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EFFICIENCY STUDY OF A SINGLE DAY SMOKE DRYER

This thesis was submitted to the Department of Chemical & Process Engineering at University of Moratuwa, Sri Lanka in partial fulfillment of the requirement for the degree of

MASTER OF SCIENCE IN POLYMER TECHNOLOGY

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DECLARATION

I do hereby declare that the work reported in this project report was exclusively carried out by me under the supervision of Dr. Susantha Siriwardena and Dr. Shantha Walpalage. It described the results of my own independent research except where due reference has been made in the text. No part of this project report has been submitted earlier or concurrently for the same or other degree.

Date: 13/09/2010

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Signature of the candidate

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To the best of our knowledge above particulars are correct.

UOM Verified Signature

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This report is dedicated to

MY PARENTS

ALL MY TEACHERS

MY BELOVED WIFE

&

MY LITTLE DAUGHTER VINETHMEE

ACKNOWLEDGEMENTS

I wish to express my deep sense of gratitude to my supervisors Dr. Shantha Walpalage (Senior Lecture, Department of Chemical & Process Engineering, University of Moratuwa) and Dr. Susantha Siriwardena (Head, Raw Rubber Process Development & Chemical Engineering Department, Rubber Research Institute) who have always been approachable, helpful and extremely patient in their guidance throughout my research project.

I consider it as a pleasant occasion to acknowledge Dr. A. G. T. Sugathapala who has given kind and patient guidance, encouragement and valuable assistance throughout the research project.

My special thanks go to Head of the Department, Chemical & Process Engineering, University of Moratuwa, Director, Rubber Research Institute, Sri Lanka and Head of the Department, Mechanical Engineering, University of Moratuwa, for giving me unrestricted instrumental facilities during the execution of research project. Sincere thanks are also due to other staff members of the University of Moratuwa and Mr. Sarath Siriwardena, Mr. A. K. D. Warnajith, at Rubber Research Institute who helped me in many ways.

Also my sincere thanks go to Mrs. Maddumage and her kind employers at the "*Sixteen Acre Estate*" at Padukka who gave me a great support during this research project.

I take this opportunity to express my sincere thanks to all personalities who could not mention here name by name for helping me in various ways.

I would like to thank my beloved wife Niwanthi who has always behind me patiently during the period of execution of the research project.

Indrajith Rathnayake

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ABSTRACT

The energy utilization and the time required to dry RSS using conventional type smoke house are significantly high. Also the conventional type smoking-room used for producing RSS gives large differences of temperature and velocity; these result in non-uniform drying of the rubber sheets. In a conventional smokehouse, the energy losses due to loading and unloading of the sheets as well as time required for complete dryness is very much high.

A Compact, well insulated drying unit with multipurpose gravel layer was designed and fabricated new operational practices for efficient energy utilization of Ribbed Smoke Sheet (RSS) Drying were also introduced. The overall drying performance was evaluated in term of drying efficiency and firewood consumption. Quality of the end product was also evaluated. A comparison also made against the performance of conventional smoke house. Social issues also compared with conventional system. The new system reduces the drying period from 5 days to one day, while space requirement also reduce by the same percentage when comparing with the conventional smoke house.

No Significant difference of the quality of sheets dried using SS drying system against sheets dried in conventional smoke house was observed. However, dirt content in the sheets dried in the new system is lower tan that dried in a conventional system. The Single day Smoke dryer (SS dryer) has the efficiency of 51.7%, it is a very good value compared with a conventional smoke dryer which has the efficiency of 31%. The most interested feature of the SS dryer is the low space utilization compared with the conventional type smoke house and also the time requirement for fabrication of the SS dryer is very short. In addition to the above advantages, the dryer can be operated by one person and the health issues are very limited to compare with the conventional smoke house.

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CHAPTER 1

INTRODUCTION

Raw rubber manufacturing industry is an integral sector in the Sri Lankan economy. Raw Natural rubber produced in Sri Lanka contributes to the local economy in many ways. It earns foreign exchange through exports of rubber in raw form and supplies raw material for local rubber product manufacturing sector during which an attractive value addition is achieved. The rubber product manufacturing industry is one of the five largest GVA (Gross Value Added) sub sectors in Sri Lank. Rubber industry has been played an important role in the Sri Lankan economy in term of the contribution to the Gross Domestic Product (GDP) foreign exchange earnings, value addition, agro-based industries, and employment generation since so many years. Both raw rubber and rubber product manufacturing sectors provide a significant number of employment opportunities to the nation. As an example, over 200,000 persons are directly employed in the rubber industry and rubber cultivation sector and over 30,000 persons are employed in the rubber based industries. The exports of approximately, 33% rubber in raw form earned LKR 7.2 billion while converting the balance in to rubber products earns the LKR 72 billion. In the year 2006, export of rubber products and raw rubber earned a revenue equivalent to Rs. 46,864 million and Rs. 9,341 million respectively. It is estimated that domestic sales of rubber products earned a revenue equivalent to Rs. 6.809 million. The export volume in 2006 is 46,343 metric tons (mt), with a 47 per cent rise over 2005. In the case of RSS export a 62 per cent rise has been recorded. It is projected that Sri Lanka will require 180,000 mt of NR by 2016 with a land productivity of 1,800 kg/ha. The global demand for NR continues to be higher than supply. This will result in NR prices to remain high in the future as well. The NR production has to be increased through productivity improvement in the short term and through increased rubber extent in the long term (1).

Sri Lanka produces four main grades of raw rubber namely Ribbed Smoke Sheets (RSS), Latex Crepe (LC), Latex concentrate and Sri Lanka Standard Rubber (SLR). In addition, there are few other rubber grades produced locally at small scale. Some of them are Sole Crepe, Scrap Crepe, Skim Rubber and Deproteinised Natural Rubber. With regard to rubber product manufacturing sector it has achieved a tremendous development in past 20-

30 years. This industry has contributed to 5 % of Sri Lanka export earnings and shows a potential of growing up to 10%. Main rubber products manufactures in Sri Lanka are solid tires, pneumatic tire, carpet and dipped products such as gloves. It has been estimated that both these sectors provide direct and indirect employment opportunities more than 500,000. This shows that the important of manufactures raw rubbers to the Sri Lankan economy.

Production figures of the main raw rubber grades from 2000 to 2007 are given in Table 1.

Table 1: Production of raw rubber by different types between year 2000 and 2007

Year	Sheets (MT)	Sheets (%)	Latex Crepe (MT)	Latex Crepe (%)	SLR (MT)	SLR (%)	Latex Other (MT)	Latex Other (%)
2000	34003	38.8	28110	32.1	3879	4.4	15344	17.5
2001	30344	35.2	26112	30.3	3657	4.2	19461	22.6
2002	42770	47.3	20831	23.0	1231	1.4	20514	22.7
2003	50015	54.4	17131	18.6	1193	1.3	18359	20.0
2004	46705	49.3	12481	13.2	2812	3.0	27000	28.5
2005	50170	48.1	12914	12.4	5880	5.6	29766	28.5
2006	46260	42.4	20224	18.5	9038	8.3	28076	25.7
2007	48875	41.6	21756	18.5	9564	8.1	31586	26.9

(Source: Statistical Hand Book, 2009, Rubber Development Department.)

It is evident from the data presented in Table 1 that the major share of natural rubber production in Sri Lanka (about 45%) is in the form of sheet rubber which is the oldest and the simplest method of processing latex into a marketable form. Crepe rubber which held the second major share of the natural rubber market has become the third major type of raw rubber produced while latex and other grades enjoyed the second major position since 2003. SLR grade has maintained the lowest percentage of the total local natural rubber production. In addition to be in the highest major grade of rubber, RSS is produced by a wide spectrum of growers from small holders to plantation sector, therefore sheet rubber production is become more important industry in Sri Lanka. Therefore, RSS manufacturing process is discussed together with brief introduction of manufacture of other three grades below. Smoke House use to smoke RSS in Sri Lanka and the most of these RSS was produced by small-scale and medium scale producers and there are only a few estates that manufacture more than 1000 kg per day.

1.1. Outline of the Ribbed Smoke Sheets (RSS) manufacturing process

Ribbed smoked sheets (RSS) production from latex occurs in either factory-scale facilities (on estates and larger smallholdings) or in tiny field units (individual smallholdings). Despite its variability in scale, it always includes the following operations: collection of latex , blending, coagulation, milling, drying, and finishing. The layout for RSS production (factory-scale processing) is detailed in the figure below (Fig 1)

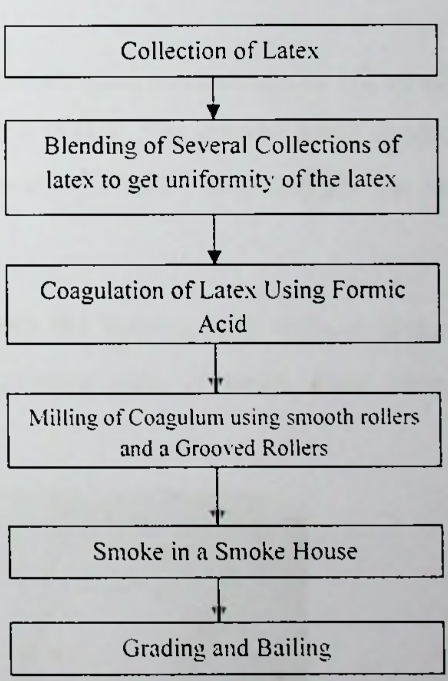

Fig 1: Process flow chart of RSS manufacturing

AS could be seen in Figure 1, NR latex is coagulated in suitable containers into thin slabs of coagulum and rolled through smooth rollers followed by a grooved set and dried to obtain sheet rubber. Depending upon the drying method, sheet rubbers are classified into two: Ribbed Smoked Sheets and Air Dried Sheets (Pale Amber Unsmoked Sheets).

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For processing latex into sheet rubber, it is important that the latex collected is brought to the processing centre before pre-coagulation sets in. In cases where the latex is found to be prone to pre-coagulation, an anticoagulant is used.

Latex brought to the centre is strained through 40 and 60 mesh stainless steel sieves. The volume of latex is measured with a standard vessel and a calibrated rod. The dry rubber content (DRC) is estimated with a "metrolac", which is a special type of calibrated hydrometer. However, laboratory methods are employed for accurate determination (2).

1.1.1 Latex Bulking

Latex is diluted in bulking tanks to a standard consistency of 1/2 kg of dry rubber for every 4 liters of the diluted latex (12.5% DRC). The diluted latex is allowed to stand in the bulking tank for a fixed time (usually 15 to 20 minutes) for the heavy dirt particles to sediment.

The diluted latex is drawn out from the bulking tank without disturbing the sedimented layer of impurities into the coagulation pans or tanks. Four liters of latex is usually transferred to each pan.

Fig 2: Coagulation in pans

Fig 3: Tank used for the coagulation

1.1.2 Coagulation

Acetic acid and formic acid are well known coagulum for the coagulation process but due to so many reasons formic acid is generally used for coagulation. The quantity of acid required for satisfactory coagulation depends on various factors like the amount and type of anticoagulant used, the duration of coagulation, the season, and the nature of the latex.

The acid requirement may slightly change under varying conditions and can be fixed up by experience. Only diluted acid should be used for coagulation and should be thoroughly mixed with latex.

It has been found on numerous occasions that the quality of the RSS is considerably improved by changing from acetic to formic acid. The quality of the sheets can be improved to some extent if the coagulum is rolled the same evening and put in the smoke house for smoking the same night.

1.1.3 Milling

After coagulation, the coagulum is removed from the pan or tank and thoroughly washed in running water. They are rolled either in a sheeting battery or smooth rollers to a thickness of 3 mm and finally passed through the grooved roller. While sheeting, the coagulum is continuously washed. The sheets are again washed in running water in a tank.

The wet sheets are allowed to drip on reapers arranged in a well-ventilated dripping shed. The dripping time of the sheets should not exceed 3 hours. Also direct sunlight can be used to dripping process.

Fig 4: Sheets are kept under sunlight for dripping of water

1.1.4 Smoking in Smoke Houses

Fig 5: Conventional type Smoke House

Then these sheets are dried by mean of smokes produced by firing rubber wood. These sheets are stacked on bamboo reapers inside the smoke house.

