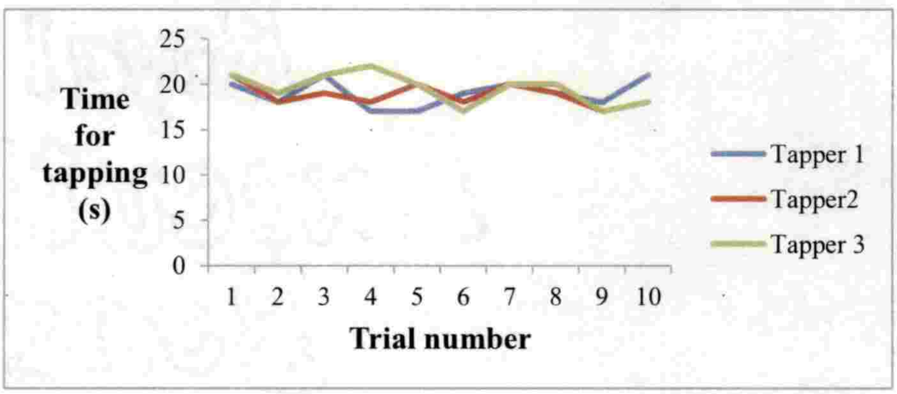


Fig.4.7. Time for tapping in manual tapping in field 1

Table.4.7. Time for tapping operations in manual tapping in field 1

Trial No.	Time for tapping operations (s)		
	Tapper 1	Tapper 2	Tapper 3
1	20	21	21
2	18	18	19
3	21	19	21
4	17	18	22
5	17	20	20
6	19	18	17
7	20	20	20
8	19	19	20
9	18	17	17
10	21	18	18
Mean	**19**	**18.8**	**19.5**
SD	**1.491**	**1.229**	**1.716**

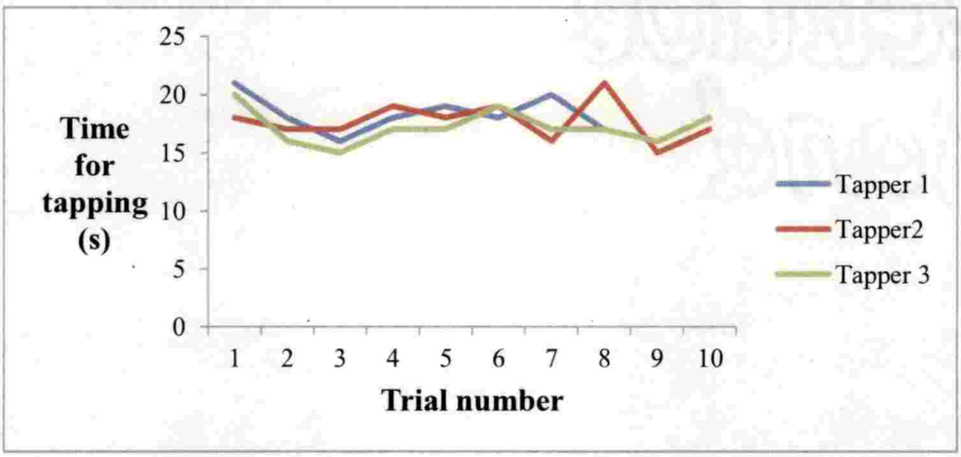


Fig.4.8. Time for tapping in manual tapping in field 2

Table.4.8. Time for tapping operations in manual tapping in field 2

Trial No.	Time for tapping operations (s)		
	Tapper 1	**Tapper 2**	**Tapper 3**
1	21	18	20
2	18	17	16
3	16	17	15
4	18	19	17
5	19	18	17
6	18	19	19
7	20	16	17
8	17	21	17
9	16	15	16
10	18	17	18
Mean	**18.1**	**17.7**	**17.2**
SD	**1.595**	**1.703**	**1.476**

The average time for tapping operations took by the three tappers in the two fields was 18.38 s. Experience, skill and health of tapper, topography of land, age and variety of trees are the factors that may affect the time required for tapping. The experience with traditional gouge knife makes the tapping easier and it took less time for taping a single tree.

4.1.5. Capacity

Capacity (number of rubber trees tapped per hour) of the manual tapping by three tappers in two field were calculated by using equation 3.1.

Table.4.9. Capacity of manual tapping

	Capacity (trees/h)		
	Tapper 1	**Tapper 2**	**Tapper 3**
Field 1	189	191	184
Field 2	198	203	209
Mean	**193**	**197**	**196**
SD	**6**	**8**	**17**

The average number of rubber trees tapped per hour by the three tappers in the two fields was 195 trees/h. The topography of land, tapping system, the position of the tapping cut, stand or number of rubber trees per hectare, the age of trees and skill of the tapper are the factors which may affect the capacity of tapping.

4.1.6. Weight of the knife

The weight of the traditional gouge knife was measured a digital weighing balance. The weight measurement was:

The weight of traditional gouge knife = 0.235 kg

4.2. DEVELOPMENT OF RUBBER TAPPING MACHINE

A rubber tapping machine was developed which consists of a cutting blade, shaft, connecting rod, crank, gear assembly, bearing, coupling, frame, casing, motor and a battery.