1.1.4.1 Introduction of conventional smoke house

A conventional type smoke house consists of a chamber into which the sheets are loaded on reapers fitted on a wooden framework. Smoke is generated in the furnace, which is usually outside the chamber. Smoke and hot air from the furnace are directed into the chamber through a flue. Air inlets and ventilators are provided at the bottom and top of the chamber respectively. These can be opened or closed for controlling temperature. Temperature can also be regulated by adjusting the rate of burning of the firewood by opening or closing the air inlets in the furnace door. A damper is usually provided at the main flue outlet, as a safety measure to prevent fire entering the chamber in an event of opening the furnace door. The chamber may be of brickwork with a reinforced concrete frame. The smoke house shall be provided with adequate drainage to facilitate removal of serum dripping from the sheets. The roof and the ceiling may be of asbestos sheets and the gap between the roof and the ceiling at the top of the walls shall be closed from all the four sides of the smoke house, so as to avoid heat loss due to air currents over the ceiling and to prevent condensed moisture containing carbon from dripping on sheets.

The time taken for each steps of making RSS in a conventional smoke house is different. It can be easily seen by considering them one by one. The most time consuming step is drying step, so this step is the most contributing step for the productivity of RSS. It is understood that reducing of drying step will enhance the productivity of this RSS production. Conventional smoke house will take 4-5 days to finish one batch of production so it is not an efficient production step.

Table 2: Time taken for several steps of RSS production

Name of the Step	Time taken/hr
Bulking	2
Coagulation	5
Milling	1
Drying	120
Finishing	2

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1.1.4.2 Major Defects in Smoked Sheets

The completely dried sheets are removed to the packing shed where they are carefully inspected and graded according to the standards published by the Rubber Manufacturers Association (RMA) Inc. Washington in Green Book. This system at present provides for six grades of ribbed smoked sheets, viz, RSS IX, RSS 1, RSS 2, RSS 3, RSS 4 and RSS 5. The grading of sheet rubber is carried out by visual examination. Normally this is accomplished by holding rubber sheets against light when the most obvious defects become apparent. The main raw rubber properties concerned when grading of the RSS are moisture content, dirt and colour. Therefore, efficient drying is of great importance in the manufacturing process of RSS.

CHAPTER 2

LITERATURE REVIEW

2.1 Drying Operation

RSS drying in a smoke house is the oldest method of drying operation used in raw rubber manufacturing industry. Not only in RSS manufacturing process, it is perhaps one of the oldest, most common and most diverse of chemical engineering unit operation. It has been reported that in literature data over four hundred types of dryers are used in industries as well as in house hold activities, among these one hundred distinct types are commonly available (3).

Drying occurs by effecting vaporization of the volatile matters by supplying heat to the wet feedstock. Heat may be supplied by convection (direct dryers), by conduction (contact or indirect dryers), radiation or volumetrically by placing the wet material in a microwave or radio frequency electromagnetic field. Over 85 percent of industrial dryers are of the convective type with hot air or direct combustion gases as the drying medium. Over 99 percent of the applications involve removal of water. This is one of the most energy-intensive unit operations due to the high latent heat of vaporization and the inherent inefficiency of using hot air as the (most common) drying medium (3).

In RSS manufacturing process, the final and the most time consuming operation prior to grading and packaging is the drying and smoking of wet sheets inside a smoke house. But in RSS manufacturing process the dryer used (Smoke House) has these three modes of heat transferring to get dried rubber sheets. Therefore, it can be inferred that the smoke house is a combinational type dryer which is involved three modes of heat transferring mechanism.

2.2 The Drying Curve

The drying curve describes the drying characteristics for each and every product that are to be dried at specific temperature, velocity and pressure conditions. For a specific product, this drying curve is a unique. Fig 6 shows a typical drying curve of a specific product.

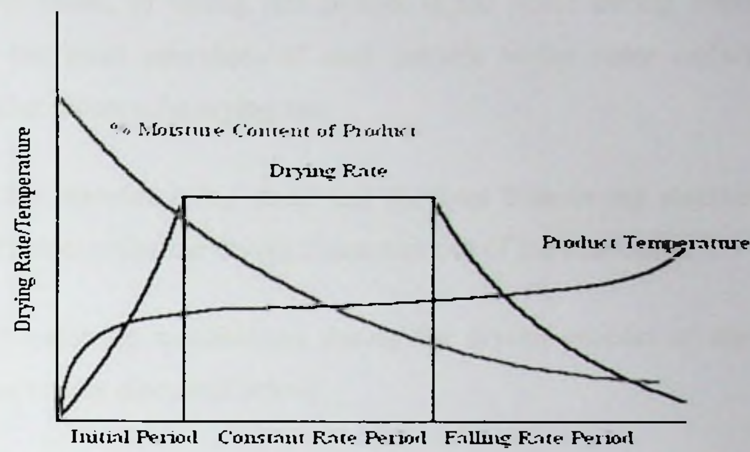

Fig 6: Typical drying curve of a product

There are three phase can be identified in this curve as First Phase, second phase and the third phase.

2.2.1 The first phase, or initial period, is where sensible heat is transferred to the product and the contained moisture in the mass. This is the heating up of the product from the loading condition to the process condition, which enables the subsequent processes to take place. The rate of evaporation increases dramatically during this period with mostly free moisture being removed.

In some instances, pre-processing can reduce or eliminate this phase. For example, if the feed material is coming from a reactor or if the feed is preheated by a source of waste energy, the inlet condition of the material will already be at a raised temperature.

2.2.2 The second phase, or constant rate period, is when the free moisture persists on the surfaces and the rate of evaporation alters very little as the moisture content reduces. During this period, drying rates are high and higher inlet air temperatures than in subsequent drying stages can be used without detrimental effect to the product. There is a gradual and relatively small increase in the product temperature during this period. Interestingly, a common occurrence is that the time scale of the constant rate period may determine and affect the rate of drying in the next phase.

2.2.3 The third phase, or falling rate period, is the phase during which migration of moisture from the inner interstices of each particle to the outer surface becomes the limiting factor that reduces the drying rate.

The nature of the material being dried and the heat transferring mechanism affect the drying curve which explains the drying characteristics of the material (3).

Possible heat transferring mechanisms during the drying process of sheet rubber in a smoke house are briefly discussed below.

2.3 Heat transferring modes in a Smoke House

The subject of heat is that a branch of knowledge dealing with the motions of molecules, whether they are in a gas, a liquid, or a solid. Adding heat to a body increases its energy. There is a significant difference between the temperature of a body and the thermal energy it contains (4).

There are three main types of heat transferring modes are recognized,

2.3.1 Conduction.

2.3.2 Convection.

2.3.3 Radiation.

2.3.1 Conduction

Smoke house consists with a baffle plate. These solid metal parts are good sources to conduct heat from the burner to rubber sheets hang on reapers. This is an atomic or molecular process. It occurs in the presence of a temperature difference and is not accompanied by any microscopic or bulk motion in the medium. Conduction is the only mode of heat transfer in a solid medium. It may also occur in a stagnant liquid or gaseous medium. The basic law of conduction is ***Fourier's law*** is explained as follows (4).
The law states that if two plane parallel surface each having an area A are separated by a distance L and are maintained at temperatures T1 and T2 respectively (T1>T2) (Figure 7), the rate of heat conduction Q at steady state through the wall is given by

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$$Q = kA\frac{(T1-T2)}{L}$$

Where, k = thermal conductivity of solid (assumed to be constant throughout the wall)

A = Surface area facing to the direction of heat transfer.

L = length of the medium.

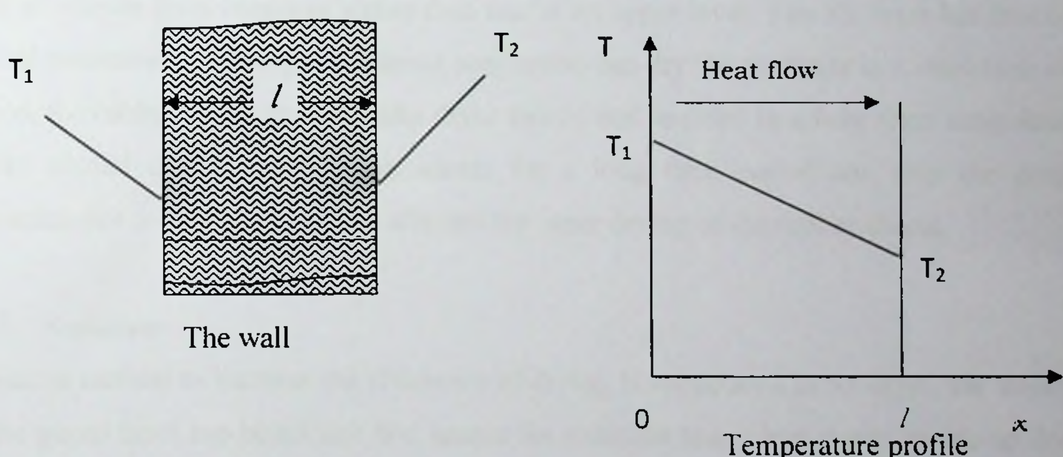

Fig 7: Heat transferring through a plan wall

2.3.2. Convection

This is the most productive type of heat transferring mode in a smoke dryer. Flue gas from the bio mass fed burner supplies heat as well as certain chemical substances that can be acct as a fungicide and antioxidants which prevent mold growth on the rubber sheets and deterioration of sheets at high temperatures. Convection means the transport of heat energy by way of displacement of fluid element from one point to another point which is at a different temperature. Convection type heat transferring can be achieved by existence of motion or a velocity field in a liquid or a gaseous medium. This speed of the motion of the gaseous medium greatly enhances the rate of heat transfer. In the SS dryer the air inlet at the bottom of the front door (Fig. 8) can supply air to the burner and this air can come out from the exit duct on the roof of the dryer. This supply of air can give a very good gaseous medium and it can be also controlled by adjusting the flappers of the exit duct as well as the plate of the inlet air point (4).

Convection may be of two types,

Forced convection - occurs when motion in the medium is caused by an external mechanical energy such as a pump, a blower, an agitator, etc. or by an externally imposed pressure gradient. In the SS dryer it does not has a forced convection since it does not consists a pump or a fan.

Free or natural convection – occurs when motion in the medium is created by an adverse density gradient, as a result of temperature difference. This happens if the temperature of a fluid at a lower level becomes higher than that at an upper level. The SS dryer has free or natural convection. Although the forced convection can dry the products in a short time of period, the rubber sheets in the smoke dryer should not be dried in a very short time since smoke should contact with rubber sheets for a long time period and also the crust formation due to fast drying can be affected the inner drying of the rubber sheets.

2.3.3. Radiation

Radiation method to increase the efficiency of drying is introduced in SS dryer, the stones on the gravel layer can be act as a heat source for radiation heat. Once it gets heated up due to the heat supply from the heat source, the stones can absorb the heat and it can be supplied heat as a radiation heat. The radiation heat can be expressed as a body at a temperature above absolute zero always emits energy in the form of electromagnetic waves. The rate of release of such energy is proportional to the fourth power of the absolute temperature of the body. This phenomenon is called radiation and the basic governing law is known as the ***Stefan-Boltzmann law***. Ordinarily, the contribution of the radiative component to the total rate of heat transfer from a body becomes significant, if the temperature of the body is sufficiently high. The Figure 8 shows the graphical representation of these three heat transferring modes inside the SS dryer (4).

The Stefan-Boltzmann law is given by the following equation.

$E = kT^4$

Where,

E = energy radiated per second by a body at an absolute temperature T,

k = proportionality constant.

T = Absolute temperature.

In systems of the smoke house interested, heat transfer mostly occurs by a combination of all of the above three methods.

Specific Heat.

The specific heat is the amount of heat per unit mass required to raise the temperature by one degree Celsius.

$$\Delta H = m \times c \times \Delta t$$

where,

ΔH = total heat added in Kilo call.

m = mass of the body.

Δt = raise in temperature in ^0C

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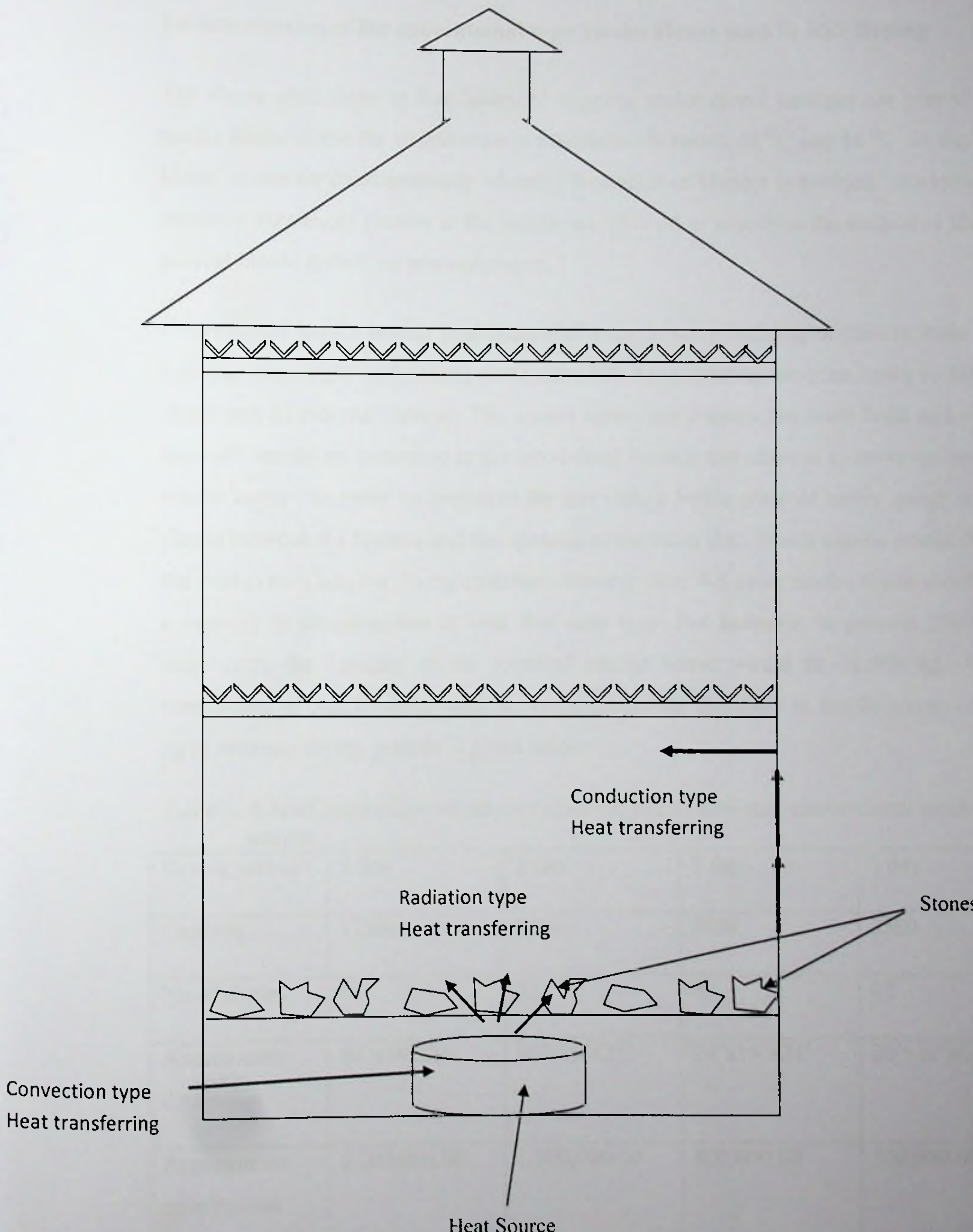

Fig 8: Graphical representation of Heat transferring mode of the SS dryer

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2.4 Introduction of the conventional type Smoke House used in RSS Drying

The sheets after three or five hours of dripping under direct sunlight are placed in the smoke house where the temperature is maintained between 48 ^{0}C and 54 ^{0}C. In the smoke house, sheets are dried gradually whereby formation of blisters is avoided. In addition, the creosotic substances present in the smoke are allowed to adsorb to the surface of sheets to prevent mould growth on smoked sheets.

Conventional smoke houses used consist of a single story building or (two or three storey building (for larger daily crops more than 500 kgs), internal wooden racks to hang the sheets and an external furnace. The smoke rooms are constructed from brick and cement. Heat and smoke are generated in the wood-fired furnace and allowed to move up inside the smoke house. In order to minimize the fire risk, a baffle plate of heavy gauge metal is placed between the furnace and the opening of the main duct which carries smoke through the duct system into the drying chamber. Since it takes 4-5 days, smoke house should have a capacity to accommodate at least five days crop. For example, to process 2500 kg of daily crop, the capacity of the required smoke house would be 12,500 kg. A brief comparison of cost involved with conventional drying chambers to handle a crop of 2,500 kg at different drying periods is given below.

Table 3: A brief comparison of the cost involved in different size conventional smoke houses

Drying period	5 day	3 day	2 day	1 day
Capacity	12500	7500	5000	2500
No of stories	03	03	03	02
Approximate dimension	60'x19'x21	36'x19'x21'	24'x19'x21'	20'x19'x14'
Approximate construction crop (Rs) (an estimation)	2,200,000.00	1,300,000.00	800,000.00	500,000.00

The usual drying time in this type of smoke house is four to five days. The disadvantages of this type of smoke house are that only batch wise operation is possible and more labour is required, since sheets are turned over on the reapers every day.

Drying of sheets in a smoke house has definite advantages.

1. It is quicker than sun-drying and does not cause oxidation by ultraviolet radiation.
2. Inside the smoke house, there is only limited supply of air and it is mostly filled with smoke and carbon dioxide. Hence, chances for oxidation of rubber are very limited, provided the temperature is within the said limits.
3. Also, the creosotic i.e. materials present in smoke, get deposited on the surface of the sheets thereby preventing mould growth on sheets.

Also a good smoke house should have the following features for the better output and quality RSS sheets.

* Minimum drying time
* Maintenance of temperature in the range of 48-54 ^{0}C
* Maximum fuel efficiency
* Minimum heat loss
* Minimum drying cost
* Easy loading/unloading of sheets
* Minimum labour requirement

There are various types of smoke houses, all working on the same general principle. The essential features of a smoke house are a chamber in which the sheets can be placed on reapers, a furnace outside the chamber and a flue duct connecting the furnace to the chamber.

Smoke houses are of two types, those in which the furnace is inside the drying chamber and those in which the furnace is outside.

2.4.1 Furnace inside the Chamber

Smoke house of the pit-fired-type and trolley box type which are used in Sri Lanka come under this. In the pit-fired-type, smoke is generated by burning firewood in a central pit, which is inside the smoke house. A thick gauge galvanized iron sheet, slightly larger in size than the mouth of the pit, is fixed 25 cm above so as to spread the smoke. The sheets are hung inside the chamber and a minimum space of 200 cm between the fire and the bottom layer of the sheet is given to avoid overheating of the sheet near the pit. In the trolley box furnace-type, smoke is generated in a fire trolley on wheels. The advantage of this type of smoke house over the pit-fired-type is that the smoke house can be kept clean since operations such as loading of firewood and removing the ash can be done outside the smoke house.

2.4.2 Furnace outside the Chamber

There are two types of smoke houses with external furnaces, the ground-floor type and the tunnel-type. In the ground-floor type, the smoke from the furnace is directed to the centre of the smoking chamber. The sheets are hung on reapers fitted on a wooden framework. Fresh sheets, after dripping, are put on reapers near the ground and on the next day they are taken from the lower reapers and hung on the upper ones.

Generally, the sheets are turned on the reapers every day for uniform smoking and drying and to avoid reaper marks on dry sheets. Four days of smoking is generally sufficient under normal conditions, but during the rainy season five to six days are required for satisfactory drying of sheets.

Irrespective of the type of smoke house, in the conventional systems, sheets are loaded into the chamber daily and hung on the reapers and turned every day to get rid of reaper marks. This cumbersome practice is necessary which would otherwise downgrade sheets. The sheets which are first hung on reapers near the ground are moved to the upper level each day. The drying process is therefore, interrupted every day for this purpose by keeping the smoke house opened for few hours to reduce the temperature inside the smoke house in order to enter it. During the unloading period of completely dried sheets also interrupts the continuous drying of sheets. During this interrupted period, a considerable amount of heat is wasted. Discontinuous drying again reduces the efficiency of the dryer as extra energy should be supplied to reheat the entire chamber to the required drying temperature (48 -54 ^{0}C). In addition, heat losses occur due to leaks as the conventional smoke houses which are not well insulated.

In the conventional system, labour requirement is significant as it is necessary to load the wet sheets and unload the dried sheets into and from multi-storey buildings. Labour is also required to turn the sheets every day and to feed fire wood and controlling of its burning.

Inside the conventional smoke houses, there is only limited supply of air and it is mostly filled with smoke and carbon dioxide. Therefore, current smoking practices are not carried out in a healthy and conducive environment. Workers, therefore, are not willing to work inside a smoke house. It has been identified many disadvantageous in the existing smoking process and some of them are briefly discussed below.

The drying operation is interrupted for loading and unloading of sheets which are primarily responsible for poor drying efficiency in conventional smoke houses. In addition to the poor drying efficiency, a number of other problems in the existing drying system have been identified and some of them are summarized below;

1. Rubber wood, which has been the main source of energy for the drying of rubber for many years has become a very expensive and scarce source of energy due to its high timber value, after chemical treatment (Mohd and Sopian, 1991; Walpita et al. 1984). Rubber wood as timber also has an expanding international market which should be exploited as a foreign revenue (Karunaratna, 1993).

2. Unhealthy working environment and cumbersome operating practices.

3. Continuous vigilance to prevent downgrading of the quality of rubber while smoking.

According to above explanation, it is well understood that the efficiency of smoke house will enhance the productivity and the quality of RSS production. Raw Rubber Process Development & Chemical Engineering Department of RRI Sri Lanka was studied this matter thoroughly and made a one day efficient smoke house for RSS Drying. This dryer is also operated by burning very low cost readily available energy source. Furthermore, the

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operation of the smoke house is very simple and can be handle done by lesser number of operators very easily (5).

A study on the conventional smoke drying of sheets has been carried out to optimize the process of smoke house in many ways. Department of Mechanical Engineering, Prince of Songkhls University, Hat Yai, Thailand carried out a very good survey on the smoking process of rubber sheets. They have monitored the smoking process and found that only 31% of the input heat was useful while the other 51% has been lost through the conduction and another 11.8% lost through the ventilation. In order to improve the efficiency of the smoke house, it has been found those two parameters such as energy and the moisture contents of fire wood and inlet air should be managed. Furthermore, it has been suggested that use of a dehumidifier at the air inlet could significantly increase the productivity and it could decrease the processing time too. (6)

Another research work has also carried out in the same university on the factors affecting the curing of rubber sheets in smoke houses. It was studied with respect to surrounding humidity, air flow rate and loading density. It has been reported that the curing time was inversely proportional to the relative humidity of inlet air. Also role of air flow rate at 40% relative humidity and specific air flow rates of 0.012 - 0.083 m^3/h kg was not clearly found. In addition, it is found that the moisture content of firewood used is affect significantly to the smoke drying period (7).

Use of solar energy for the smoke process was carried out and they have studied a model of the solar assisted RSS system using finite element method. These solar assisted rubber smoking system can be decreased the fuel usage of the smoking forces. In that research work, it has been introduce the pre heating system prior to the smoke drying process to lower the moisture content of the rubber sheets to be dried. It could increase the efficiency of the drying process due to low percentage of moisture content of smoke sheets (8). In the single day smoke drying process, the dripping step under the sun light at 6 hours can increase the same manner.

In addition to above research work, researchers in Prince of Songkla University, Thailand has been introduce a computational simulation in order to improve the flow uniformity and temperature variation inside the smoke house. The effect of the size, position and number of gas supple ducts and ventilating lid which were at the inlet and the outlet of smoke room investigated using computational fluid dynamics (CFD) simulation. It has been found that size, position and number of gas supplied ducts and ventilating lids significantly affect the temperature and velocity distributions. The researchers aimed to save energy by least 31.25% using that study. Also they suggested the size of the hot gas supplies ducts for specific size of smoke driers. The temperature variation of the different levels of the smoke house was studied and found that the range of variation 60 ^{0}C to 65 ^{0}C. The 5 ^{0}C of variation is a good character for typical smoke house, since large temperature variation can affect to product quality (9).