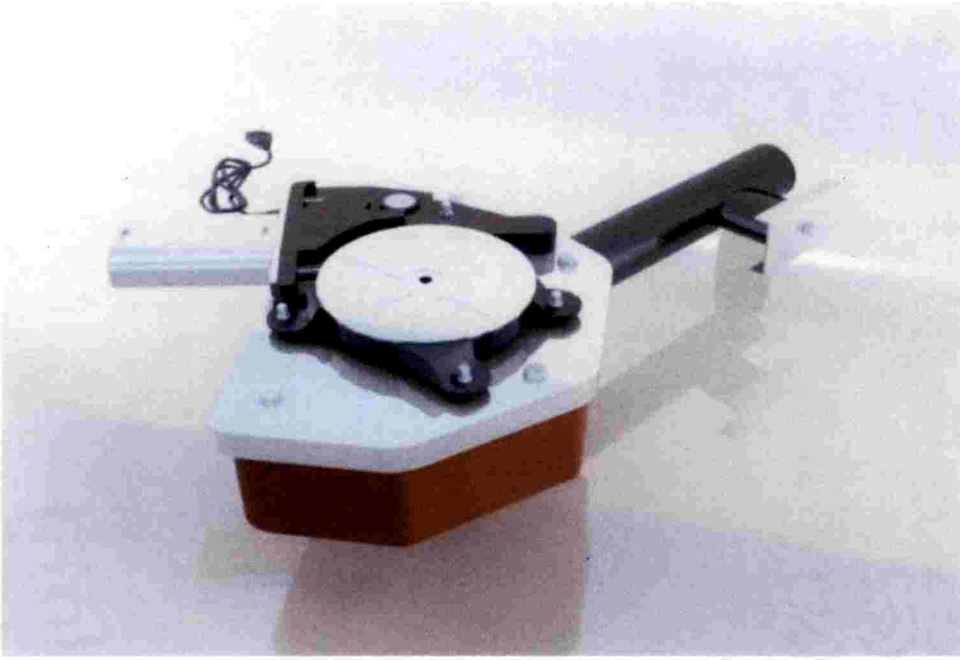


Fig.4.9 Isometric view of the rubber tapping machine

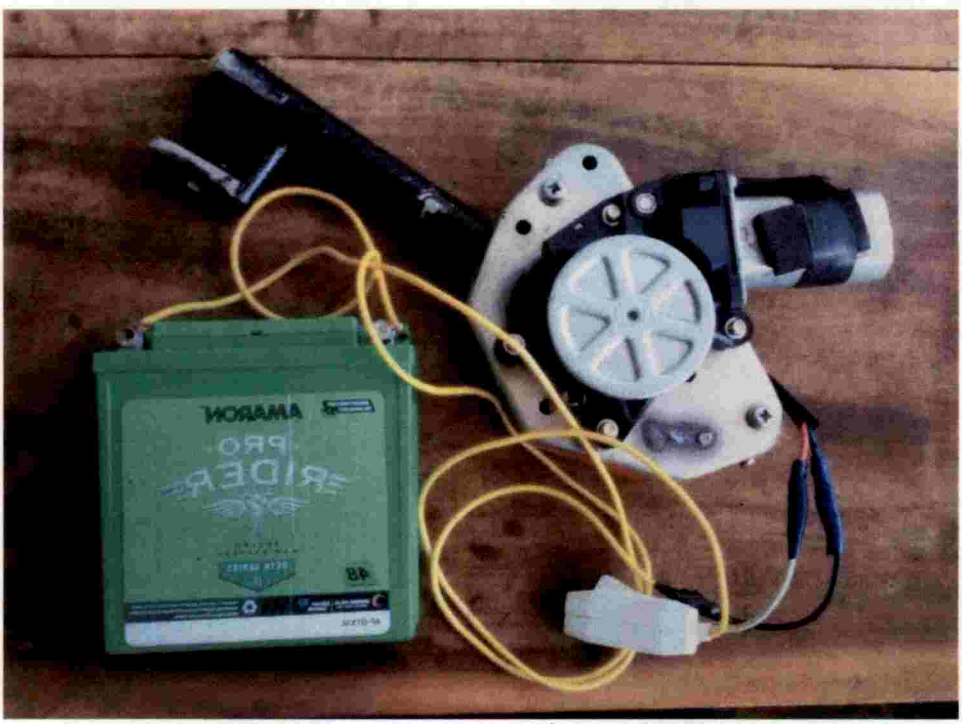


Plate.4.1. Rubber tapping machine with power source

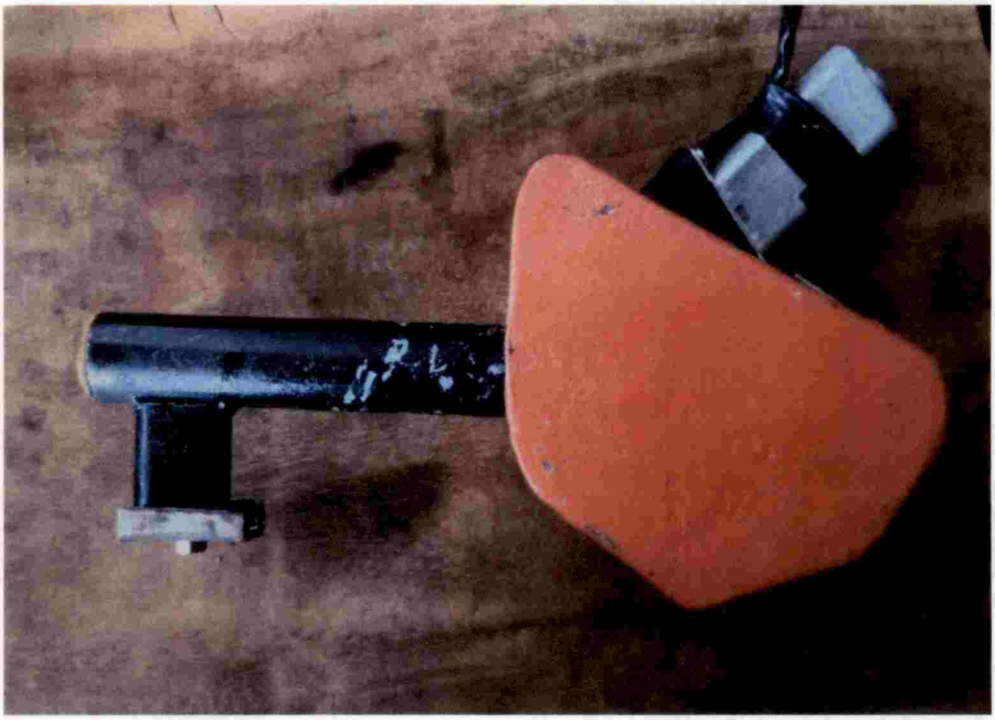


Plate.4.2. Left side view of rubber tapping machine

Plate.4.3. Right side view of rubber tapping machine

4.2.1. Cutting Blade

A reciprocating, replaceable cutting blade of 0.5 mm thickness having cutting width of 1 cm and a supporting edge of 4 cm length was developed. The blade is reciprocated with a stroke length of 30 mm and 144 strokes per minute.