The health effect of smoke process also taking in to consideration. In Thailand, researchers found that shoots particles produced from rubber tree wood combustion can be negatively affected on workers health as well as poor quality rubber sheets. So that it is introduced separation equipment for removing shoots particles. It has been reported that impaction wall can collect large shoots particles. In the SS drier chamber the gravel layer act as a barrier for shoot particles; hence it can stop contamination shoots particles with rubber sheets (10).

In Sri Lanka, researches at RRISL reported that effect of drying conditions on the technological properties of natural rubber. The rheological and technological properties of rubber compounds were tested and found that sun drying of rubber sheet for up to 2days with smoking for up to 2 days give equivalent physical properties compared to purely smoked rubber sheets. Also it has been reported that 2 to 4 days of drying under the sun light has no effect to the physical properties of rubber sheets. This work would encourage the dripping process under the sun light for extended hours (11). Another research was carried out to explore the possibility of utilizing sun light to drying raw latex grades of rubber. In this work they found that the sun drying of sheet rubber (RSS) for 3 to 4 days for complete dryness would not adversely affect the physical or vulcanization properties of rubber .But they recorded sun drying is carried out only for one or two days to get honey/brown colored rubber sheets (12).

CHAPTER 3

EXPERIMENTAL

(Materials and Methods)

3.1 Single day Smoke dryer (SS dryer).

The smoke house fabricated at "*Sixteen Acre* Estate", Waga, Padukka, Sri Lanka according to the specifications given by Rubber Research Institute of Sri Lanka (RRISL) was used for this study. The dryer consists of a well insulated enclosure, a trolley to hang sheets and a gravel heating bed on a baffle plate and a chamber with the dimensions shown in the Table 4.

Table 4: Specifications of the SS dryer

Parameter	Value
Width of the drying chamber (m)	0.10
Length of the drying chamber (m)	0.10
Height of the drying chamber (m)	0.240
Volume of the drying chamber (m^3)	2.55
Dryer capacity (kg of dry rubber)	47.35

The dryer can be accommodated 47 kg of rubber. A saw dust burner was introduced as the heat source. The inner and outer covers of the drying cabinet were made with two layers of Galvanized Iron sheet (gauge 26) and insulated with compressed glass wool layer (density 48 kg / m^3 and thickness 0.025 m) sandwiched in between. An adjustable flap was fixed in the chimney to control the air flow through the chimney. An adjustable air inlet was fixed at the bottom of the chamber to control the air flow into the dryer. A gravel heat storage unit with the baffle plate was also introduced in the dryer to act as a heat stabilizer, ash protector and fire arrestor just above the burner (Figure 9). A separate movable sheet hanging unit (trolley hanger) was introduced instead of immovable wooden racks housed in the conventional smoke houses (Figure 12).

3.2 Conventional smoke house.

Existing conventional smoke house with an external furnace at the same estate ("*Sixteen Acre* Estate", Waga, Padukka) was used to carry out a comparative study. The details of the conventional smoke house are given in the Table 5. This conventional smoke house as in other conventional houses is consist of a drying chamber build up of cement and brick walls and a immovable track system for hanging of sheets. Since average drying period in a conventional smoke house is five days, capacity of this type of smoke house is designed to accommodate five days crop in the drying chamber. Further details of this type of smoke house could be found in elsewhere.

Table 5: Details of the conventional smoke house

Parameter	**Value**
Width of the drying chamber (m)	3.05
Length of the drying chamber (m)	2.83
Height of the drying chamber (m)	2.40
Volume of the drying chamber (m^3)	23.29
Dryer capacity (kg of dry rubber)	140

3.3 Manufacturing process of rubber sheets.

Rubber sheets used in this study were manufactured according to the standard manufacturing procedure for the manufacture of RSS sheets (2). Field latex were strained through 40 Monel mesh and diluted to the standardized DRC of 12.5. Formic acid was used to coagulate the latex. Formic acid diluted to 1% was added at a rate of 350 ml of 85% concentrated acid per 100 kg of dry rubber at the estate. Each sheet had dimensions of 430 mm (W) x 560 mm (L) x 4.5 mm (T) and weights of sheets were varied between 0.450 kg – 0.550 kg.

3.4 Drying process

Approximately 30 kg of dry rubber (full capacity of the dryer) were hung on the trolley and kept for a period of six hours for dripping at ambient temperature (27 ^{0}C) under sunlight before loading into the drying chamber. Heat was then supplied using the saw dust furnace and the temperature profile of the dryer was recorded at specified intervals. The weight of three rubber sheets hung at three different locations in the dryer (upper, middle and bottom) were recorded on hourly basis. The measuring points that were selected to measure the temperature to establish the temperature profile are shown in Figure 10.

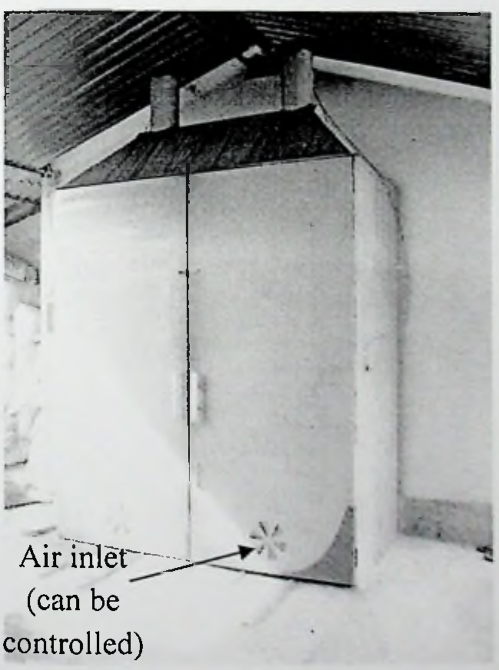

Fig 9: Full view of the SS dryer

Fig 10: Rack system of the SS

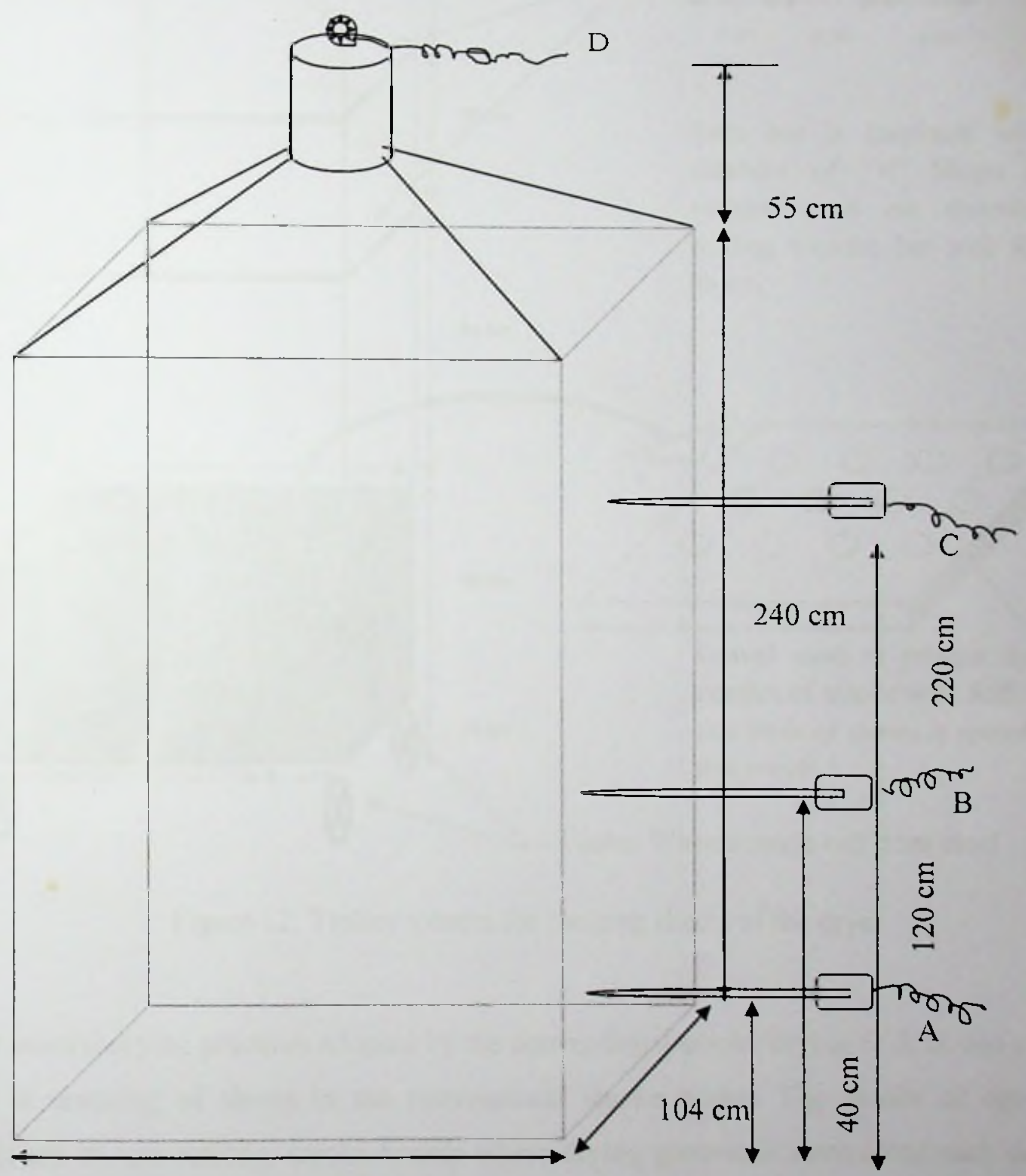

Fig 11: External view of the drying chamber

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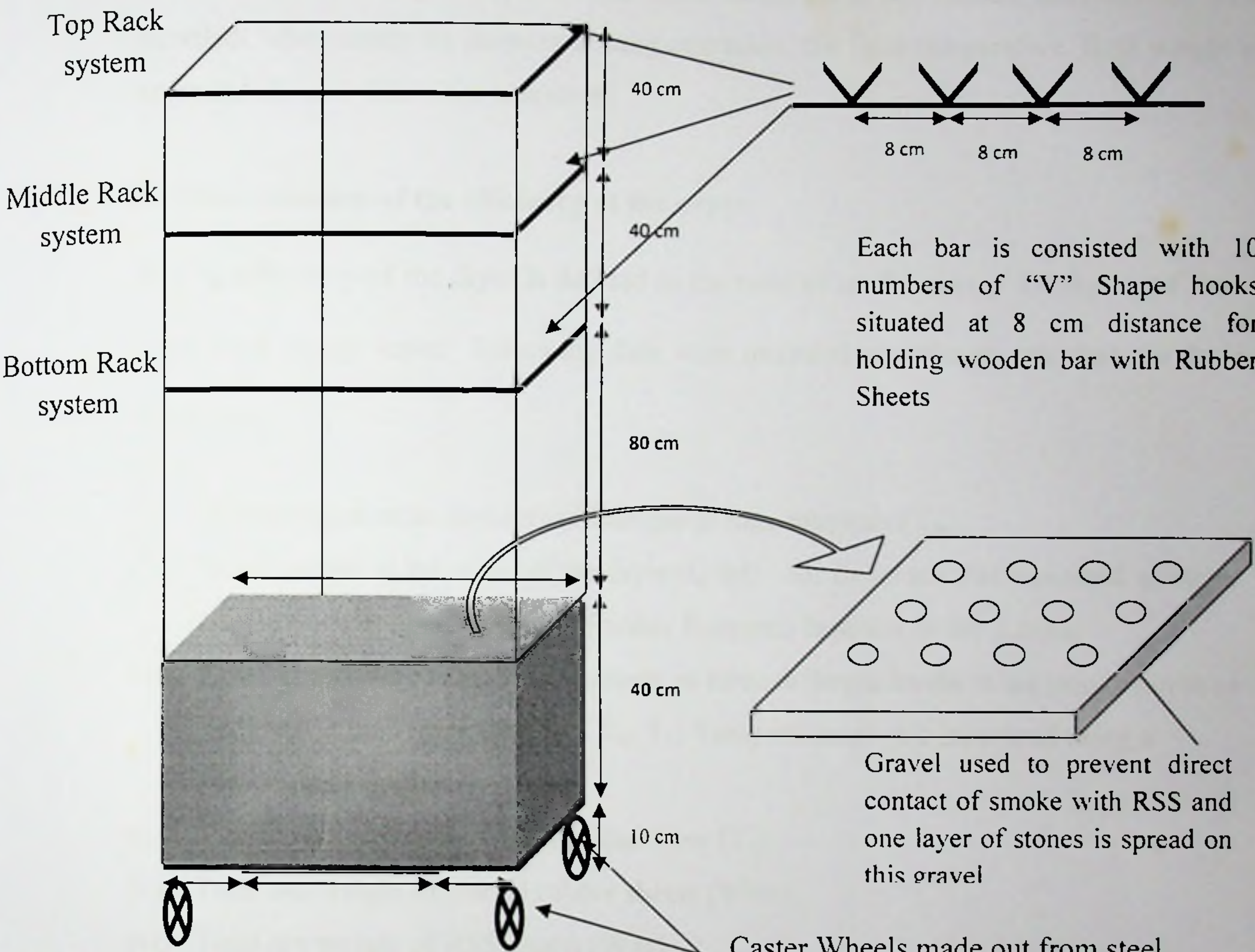

Figure 12: Trolley system for hanging sheets of the dryer

The normal drying practices adopted by the conventional smoke drying of RSS was carried out in smoking of sheets in the conventional smoke house. The details of operating practices in conventional smoke houses where drying process is interrupted each day for loading and unloading processes is found in elsewhere (2).