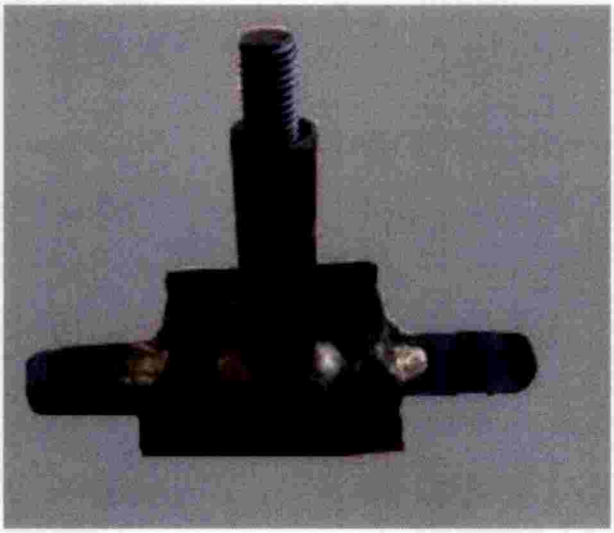


Plate.4.4. Side view of cutting blade

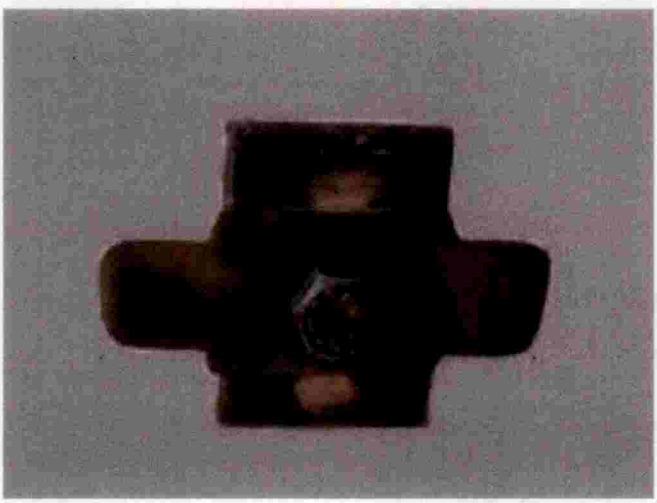


Plate.4.5 Bottom view of cutting blade

4.2.2. Shaft

The shaft of 175 mm length and 10 mm diameter was developed.

Plate.4.6. Shaft

4.2.3. Connecting Rod

A connecting rod of 65 mm length and 18 mm width was developed.

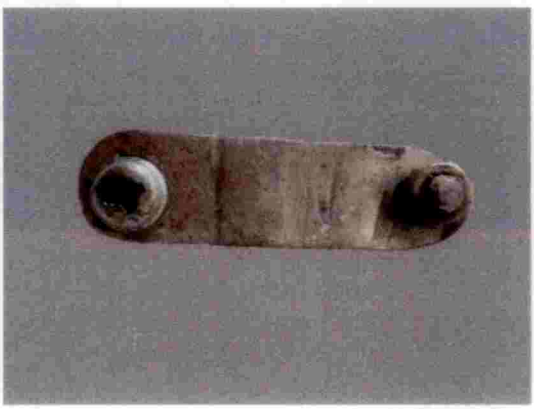


Plate.4.7. Connecting rod

4.2.4. Crank

A crank of 50 mm diameter and 7 mm thickness was developed. The crank connects the shaft and the gear assembly and rotates at a speed of 288 rpm.

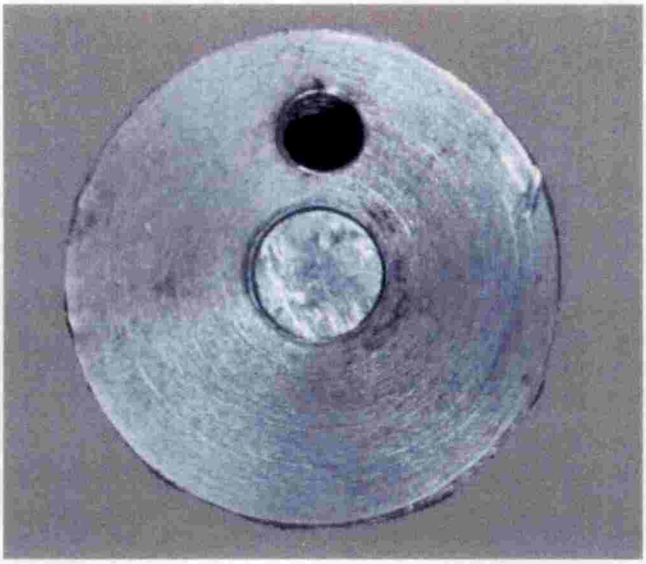


Plate.4.8. Crank

4.2.5. Gear Assembly

The gear assembly consists of two gears with 12 teeth and 48 teeth were developed to obtain a speed ratio of 4. The gear with 12 teeth and 48 teeth rotates at a speed of 288 and 72 respectively.

Plate.4.9. Gear with 48 teeth

Plate.4.10. Gear with 12 teeth

4.2.6. Bearing

. Two bush bearings were fixed in the two ends of the reciprocating shaft for the purpose of easy sliding of the shaft in the shaft casing.

Two double shielded deep groove ball bearings were welded by side to side and the bearing seat was developed.

Plate.4.11. Bearing seat

4.2.7. Coupling

A coupling was developed to support the connection of gear shaft with motor through which the power is transmitted.

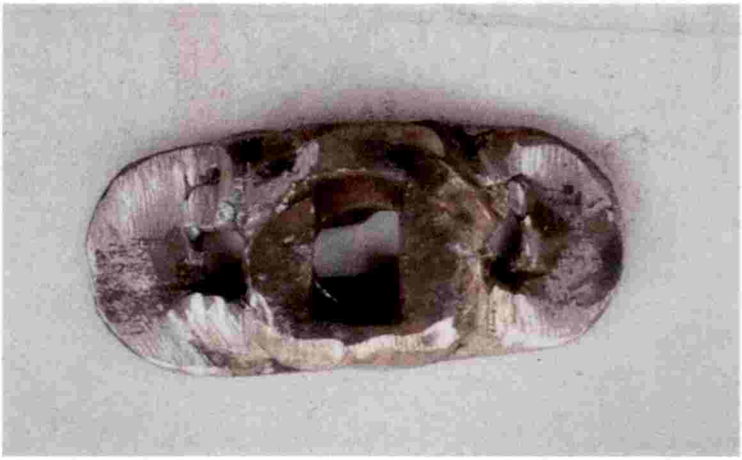


Plate.4.12. Coupling

4.2.8. Frame

A frame of mild steel is provided for mounting the crank, gear assembly and bearing seat.

Plate.4.13. Frames

4.2.9. Casing

Outer casing made of cast iron for encompassing the gear assembly, fly wheel, connecting rod, coupling, reciprocating shaft and bolt of cutting blade was developed to protect the tapper from all moving parts.