3.5 Estimation of energy input from the saw dust burner used.

The energy input from the saw dust burner per minute was estimated as follows. The known weight of saw dust was packed in the saw dust burner and a barrel contained known weight of water was placed above the burner. The saw dust in the burner was ignited and the whole system inserted in to the SS drying chamber. Initial temperature of the water was noted down. Temperatures of water were measured at one minute intervals and were recorded. After ninety six minutes heating operation, the final temperature, final weight of water and the saw dust were measured.

3.6 Determination of the efficiency of the dryer.

Drying efficiency of the dryer is defined as the ratio of useful energy for drying of sheets to the total energy input. Following data were recorded in order to calculate the drying efficiency.

(i) Temperature measurements of flue gas in time intervals (T_{fg}).

(ii). Air flow rate at the outlet of the dryer (Qout). Air flow rate was measured using an air flow meter available at the Rubber Research Institute of Sri Lanka.

(iii). Inlet temperature (Tin) Temperatures in three different levels in the smoke house as indicted in the Figure 08 (T_{top}, T_m, T_b) Temperatures were measured using a temperature probe.

(iv). Surface temperature of walls of the dryer (T_s).

(v). Total wet weight of loaded rubber sheets (Wws).

(vi) Total dry weight of RSS sheets (Wds).

(vii) Saw dust consumption (Wsd)

3.7 Determination of moisture content in rubber sheets.

Moisture contents of the dried sheets and saw dust were measured using a moisture balance **(Figure 13, MB 200X, Citizen)** available at the Mechanical Engineering Department of the University of Moratuwa.

Figurl3: Moisture Balance

3. 8 Evaluation of the Quality of the ribbed smoked sheets.

Raw rubber properties of the smoked sheets dried in SS drying system and in conventional drying system were evaluated to determine the quality of the sheets. The raw rubber properties studied and a brief description of the standard test method used are summarized in Table 6.

Table 6: ISO numbers and description of raw rubber properties

Property	Description	Method
Volatile matter (VM) % (w/w)	Volatile matter content escaped from the sample when it is heated at 105 ^{0}C until it reach a constant weight	ISO 248-1979(E)
Dirt Content % (w/w)	Foreign matter content in the sample	ISO 249-1974 (E)
Ash Content % (w/w)	Metal oxide content of the sample	ISO 247-1978 (E)
Plasticity (P_0)	Plasticity of the sample	ISO 2930-1981 (E)
Plasticity Retention Index (PRI)	Resistance of the sample for resistance to thermal oxidative degradation	ISO 2007- 1981 (E)

CHAPTER 4

RESULTS & DISCUSSION

4.1 Energy input from the saw dust burner used.

To calculate the energy input from the saw dust burner, following data were collected and tabulated in following Tables (tables 7-9).

Table 7: Temperature of water container with heating period

Heating period (min)	Temperature of water (^0C)
0.0	27
30.0	90
60.0	95
96.0	90

Table 8: Weight readings of the water container

Weight of the empty container(kg)	0.2
Weight with water (kg)	5.4
Weight after 96 minute period (kg)	1.4

Table 9: Weight of saw dust and dried rubber sheets of SS Dryer

Weight of the saw dust used (kg)	40
Total wet weight of sheets (kg)	75
Total dry weight of sheets (kg)	47.35

Following data were collected to investigate the fire wood consumption of the conventional smoke house.

Table 10: Weight of wood and dried rubber sheets of Conventional Smoke House

Day	Weight of wood utilized (kg)	Weight of rubber sheets (kg)
1	50	No output
2	48	79
3	54	73
4	63	130
5	47	86
6	50	136
7	56	48
Total	368	552

Following data table were tabulated to calculate the saw dust consumption of the SS dryer.

Table 11: Weight of saw dust burner

Weight of the empty barrel (kg)	4.5
Weight of the burner (kg)	20.5
Weight after 96 minutes (kg)	13.1

Moisture percentages of relevant materials were also measured by using the moisture balance .

Table 12: Average Moisture percentage of different materials used in the study

RSS dried in SS dryer	1.63
RSS dried in a conventional dryer	2.83
Saw dust used for the study	35.23
Fire wood	45.51

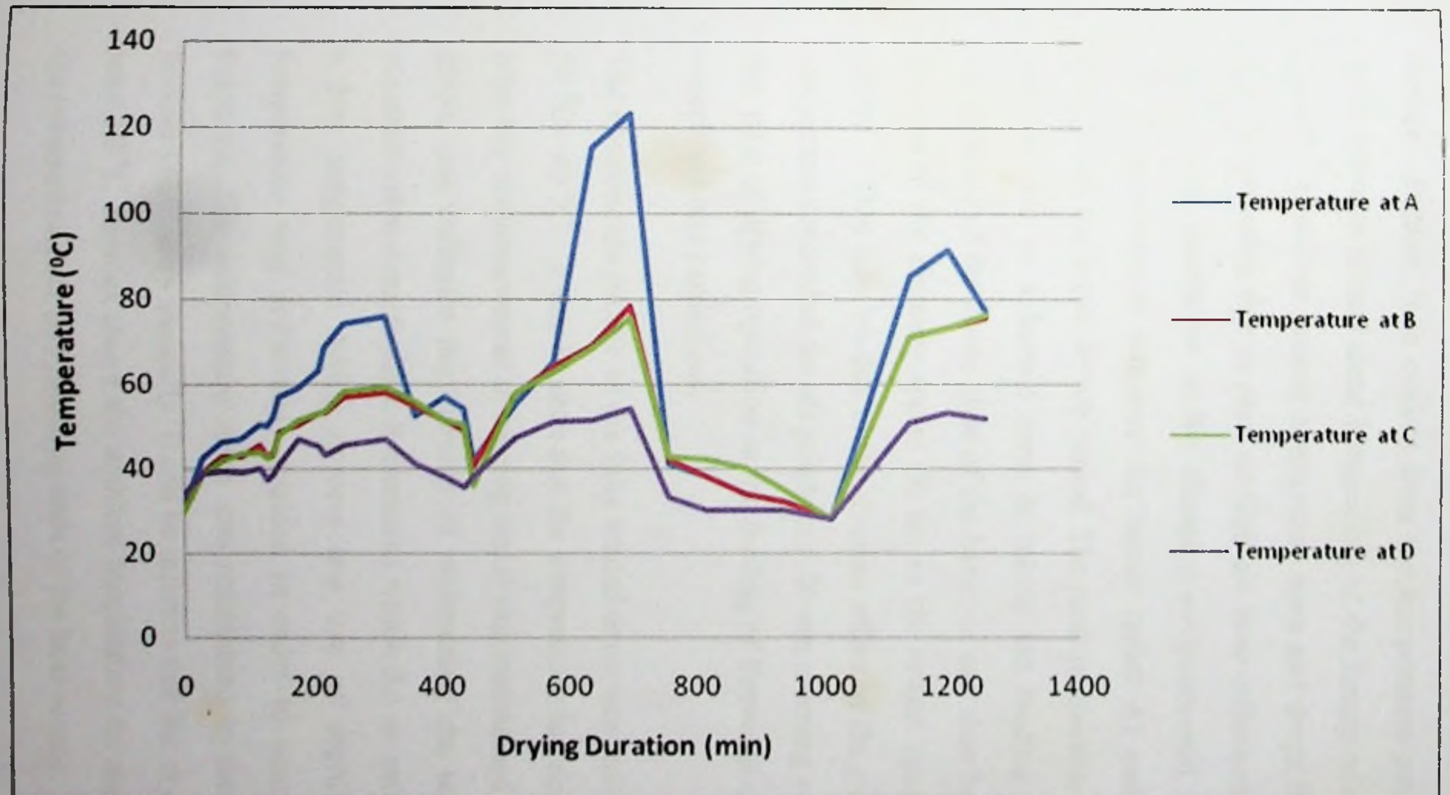

Figure 14: Temperature variation at different locations in the SS dryer vs drying duration

4.2. Temperature Profile inside the SS dryer.

It can be seen in the Figure 14 that temperature inside the dryer (B & C profiles) varies between 40 ^{0}C to 65 ^{0}C, which lies between the recommend drying temperature for sheet rubber. Further, it is evident from the temperature profiles that temperature inside the dryer remains almost same irrespective of the height of the location in question from the burner. However, instant temperature rises and drops that can also be seen in the dryer may be probably due to slow or high air flow influenced by improper adjustment of top and bottom ventilators or the changing environmental factors (ambient wind velocity). The temperature at just over the burner (point A) maintained the highest temperature throughout the entire drying period. The peak temperature at 10.6 hour (695 min) perhaps may be due to a human error in taking the reading such as measuring the surface temperature of the cover plate of the barrel of saw dust burner. In contrast, temperature at the exit of the chimney (point D) shows the lowest temperature during the entire drying period. This may be due to the dilution effect of flu gas with ambient air. The lowest temperature recorded for all points at 6.00 am morning reflects an operational problem in this type of drying operation as the feeding of firewood during the night is not effectively supervised and carried out.

The temperature profile of the fully loaded dryer was maintained at a temperature range of 55 ^{0}C - 65 ^{0}C. It can be seen that the temperature has risen above 55 ^{0}C within two hours after the commencement of heating and it was maintained in that the range afterwards. The graph also indicates the inability of maintaining the temperature inside the dryer at a constant value even though, it maintains within the set range. It should be noted that this is a low temperature drying process and use of sophisticated methods to adjust the temperature was deliberately avoided in order to simulate the field level operational practices. The temperature range was maintained in the dryer by adjusting the top and bottom ventilators manually. It can be inferred that the dryer was capable of maintaining at least 30 ^{0}C degrees above the ambient temperature throughout the drying period except at the commencement and finishing ends of the heat source.

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4.3. Surface Temperature variations with the time.

Figure 15 presents the temperature variation of the surface of the dryer with the drying period. It shows the similar temperature pattern with the temperature inside the drying tower. It is an expected pattern as the surface temperature of the dryer is determined by the temperature gradient across the insulated double layer wall. It should also be noted that average temperature difference between the surface temperature and the ambient temperature is remains approximately at six degrees and therefore, it can be inferred that heat loss due to the radiation could be neglected. In other hand, this low surface temperature compared with inside temperature shows the effectiveness of the insulation used in this dryer.

Figure 16 shows the variation of air flow rate of exit duct during the drying cycle of the sheets in question. It is evident from the figure that the variation of rate of air flow is not uniform or no well defined pattern. Therefore, it can be inferred that the dryer has failed to establish a uniform air flow rate during the drying operation. In fact, there is no inlet air flow control mechanism and is determined by the environmental conditions such as ambient wind speed, its direction and etc. This non-uniform air flow rate through the dryer could be one of the reasons for variations of the temperature seen in side the dyer (Figure 14) during the drying cycle. However, introduction of additional control systems to maintain a uniform air flow is not only increase the cost of the dryer, but it increases the complexity of the operation practices too making it is not suitable for this low temperature drying operation operated by small scale RSS manufactures scattered in the country. On the other hand, this type of system is not essential as the drying and smoking of RSS sheets can be carrier out in a wide temperature range (55 ^{0}C – 65 ^{0}C) with out adverse effects on the quality of rubber(5).