Plate.4.14. Casing

4.2.10. Motor

The motor connected with the gear assembly convert the electrical energy from power source to mechanical energy. The motor used in the rubber tapping machine was a DC shunt wound motor which was usually used as wiper motor in cars. A 12 V, 185 W motor was used. The motor had a rotational speed of 72 rpm.

4.2.11. Battery

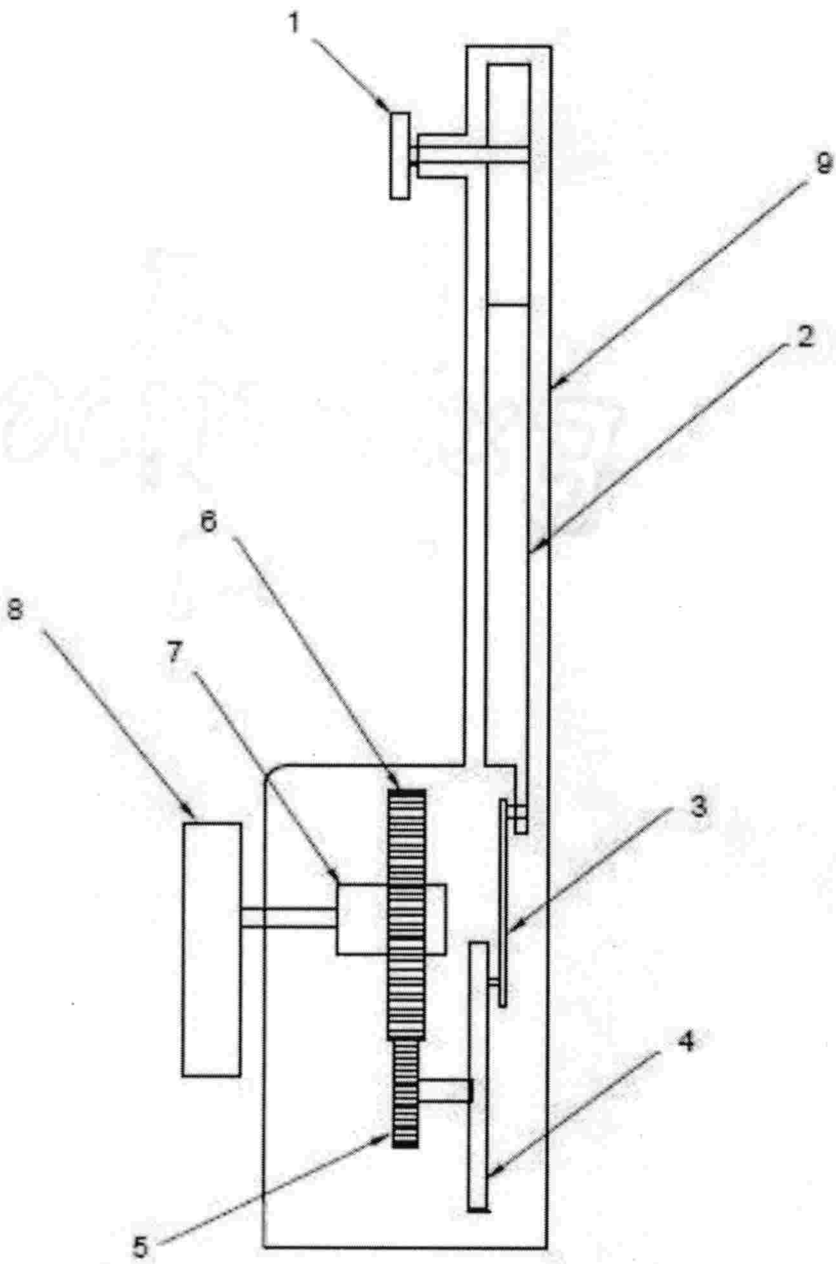
Battery is the electrical power source for the developed rubber tapping machine. A 12 V battery of 5 Ah capacity was used. Electrical cables were used to connect the battery with the motor. A switch was used for on/off the connection between the battery and the rubber tapping machine.

4.3. OPERATION OF RUBBER TAPPING MACHINE

The rubber tapping machine is connected to a 12 V, 5 Ah battery. The battery powers the motor. 0.25 hp wiper motor was used and it delivers a rotational speed of 72 rpm. The rotary motion of the motor is transmitted to the gear assembly using a gear shaft. The gear of 48 teeth which is connected with the motor rotates at 72 rpm. The speed is increased to 288 rpm by meshing gear of 48 teeth with 12 teeth gear to obtain a speed ratio of 4. A crank is attached to the gear of 12 teeth and rotates at 288 rpm. A connecting rod linking the shaft and the crank converts this rotary motion into reciprocating motion of the shaft. The required stroke is achieved by an eccentricity of 15 mm in the connecting rod. The blade is reciprocated along with the shaft with a stroke length of 30 mm and 144 strokes per minute. The reciprocating motion of the cutting blade helps to cut the bark of the rubber tree while tapping.

4.4. PERFORMANCE EVALUATION OF THE RUBBER TAPPING MACHINE

Only a prototype of the rubber tapping machine was developed and the performance evaluation at this stage may not reflect the actual performance of the machine. The performance of the developed rubber tapping machine was evaluated based on field trial as described in 3.4.1. The performance of the machine was evaluated in terms of its capacity, depth of cut of bark, bark consumption or thickness of cut of bark, time for tapping operations, weight of the machine as described in 3.4.2 to 3.4.6.



1. Blade	4. Crank	7. Bearing seat
2. Shaft	5. Small gear	8. Motor
3. Connecting rod	6. Large gear	9. Casing

Fig.4.10. Schematic view of rubber tapping machine

4.4.1. Field Trial of the Developed Rubber Tapping Machine

The field evaluation of the developed rubber tapping machine was done at two farmer's field at Kodanad and Malayattoor villages in Ernakulam district by three tappers. The performance parameters were measured from the field and tabulated in tables. The results of the performance evaluation are discussed.

Plate.4.15. Field evaluation of rubber tapping machine

4.4.2. Depth of Cut of Bark

The depth of cut or depth at which the cutting blade will penetrate through the bark during tapping was measured using a steel rule. The depth of cut by using the developed rubber tapping machine by tapper 1, 2 and 3 were tabulated in the Table.4.10 and 4.11 separately for field 1 and 2.

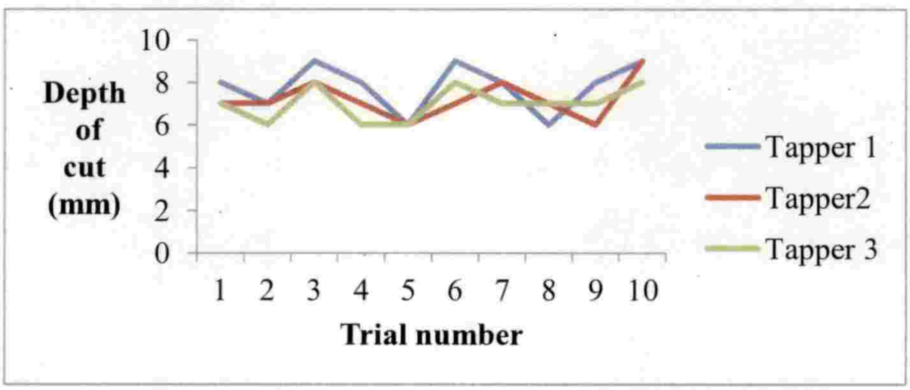


Fig.4.11. Depth of cut of mechanical tapping in field 1

Table.4.10. Depth of cut of mechanical taping in field 1

Trial No.	Depth of cut (mm)		
	Tapper 1	Tapper 2	Tapper 3
1	8	7	7
2	7	7	6
3	9	8	8
4	8	7	6
5	6	6	6
6	9	7	8
7	8	8	7
8	6	7	7
9	8	6	7
10	9	9	8
Mean	**7.8**	**7.2**	**7.0**
SD	**1.135**	**0.919**	**0.816**

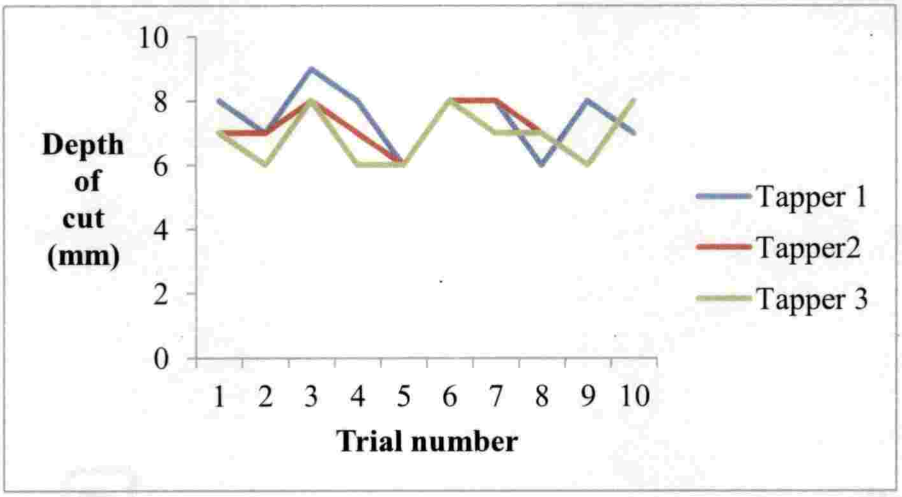


Fig.4.12. Depth of cut of mechanical tapping in field 2

Table.4.11. Depth of cut of mechanical tapping in field 2

Trial No.	Depth of cut (mm)		
	Tapper 1	**Tapper 2**	**Tapper 3**
1	8	7	7
2	7	7	6
3	9	8	8
4	8	7	6
5	6	6	6
6	8	8	8
7	8	8	7
8	6	7	7
9	8	6	6
10	7	8	8
Mean	**7.5**	**7.2**	**6.9**
SD	**0.972**	**0.789**	**0.876**

The average depth of cut of the developed rubber tapping machine obtained from the three tappers in the two fields was 7.26 mm. The depth of cut obtained in rubber tapping machine was within the range of 6-8 mm that is recommended by Rubber Board. The experience, health and skill of tapper and variety and age of trees may affect the depth of cut.

4.4.3. Bark Consumption or Thickness of Cut of Bark

The thickness of the bark removed during tapping with the rubber tapping machine was measured using Vernier calipers. The thickness of cut using rubber tapping machine by tapper 1, 2 and 3 were tabulated in the table 4.12 and 4.13 separately for field 1 and 2.

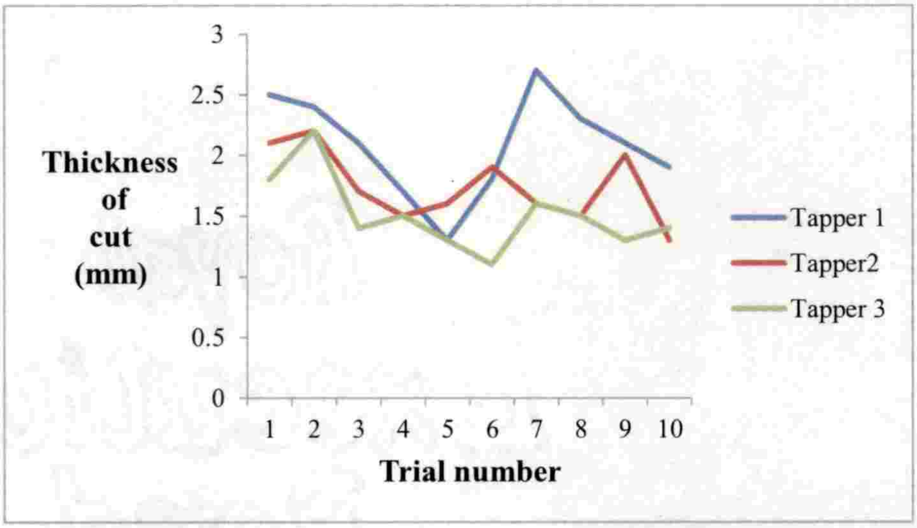


Fig.4.13. Thickness of cut of mechanical tapping in field 1

Table.4.12. Thickness of cut of mechanical tapping in field 1

Trial No.	Thickness of cut (mm)		
	Tapper 1	Tapper 2	Tapper 3
1	2.5	2.1	1.8
2	2.4	2.2	2.2
3	2.1	1.7	1.4
4	1.7	1.5	1.5
5	1.3	1.6	1.3
6	1.8	1.9	1.1
7	2.7	1.6	1.6
8	2.3	1.5	1.5
9	2.1	2.0	1.3
10	1.9	1.3	1.4
Mean	**2.08**	**1.74**	**1.51**
SD	**0.4185**	**0.2951**	**0.3071**