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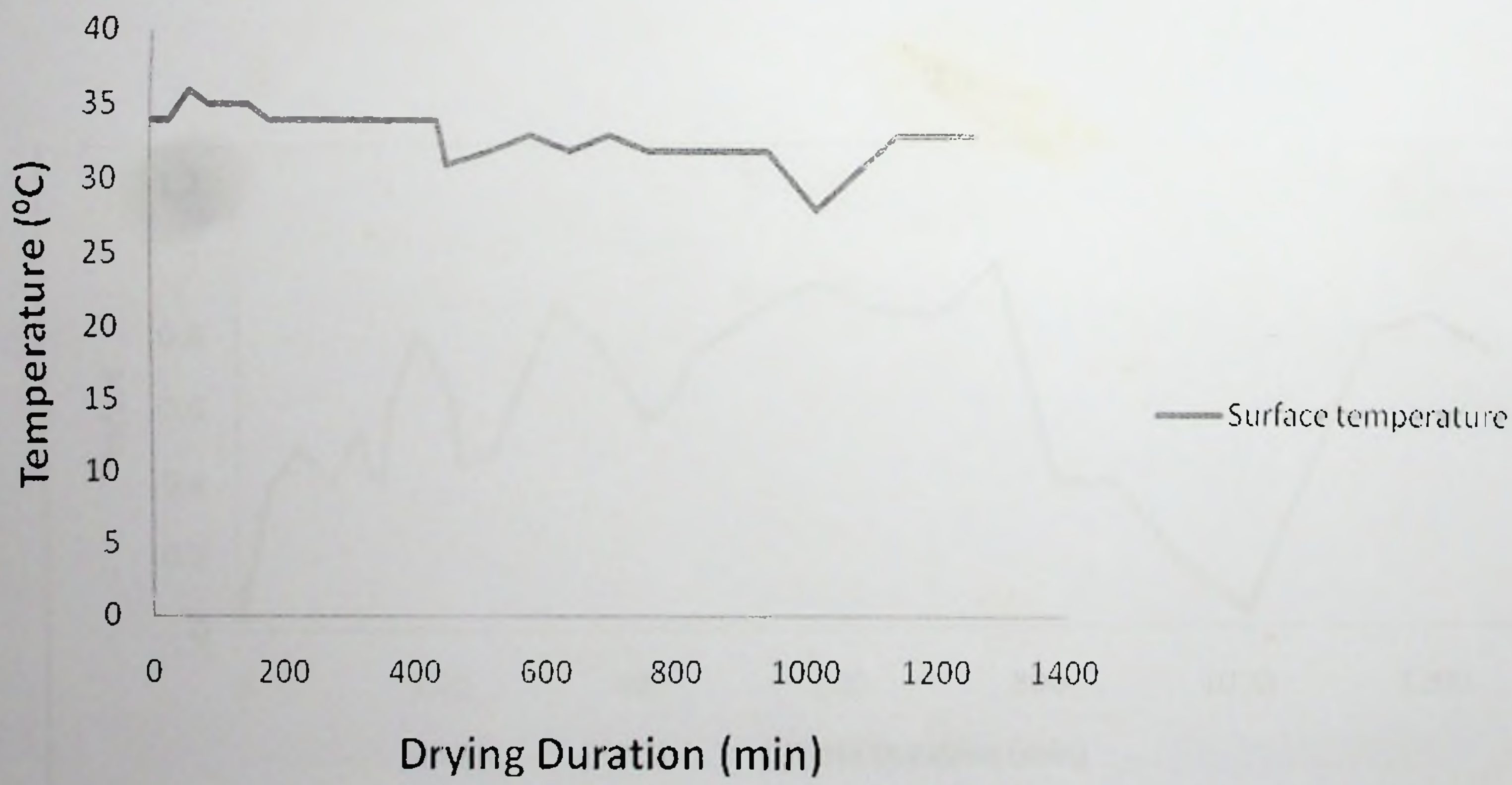

Figure 15: Changing of Surface Temperature with Time

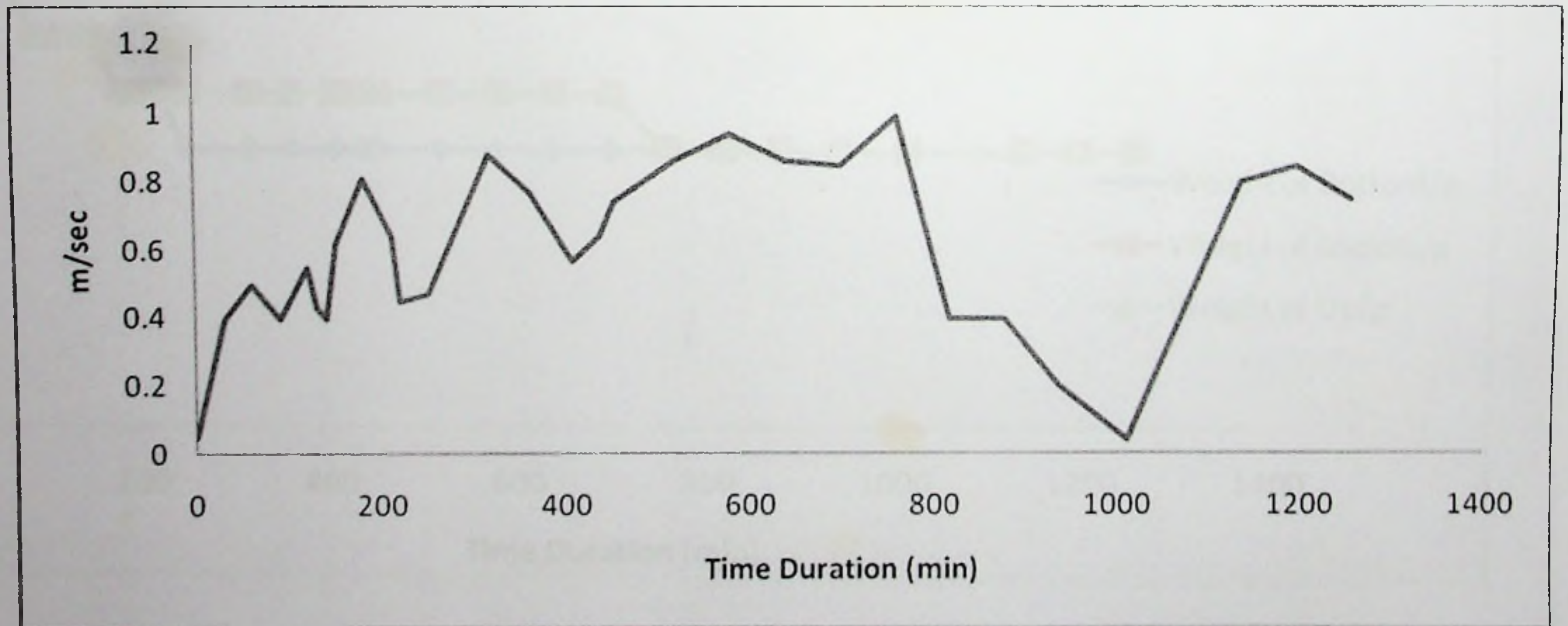

Figure 16: Air Flow rate of exit duct vs Time

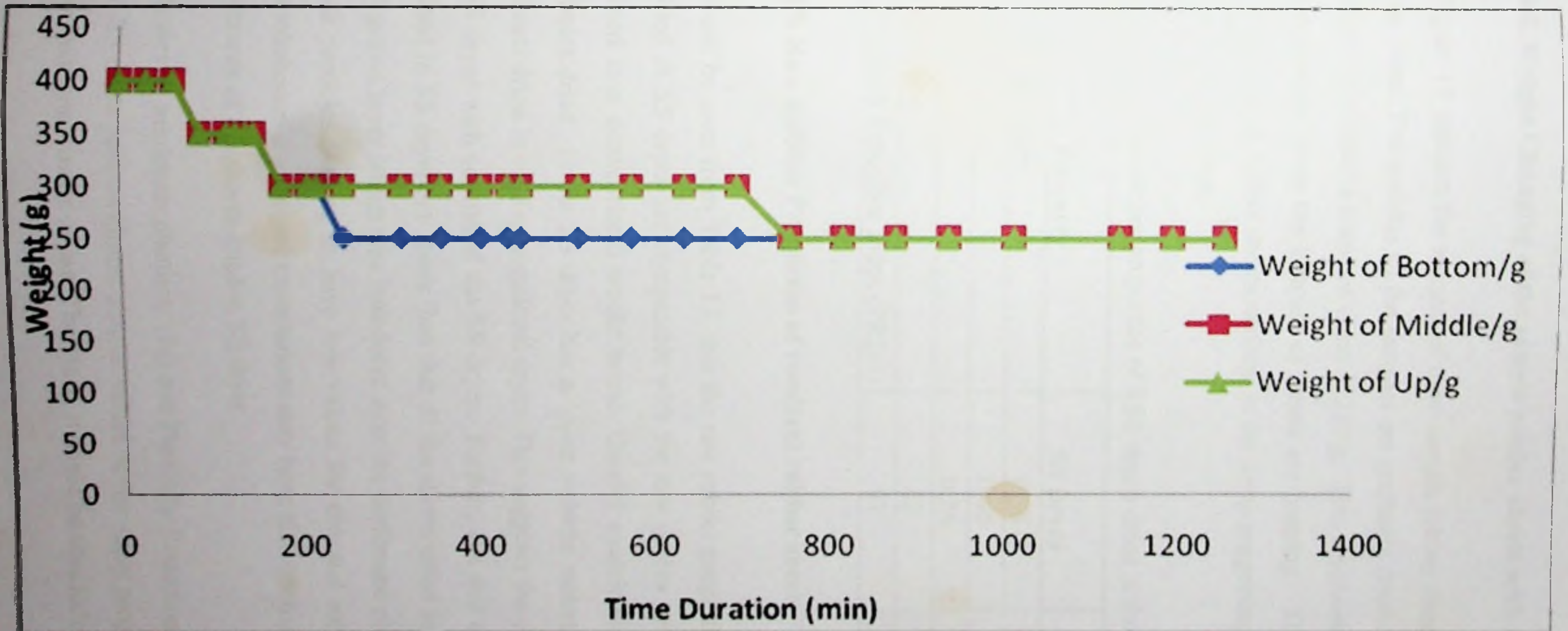

Figure 17: Weight Changing with Time of Samples at three different locations of the smoke house.

4.4. Weight Changing of the sample rubber sheets with the time.

Figure 17 presents the weights of three sample rubber sheets dried in different positions of the dryer. The weights of the samples are gradually decreased with the drying period and finally it reaches a constant value of 250 g. This results-show that the weight reduction is independent from the location of sheets are hanging. Therefore, it can be inferred that drying rate of rubber sheets uniform in the dryer suggesting dryer design is success for this type of application.

Table 13: Raw rubber properties of RSS sheets dried in the SS dryer

Property	SS Dryer	Conventional Smoke House
Volatile matter	0.48	0.38
Dirt	0.46	0.67
Ash	0.24	0.28
Plasticity	42	44
Plasticity Retention Index (PRI)	87	89

4.5. Raw Rubber Properties of resultant rubber sheets.

It can be seen from Table 13, that the raw rubber properties of the RSS sheets that were dried in SS dryer are comparable with the raw rubber properties of the sheets that were dried in a conventional smoke house. Careful examination of these results show those sheets dried in the SS dryer has a lower volatile matter content with compared to the sheets dried in the conventional dryer. This suggests the drying efficiency is higher in the SS dryer with compared the SS dryer. Further, dirt and ash contents of the sheet rubber dried in SS dryer are lower than that of the sheets dried in the conventional smoke house. A gravel layer which was introduced over the perforated metal plate may act as strainer for ash particles leading to have low values for dirt and ash. Easiness of maintenance of smokehouse at a cleaner environment may have also contributed to these lower dirt and ash contents of the sheets dried in SS dryer.

However, minimum plasticity (P_0) and Plasticity Retention Index (PRI) of the sheets dried in SS dryer possess almost similar values to the same properties of the sheets dried in the conventional smoke house. Therefore, it could be concluded that the raw rubber properties of the sheets smoked in the SS dryer have no adverse effect on their raw rubber properties in comparison of the sheets dried in a conventional smoke house. In other words, sheets dried in the SS dryer meet the guaranteed quality requirements of sheet rubber.

4.6. Social Aspects.

4.6.1. Operational Practices

In this new system, trolleys are loaded and unloaded in an open area outside the enclosure. It is a much easier and efficient operation compared to the current practice of the conventional smoke house. One of the major advantages of this new system is that operation is very cleaner and easy and hence labour attractive.

4.6.2. Labour Requirement.

In the SS dryer, sheets are hung on trolleys which could be moved out of the drying cabinet. This practice is much easier and faster and therefore, labour output would be increased. Trolleys are moved out only once during the drying period to turn over sheets. During this period, the dryer is kept closed and heat is retained on the gravel layer which act as a heat storage unit.

4.6.3. Community Health.

In the new drying system, one does not need to enter inside the smoke chamber with the introduction of trolleys. In addition, efficient energy utilization and efficient burning have reduced the emission of the environmentally harmful gases such as CO/ CO_2.

CHAPTER 5

CALCULATIONS

In the calculation process of total energy provided by heat source, it is assumed that heating rate is constant during the entire operation of the dryer.

5.1 Energy input from the saw dust burner used.

Table 14: Data to be used to calculate the energy input rate from the saw dust burner

Data	Value	Reference
m (kg)	4	Table 8
c ($jkg^{-1}\,{}^0C^{-1}$)	4200	
θ (jkg^{-1})	63	Table 7
λ (j/kg)	2,260	

Total energy input (E) = Energy required to vaporized 4 kg of water at 90 ^0C

$= m\, C_w\, \theta + \lambda m$

Where,

m = Saw dust consumption (m)

C_w = Heat capacity of water ($j\ kg^{-1}\ {}^0C^{-1}$)

θ = Temperature rise (^0C)

λ = Latent heat of evaporated water ($j\ kg^{-1}$)

Therefore, $E = (4\ kg \times 4200\ j\ kg^{-1}\ {}^0C^{-1} \times (90-27)\ {}^0C) + (2260\ j/kg \times 4\ kg)$

$= 1058400\ j + 9040\ j$

$= 1067440\ j$

Duration of saw dust burner used = 96 min

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Therefore, energy releasing rate = 1067440 j / (96 min)

= **11119.17 j / min**

Therefore, total energy taken from the dryer in the drying period of 1250 min

= **13898963 j**

5.2 Total energy requirement to dry sheet rubber in SS dryer.

To calculate the energy requirement of the SS dryer, two methods were used. One method is used by applying mCθ equation for the entire system. To do these mean values of temperature variations for each and every time durations (APPENDIX 1) and average change of water content in the dried rubber sheets were used (E1).

In the second method of calculation mCθ equation was calculate for each and every time durations and finally the obtained values were summed up (Calculation Table 1) (E2).

- Total energy requirement (E1)= (Energy used for the drying of rubber sheets + Utilized energy for evaporation of moisture + Latent heat of evaporation of water (vaporization))

  $= m_R C_R \theta + m_w C_w \theta + \lambda m_w$

Where,

- m_R = Dry weight of rubber
- C_R = Specific heat capacity of rubber (1700 j kg^{-1} $^0C^{-1}$)
- θ = mean temperature of water
- m_w = mean weight of water
- C_w = specific heat capacity of water (4200 j kg^{-1} $^0C^{-1}$)
- λ = latent heat of water (2260 j /kg)

Table 15: Data to be used to calculate the Total energy requirement to dry sheet rubber in SS dryer.

Data	Value	Reference
m_R (kg)	47.35	Table 9
c_R ($jkg^{-1}\,{}^0C^{-1}$)	1700	-
θ (${}^0C$)	(76.3-30.4)	APPENDIX 1
m_w	27.65	
λ (j/kg)	2260	

Therefore, E1 = 1955340 +5330367.0 + 41442.8

= **<u>7327149.8j</u>**

5.3 Drying efficiency Of SS dryer.

$$\text{Drying efficiency} = \frac{\text{Utilized energy for evaporation of moisture + Energy required for the drying of rubber sheets + Energy required for heat up sheets from ambient temperature to final temperature.}}{\text{Total energy Input/kg of Rubber}}$$

$$\text{Drying efficiency} = \frac{\text{Total energy utilized for drying of rubber x100}}{\text{Total energy Input rate}}$$

$$= \frac{E1x100.}{E}$$

Drying efficiency $= \dfrac{7327149.8j.}{13898963\ j} \times 100$

$= \underline{52.7\%}$

Calculations present in Calculation Table 1. give the total energy used (E2) by the system by means of time duration.

The total value of the energy from calculation table 1 = 7047414.5 j

Drying efficiency $= \dfrac{E2x100.}{E}$

Therefore the efficiency $= \dfrac{7047414.5\ j}{13898963\ j} \times 100$

$= \underline{50.7\ \%}$

5.4 Dry rubber wood consumption for drying of sheet rubber in the Conventional Smoke House.

Average weight of fire wood consumption = 52.57 kg

Moisture content of firewood used = 45.51 % (from Table 12)

Average dry weight of firewood = 52.57 kg X 54.49/100

= 28.6 kg.

Average weight of rubber dried = 78.85 kg (Average value from table 10)

Final moisture content of rubber sheets = 2.83 % (table 12)

Dry rubber content of dried rubber sheets = 78.85 kg X 97.17/100

= 76.62 kg

Therefore, rubber wood (dry) consumption for drying 1 kg rubber in the

Conventional dryer = 28.6 /76.62

= 0.373 kg

5.5 Dry rubber wood consumption for drying of sheet rubber in the SS dryer.

Average saw dust consumption = 40.0 kg

Moisture content of saw dust used = 35.23 % (from Table 12)

Average dry weight of saw dust = 40 X 64.77/100

= 26.0 kg.

Average weight of rubber dried = 47.35 kg (Table 9)

Final moisture content of rubber sheets (SS dryer) = 1.63 %

Dry rubber content of dried rubber sheet = 47.35 kg X 98.36/100

= 46.6 kg

Therefore, saw dust (dry) consumption for

drying rubber in the SS dryer = 26/46.6

= 0.558 kg of rubber dried

5.6 Comparison of firewood cost for drying of rubber.

Considering the average value of 1 kg of firewood is 7.50/= Sri Lankan Rupees

Cost of 1kg of firewood (Rs.) =7.50

Firewood cost per 1 kg of RSS drying in conventional smoke (Rs) = 0.373 X 7.5

= 2.79

In the case of saw dust burner, saw dust obtained from a saw mill is free of charge but considering the transport cost for saw dust as one rupee per kg, it can be calculated the cost of drying for SS dryer.

Saw dust cost per 1 kg of RSS drying in SS dryer = 0.558X 1.00

= 56 cents

However this value can be varied with the availability of saw dust in different part of the country. The value of a one kg of saw dust could be more in some places whereas it may be available free of charge in other places where saw mills are operated extensively. But the saw dust is the byproduct from saw mills and the use of it as an energy source is a good practice for energy conservation. Other sources of energy such as bio gases, paddy husk, pre heat treatment using sunlight would be greatly reduce the cost of production of RSS using the SS dryer.

Calculation Table 1: Calculation of $m_r c_r \theta$ (for Dry rubber content), $m_w c_w \theta$ (for water content), λmvp (Energy needed for evaporation of Water) and Total energy

Time duration	mrcrθ (for Dry rubber content)	mwcwθ(for water content)	λmvp (Energy needed for evoparation of Water)	Total energy
00:00:00-13:10:00	458003.3972	1173885.732	0	1631889.129
13:10:00-13:40:00	161465.6044	413844.4613	0	575310.0658
13:40:00-14:10:00	32603.63167	69783.497	21187.5	123574.6287
14:10:00-14:40:00	108678.7722	186674.1567	0	295352.9289
14:40:00-15:10:00	-77627.69444	-133338.6833	0	-210966.3778
15:10:00-15:20:00	65207.26333	112004.494	0	177211.7573
15:20:00-15:31:00	225120.3139	386682.1817	0	611802.4956
15:31:00-15:40:00	111783.88	144757.704	21187.5	277729.084
15:40:00-16:10:00	130414.5267	113758.988	0	244173.5147
16:10:00-16:40:00	91600.67944	79902.14633	0	171502.8258
16:40:00-17:10:00	215804.9906	157837.7897	7062.5	380705.2802
17:10:00-17:40:00	63654.70944	37587.72033	0	101242.4298
17:40:00-18:25:00	-465766.1667	-275032.1	0	-740798.2667
18:25:00-19:10:00	-52786.83222	-31170.30467	0	-83957.13689
19:10:00-19:55:00	-99363.44889	-58673.51467	0	-158036.9636
19:55:00-20:25:00	-551156.6306	-325454.6517	0	-876611.2822
20:25:00-20:40:00	821301.0072	484973.2697	0	1306274.277
20:40:00-21:45:00	332246.5322	196189.5647	0	528436.0969
21:45:00-22:45:00	931532.3333	550064.2	0	1481596.533
22:45:00-23:45:00	381928.2567	225526.322	0	607454.5787
23:45:00-0:45:00	-2344356.372	-723703.2367	14125	-3053934.609
0:45:00-1:45:00	-122651.7572	-3300.119667	0	-125951.8769
1:45:00-2:45:00	-155255.3889	-4177.366667	0	-159432.7556
2:45:00-3:45:00	-139729.85	-3759.63	0	-143489.48
3:45:00-4:45:00	-232883.0833	-6266.05	0	-239149.1333
4:45:00-6:00:00	2226362.277	59903.438	0	2286265.715
6:00:00-8:00:00	159913.0506	4302.687667	0	164215.7382
8:00:00-9:00:00	-136624.7422	-3676.082667	0	-140300.8249
9:00:00-10:00:00	-1065266.113	2222727.589	105937.5	1263398.976
total	1826060.348	5051854.202	169500	7047414.549

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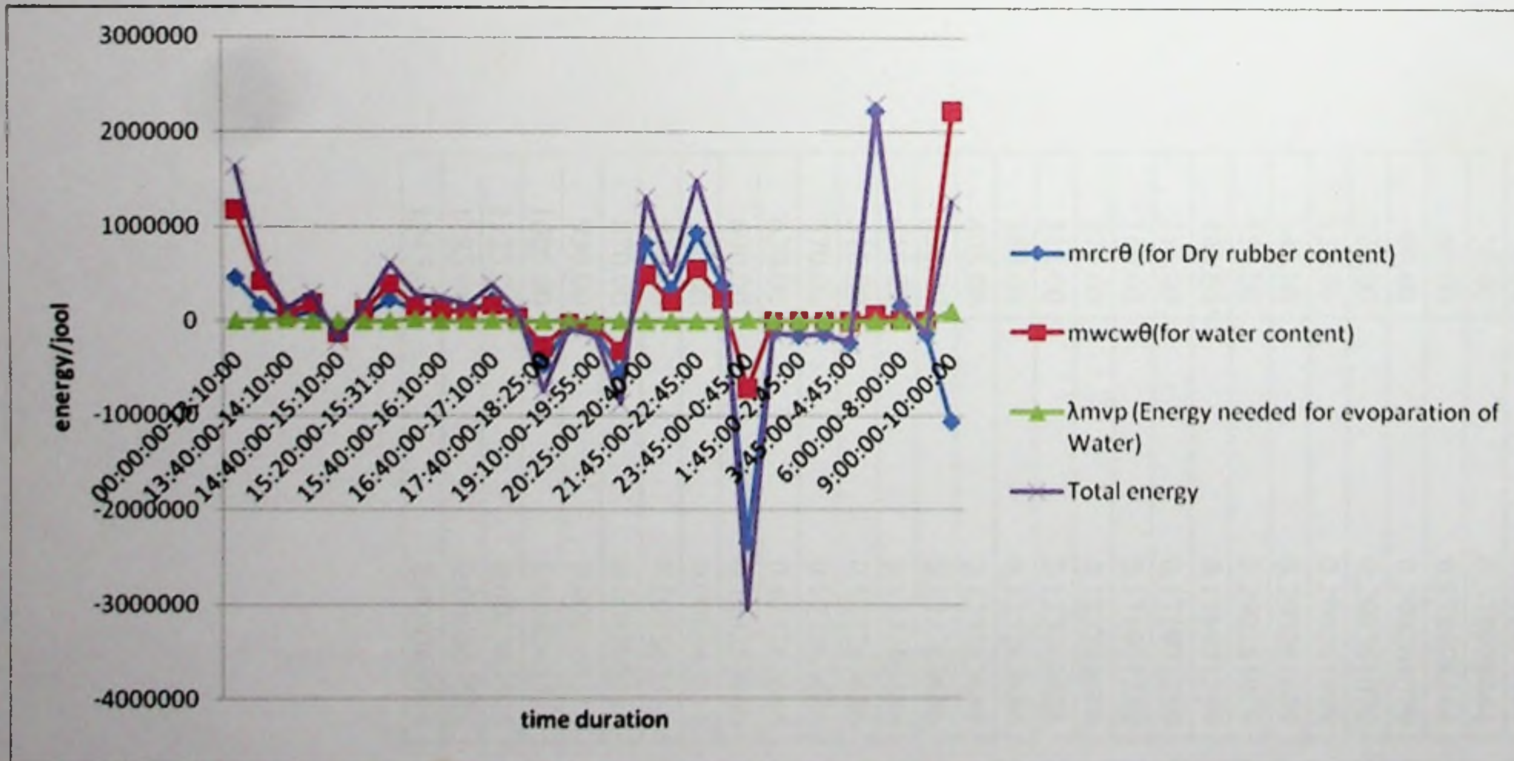