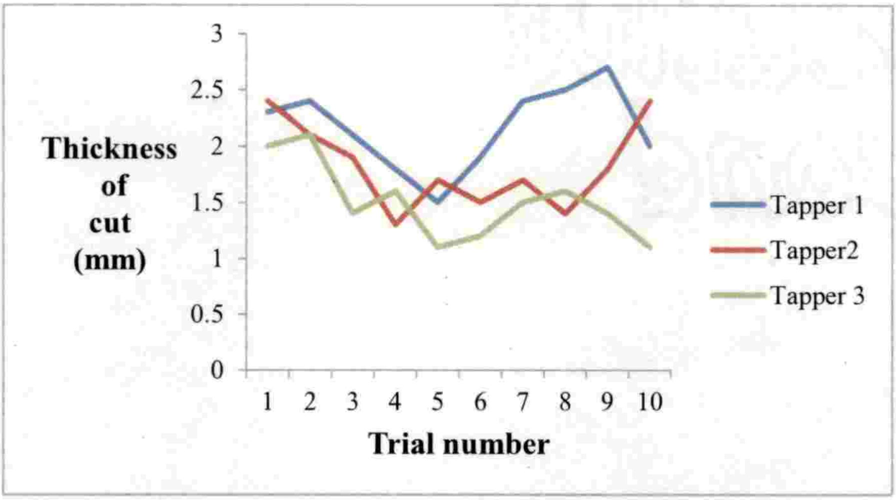


Fig.4.14. Thickness of cut of mechanical tapping in field 2

Table.4.13. Thickness of cut of mechanical tapping in field 2

Trial No.	**Thickness of cut (mm)**		
	Tapper 1	**Tapper 2**	**Tapper 3**
1	2.3	2.4	2.0
2	2.4	2.1	2.1
3	2.1	1.9	1.4
4	1.8	1.3	1.6
5	1.5	1.7	1.1
6	1.9	1.5	1.2
7	2.4	1.7	1.5
8	2.5	1.4	1.6
9	2.7	1.8	1.4
10	2.0	2.4	1.1
Mean	**2.16**	**1.82**	**1.5**
SD	**0.3658**	**0.3853**	**0.3432**

The average thickness of cut of the developed rubber tapping machine obtained from the three tappers in the two fields was 1.8 mm. The thickness of cut obtained in tapping by rubber tapping machine was within the range of 1-2 mm that is recommended by Rubber Board. The experience, health and skill of tapper and variety and age of trees may affect the thickness of cut.

4.4.4. Time for Tapping Operations

The time required for performing tapping operation in a single tree was measured using a stopwatch. The time for tapping while using rubber tapping machine by tapper 1, 2 and 3 were tabulated in the table 4.14 and 4.15 separately for field 1 and 2.

Table.4.14. Time for tapping operations in field 1

Trial No.	Tapper 1	Tapper 2	Tapper 3
1	24	23	25
2	22	21	26
3	23	22	24
4	20	24	27
5	25	22	23
6	26	23	21
7	24	25	24
8	25	21	26
9	23	18	21
10	26	22	23
Mean	**23.8**	**22.1**	**24**
SD	**1.874**	**1.912**	**2.055**

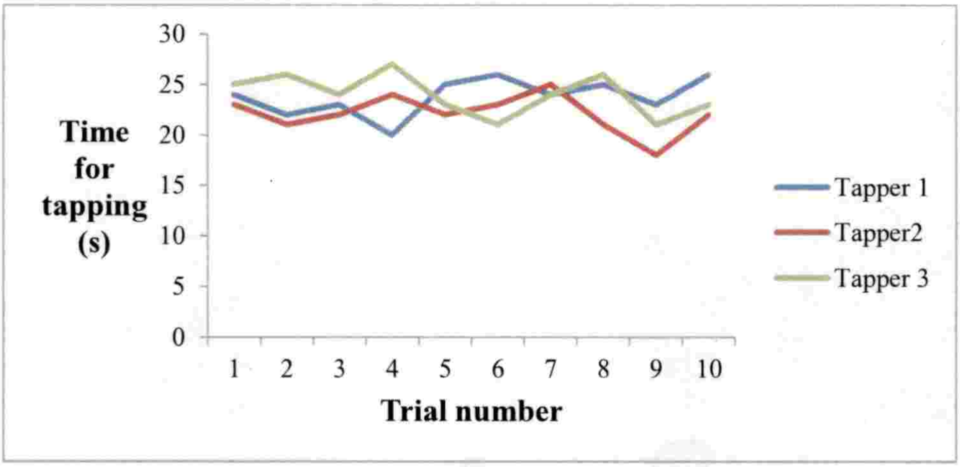


Fig.4.15. Time for tapping in field 1

Table.4.15. Time for tapping operations in field 2

Trial No.	Tapper 1	Tapper 2	Tapper 3
1	23	22	23
2	22	23	21
3	21	25	18
4	23	22	24
5	22	21	22
6	24	25	26
7	26	27	25
8	25	24	20
9	21	18	18
10	19	22	21
Mean	**22.6**	**22.9**	**21.8**
SD	**2.066**	**2.514**	**2.741**

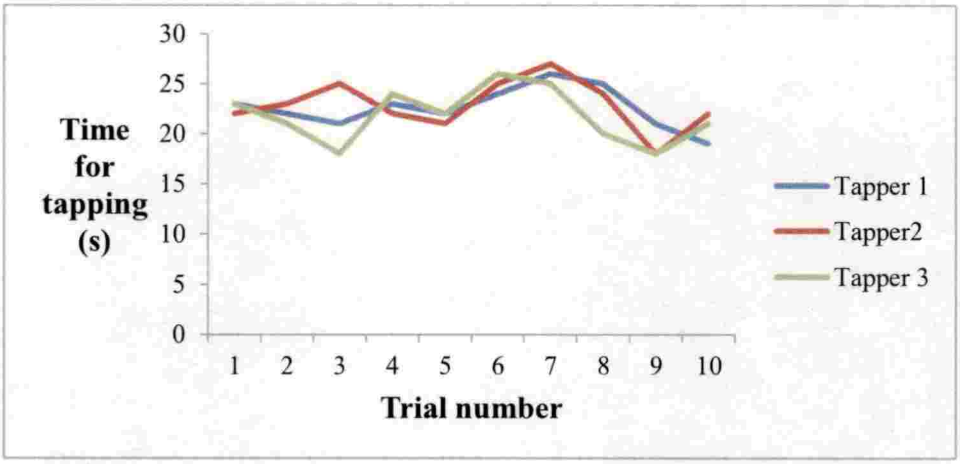


Fig.4.16. Time for tapping in field 2

The average time for tapping of the developed rubber tapping machine obtained from the three tappers in the two fields was 22.86 s. Experience, skill and health of tapper, topography of land, age and variety of land are the factors that may affect the time required for tapping. Lack of proper training and experience with the rubber tapping machine may be the reason for a more time for taping a single tree.

4.4.5. Capacity of the Machine

Capacity (number of rubber trees tapped per hour) of the rubber tapping machine by three tappers in two field were calculated by using equation 3.1.

Table.4.16. Capacity of mechanical tapping

	Capacity (trees/h)		
	Tapper 1	**Tapper 2**	**Tapper 3**
Field 1	151	162	150
Field 2	159	157	165
Mean	**155**	**159**	**157**
SD	**6**	**4**	**5**

The average capacity of the developed rubber tapping machine obtained from the three tappers in the two fields was 157 trees/h. The topography of land, tapping system, the position of the tapping cut, stand or number of rubber trees per hectare, the age of trees and skill of the tapper are the factors which may affect the capacity of tapping.

4.4.6. Weight of the Machine

The weight of the rubber tapping machine with and without power source (battery) was measured using a digital weighing balance. The weight measurements were:

The weight of the rubber tapping machine without power source (battery) = 1.6 kg

The weight of the rubber tapping machine with power source (battery) = 3.6 kg

Plate.4.16. Rubber tree tapped with developed rubber tapping machine

4.4.7. Comparison of the Performance of Developed Rubber Tapping Machine with Manual Tapping

The depth of cut of tapping with manual and mechanical tapping was 6.7 and 7.2 mm respectively. The developed machine cuts the bark of rubber tree at a depth which is comparable with manual tapping. The variation in the depth of cut with the rubber tapping machine may be due to lack of training, experience and skill with the newly developed rubber tapping machine and the higher weight of the machine compared to the traditional knives.

The average thickness of cut in tapping with rubber tapping machine were 1.8 mm and is comparable with the manual tapping where the average thickness of cut was 1.5 mm. Lack of training, experience and skill with the newly developed rubber tapping machine and the higher weight of the machine must have affected the performance of the machine.

The time for tapping obtained was 18 and 23 s for manual and mechanical tapping respectively and the time took by the developed machine was high.

The capacity of tapper in manual tapping and mechanical tapping shows that the capacity reduces while tapping with rubber tapping machine. The difference between the capacity of tapping with the traditional gouge knife and developed rubber tapping machine was minimum of 30 trees/h capacity.

The traditional gouge knife usually has a weight in the range of 200 to 300 g. The less weight of knife will improve the performance of the tapper. Even though the developed rubber tapping machine has more weight compared with the traditional knives and affects the performance of the tapper but this weight is required in making the reciprocating cutting action of the machine more effective and effortless.

4.5. COST ECONOMICS

The cost of operation of rubber tapping machine is estimated as Rs.1.16/tree whereas the manual tapping charges are Rs. 2/tree. The detailed cost economics of the rubber tapping machine is given in Appendix A.

Summary and Conclusion

CHAPTER V

SUMMARY AND CONCLUSION

Hevea brasiliensis, the Para rubber tree or the common rubber tree is the most important species which is the commercial source of natural rubber. Rubber is an important commercial plantation crop which is originated in Amazon basin and covers over 9.3 million hectares of plantation area in the world, of which 95% belongs to Asia. India is in the sixth position in the production of natural rubber with a share of 5% of world production and occupied second position in productivity during the year 2016. The hinterlands of the southwest coast, mainly Kerala and Kanyakumari District of Tamil Nadu are the traditionally cultivating areas of rubber in India. The non-traditional areas of rubber cultivation are hinterlands of coastal Goa, Karnataka, Konkan Region of Maharashtra, hinterlands of coastal Andhra Pradesh and Orissa, Andaman and Nicobar Islands and the north-eastern states,. In India, 5.59 lakh ha are under rubber cultivation and the natural rubber production during the year 2016-17 is 0.624 million tonnes. In Kerala 5.51lakh ha area is under rubber cultivation with a production of 0.54 million tonnes during the year 2016-17.

The rubber tree is a quickly growing, perennial tree attaining a height of 25 to 30 metres. The natural rubber is harvested in the form of latex (a sticky, milky colloid) through the process called tapping. Tapping is the process of making a controlled wound in the bark of rubber tree to cut open the latex vessels, which cause the flow of latex for capturing the latex. For trees tapping for the first time, tapping cut open the latex vessels and for trees under regular tapping, tapping removes the coagulum that blocks the cut ends of the latex vessels. The Hevea latex obtained from the bark of rubber tree contains 30 to 45% natural rubber particles that can be harvested and utilised for various industrial applications like automobile and domestic articles.

In India, two types of knives are used commercially for tapping called Michie Golledge knife and Jebong knife. In India, usually the tapping task by a skilled rubber tapper varies from 300 to 400 trees per day and will vary according to the topography of land, tapping system, the position of the tapping cut, stand or number of rubber trees per hectare, the age of trees and skill of the tapper. The depth of cut for obtaining best yield of rubber latex in tapping is less than 1 mm, a depth close to the cambium. Care should be taken not to injure the cambium at the time of tapping for obtaining optimum yield. For obtaining optimum yield, the annual bark consumption of about 20-23 cm is recommended. The shortage of trained labours is the main challenge faced by the plantation sector in India at present.

Before the fabrication of the machine, a study was conducted on the rubber tapping process and existing rubber tapping knives. The developed rubber tapping machine consists of a cutting blade, shaft, connecting rod, crank, gear assembly, bearing, coupling, frame, casing, motor and a battery. The rubber tapping machine is connected to a 12 V, 5 Ah battery. The battery powers the motor. 0.25 hp wiper motor was used and it delivers a rotational speed of 72 rpm. The rotary motion of the motor is transmitted to the gear assembly using a gear shaft. The gear of 48 teeth which is connected with the motor rotates at 72 rpm. The speed is increased to 288 rpm by meshing gear of 48 teeth with 12 teeth gear to obtain a speed ratio of 4. A crank is attached to the gear of 12 teeth and rotates at 288 rpm. A connecting rod linking the shaft and the crank converts this rotary motion into reciprocating motion of the shaft. The required stroke is achieved by an eccentricity of 15 mm in the connecting rod. The blade is reciprocated along with the shaft with a stroke length of 30 mm and 144 strokes per minute. The reciprocating motion of the cutting blade helps to cut the bark of the rubber tree while tapping.

The field evaluation of the developed rubber tapping machine along with traditional gouge knife were conducted in the farmer's field at Kodanad and Malayattor in Ernakulam district by three tappers. The performance of the developed rubber tapping machine was evaluated in terms of its capacity, depth of cut of bark, bark consumption or thickness of cut of bark, time for pre tapping operations, time for tapping operations and weight of the machine and compared with manual tapping.

The developed rubber tapping machine has an average capacity of about 157 trees per hour. As per the recommendations of Rubber Board, the depth of cut and thickness of cut should be in the range of 6-8 mm and 1-2 mm respectively. The machine cuts the bark with an average depth of cut of 7.2 mm and a thickness of cut of 1.8 mm. During the rubber tapping process the machine takes 23 s for tapping alone for a single tree and 21 s for pre tapping operations. The developed machine weighs 1.6 kg without the power source and 3.6 kg with power source.

In tapping with traditional gouge knife, an average capacity of about 195 trees in 1 hour was obtained. The knife cuts the bark with an average depth of cut of 6.7 mm and a thickness of cut of 1.5 mm. During the rubber tapping process, the traditional method using gouge knife takes 18 s for tapping alone for a single tree and 21 s for pre tapping operations. The gouge knife weighs 0.235 kg.

The performance of the developed rubber tapping machine in depth of cut and thickness of cut are in the recommended range. The developed rubber tapping machine takes more time for tapping compared with manual tapping. The weight of the developed machine is more compared with the gouge knife, but the weight is required in making the reciprocating cutting action of the machine more effective and effortless.

The cost of operation of rubber tapping machine is estimated as Rs.1.16/tree whereas the manual tapping charges are Rs. 2/tree.

The developed rubber tapping machine is more advantageous for tapping the rubber trees with less effort and human drudgery compared with the traditional method using tapping knives. Thus the physical strain and health problems in the field of tapping can be reduced with the application of the developed rubber tapping machine.

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Appendices

Appendix-A

1. Cost Economic of Rubber Tapping Machine

Capacity of rubber tapping machine = 157 trees/h

Life span of rubber tapping machine, L = 5 years

Annual usage = 150 days

Daily usage = 4 hours

Total working hours in a year, H = 600 hours

Salvage value, S = 10% of capital investment

Interest rate, i = 5 % per year

Capital investment of the machine, C = Rs. 16,000/-

Insurance = 1% of initial cost of machine

A) Fixed cost

i) Depreciation, D

$$= \frac{C - S}{L \times H}$$

$$= \frac{16000 - 1600}{5 \times 600}$$

= Rs. 4.8/h

ii) Interest, I

$$= \frac{C + S}{2} \times \frac{i}{H}$$

$$= \frac{16000 + 1600}{2} \times \frac{5}{100 \times 600}$$

= Rs. 0.73/h

iii) Housing charge = Nil

iv) Insurance = $(16000) \times \frac{1}{100}$

= Rs. 160/year

= Rs. 0.267/h

Total fixed cost/year = Rs. 4.8+0.73+0.26

= Rs. 5.79/h

B) Operating cost

i) Repair and maintenance, 1% = Rs. 16,000 × 5/100

= Rs.800 /year

ii) Labour cost,

Labour cost per day = Rs. 700/day

= Rs. 105000/yr

iii) Power consumption

Power consumption/day = 0.74 KWh

Power consumption/year = 0.74 × 150

= 111 KWh

Cost of 1 KWh = Rs. 4.5

Total cost = 111 × 4.5

= Rs. 499.5 /yr

Total operating cost = 800+ 105000+499.5

= Rs. 177.16/h

Total cost of rubber tapping machine = Fixed cost + operating cost

= 5.79+177.6

= Rs. 183.39/ h

= Rs. 1.16/tree

2. Cost of Manual Tapping

Total cost of manual tapping = Rs. 2/tree

DEVELOPMENT AND PERFORMANCE EVALUATION OF A RUBBER TAPPING MACHINE

By

ASWATHY M S

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ABSTRACT OF THESIS

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ABSTRACT

Hevea brasiliensis, the common rubber tree, is the most important species which is the commercial source of natural rubber. The natural rubber is harvested in the form of latex, a sticky, milky colloid through the tapping process. The Hevea latex obtained from the bark of rubber tree contains natural rubber particles that can be harvested and utilised for various industrial applications. Tapping is the process of making a controlled wound in the bark of rubber tree to cut open the latex vessels, which cause the flow of latex for capturing the latex. The process of rubber tapping poses potential risk of various health problems among rubber workers. Scarcity of skilled labours for rubber tapping is one of the main challenges in the rubber industry. Mechanization of the tapping process can reduce the effort of the labour and reduces the human drudgery. Hence, the present study was undertaken to develop a rubber tapping machine and to evaluate the performance of the machine.

The developed rubber tapping machine consists of a cutting blade, shaft, connecting rod, crank, gear assembly, bearing, coupling, frame, casing, motor and a battery. The rubber tapping machine is connected to a 12 V, 5 Ah battery. The battery powers the motor. 0.25 hp wiper motor was used and it delivers a rotational speed of 72 rpm. The rotary motion of the motor is transmitted to the gear assembly using a gear shaft. The gear of 48 teeth which is connected with the motor rotates at 72 rpm. The speed is increased to 288 rpm by meshing gear of 48 teeth with 12 teeth gear to obtain a speed ratio of 4. A crank is attached to the gear of 12 teeth and rotates at 288 rpm. A connecting rod linking the shaft and the crank converts this rotary motion into reciprocating motion of the shaft. The required stroke is achieved by an eccentricity of 15 mm in the connecting rod. The blade is reciprocated along with the shaft with a stroke length of 30

mm and 144 strokes per minute. The reciprocating motion of the cutting blade helps to cut the bark of the rubber tree while tapping.

The field evaluation of the developed machine was conducted in two farmer's field by three tappers and the performance of the was evaluated in terms of its capacity, depth of cut of bark, bark consumption or thickness of cut of bark, time for tapping operations and weight of the machine and compared with manual tapping. The developed machine has an average capacity of about 157 trees per hour. The machine cuts the bark with an average depth of cut of 7.2 mm and a thickness of cut of 1.8 mm. The developed machine weighs 1.6 kg without the power source and 3.6 kg with power source. The cost of operation of rubber tapping machine is estimated as Rs.1.16/tree whereas the manual tapping charges are Rs. 2/tree.

The developed rubber tapping machine is more advantageous for tapping the rubber trees with less effort and human drudgery compared with the traditionally using tapping knives.