Fig 18: Energy consumption and total energy vs time

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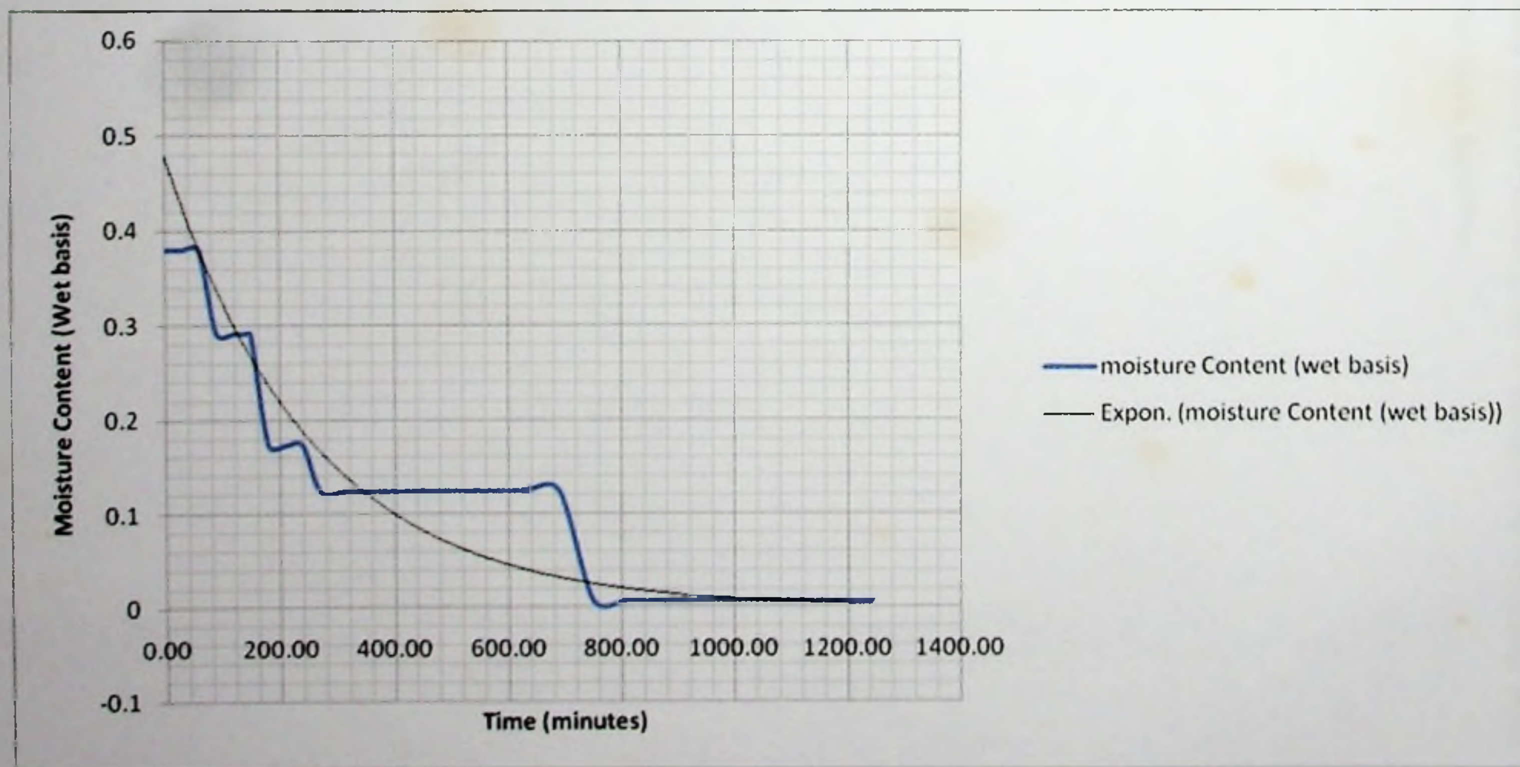
Calculation Table2: Total Moisture Content of RSS in the Dryer

Time	Moisture Content (wet basis)
0.00	0.378978444
30.00	0.378978444
60.00	0.378978444
90.00	0.290261079
120.00	0.290261079
130.00	0.290261079
141.00	0.290261079
150.00	0.290261079
180.00	0.171971259
210.00	0.171971259
240.00	0.171971259
270.00	0.123263686
315.00	0.123263686
360.00	0.123263686
405.00	0.123263686
435.00	0.123263686
450.00	0.123263686
510.00	0.123263686
570.00	0.123263686
630.00	0.123263686
690.00	0.123263686
750.00	0.006365511
810.00	0.006365511
870.00	0.006365511
930.00	0.006365511
1005.00	0.006365511
1125.00	0.006365511
1185.00	0.006365511
1245.00	0.006365511

Fig 19: Drying Curve (Changing of Moisture Content with Time)



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The drying curve (Fig 19) obtained from the research work is very similar to literature data (19), so this dryer is follows the typical drying behavior of a standard dryer. But it is obtained from exponential curve because the weighing scale used to measure weight is not much sensitive.

CHAPTER 6

CONCLUSIONS AND FUTURE WORKS

6.1. Conclusion.

The SS dryer is capable of producing a good quality RSS sheets at a high production rate, in a smaller smoke house. i. e. in this dryer, a 50 kg of RSS sheet can be smoked in a single day in a limited space (2.55 m^3) whereas in conventional smoke house an average quantity of 75 kg of RSS is produced after a drying period of five days in a comparatively larger smoke house (23.29 m^3). In other words, the loading density of newly built smoke house is 18.60 kg/m^3 whereas in conventional smoke house the loading density is very much low (6.01 kg/ m^3). (table 4, table 5).

Average drying efficiency of two method of calculation of the SS dryer is 51.7% which is a very high value with compared to the literature data of conventional system which has a drying efficiency 31%. The dryer also has following advantages over the conventional smoke house.

The SS dryer could be operated easily with less number of workers and improved healthy environment.

6.2 Future Works.

* It is proposed to carry out a comprehensive comparative study on the overall performance of the single day drying system and conventional system under local conditions

* An investigation should be carried out to study the effect of replacement of flappers with the control air flow control system.

* Studies on possibility of utilization of alternative renewable energy sources such as solar energy and bio gas as complete or auxiliary heating sources.

CHAPTER 7

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APPENDICES

APPENDIX I

Calculation of Mean value of temperatures with time

Drying Duration(min)	Temperature at A	Temperature at B	Temperature at C	Temperature at D	Mean value of temperatures
0	30.9	30.4	29.8	34.0	30.4
30	42.6	39.2	38.8	38.7	40.2
60	46.3	43.0	41.7	39.5	43.7
90	47.0	42.7	43.4	39.0	44.4
120	50.5	45.6	44.0	40.0	46.7
130	50.0	42.6	42.5	37.5	45.0
141	52.0	44.0	43.3	38.9	46.4
150	57.0	48.8	48.0	41.0	51.3
180	59.0	50.6	51.4	47.0	53.7
210	63.0	53.2	53.2	45.3	56.5
220	68.5	53.3	53.5	43.2	58.4
250	74.0	57.0	58.2	45.7	63.1
315	76.0	58.0	59.3	47.2	64.4
360	52.5	54.8	56.0	41.3	54.4
405	57.0	51.4	51.5	38.0	53.3
435	54.0	49.0	50.5	35.6	51.2
450	41.6	40.4	36.0	38.1	39.3
515	55.2	57.8	57.9	47.4	57.0
575	65.1	64.3	62.9	51.1	64.1
635	115.0	69.1	68.2	51.4	84.1
695	123.0	78.4	75.5	54.3	92.3
755	41.0	42.0	42.9	33.3	42.0
815	38.0	38.0	42.0	30.0	39.3
875	34.0	34.0	40.0	30.0	36.0
935	32.0	32.0	35.0	30.0	33.0
1010	28.0	28,0	28.0	28.0	28.0
1130	85.0	71.3	71.1	51.0	75.8
1190	91.4.0	73.2	73.1	53.4	79.2
1250	77.0	75.7	76.2	52.0	76.3

APPENDIX II

Variation of surface temperature of the dryer with time

Drying Duration(min)Time	**Surface temperature/^{0}C**
0	34
30	34
60	36
90	35
120	35
130	35
141	35
150	35
180	34
210	34
220	34
250	34
315	34
360	34
405	34
435	34
450	31
515	32
575	33
635	32
695	33
755	32
815	32
875	32
935	32
1010	28
1130	33
1190	33
1250	33

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APPENDIX III

Temperature variations at different positions with the Time

Time	Temperature of different positions of the dryer/^{0}C			
	A	B	C	D
0	30.9	30.4	29.8	34.0
30	42.6	39.2	38.8	38.7
60	46.3	43.0	41.7	39.5
90	47.0	42.7	43.4	39.0
120	50.5	45.6	44.0	40.0
130	50.0	42.6	42.5	37.5
141	52.0	44.0	43.3	38.9
150	57.0	48.8	48.0	41.0
180	59.0	50.6	51.4	47.0
210	63.0	53.2	53.2	45.3
220	68.5	53.3	53.5	43.2
250	74.0	57.0	58.2	45.7
315	76.0	58.0	59.3	47.2
360	52.5	54.8	56.0	41.3
405	57.0	51.4	51.5	38.0
435	54.0	49.0	50.5	35.6
450	41.6	40.4	36.0	38.1
515	55.2	57.8	57.9	47.4
575	65.1	64.3	62.9	51.1
635	115.0	69.1	68.2	51.4
695	123.0	78.4	75.5	54.3
755	41.0	42.0	42.9	33.3
815	38.0	38.0	42.0	30.0
875	34.0	34.0	40.0	30.0
935	32.0	32.0	35.0	30.0
1010	28.0	28.0	28.0	28.0
1130	85.0	71.3	71.1	51.0
1190	91.4	73.2	73.1	53.4
1250	77.0	75.7	76.2	52.0

APPENDIX IV

Air flow rate at the outlet of the SS dryer

Time	Air flow/msec-1
0	0.05
30	0.40
60	0.50
90	0.40
120	0.55
130	0.43
141	0.40
150	0.62
180	0.81
210	0.64
220	0.45
250	0.47
315	0.88
360	0.77
405	0.57
435	0.64
450	0.74
515	0.86
575	0.94
635	0.86
695	0.85
755	0.99
815	0.40
875	0.40
935	0.20
1010	0.04
1130	0.80
1190	0.85
1250	0.75

APPENDIX V

Variation of weight of rubber sheets dried at different locations of SS dryer

Time	Sheet 1: Bottom Rack/g	Sheet 2: Middle rack/g	Sheet 3: Upper rack/g
0	400	400	400
30	400	400	400
60	400	400	400
90	350	350	350
120	350	350	350
130	350	350	350
141	350	350	350
150	350	350	350
180	300	300	300
210	300	300	300
220	300	300	300
250	250	300	300
315	250	300	300
360	250	300	300
405	250	300	300
435	250	300	300
450	250	300	300
515	250	300	300
575	250	300	300
635	250	300	300
695	250	300	300
755	250	250	250
815	250	250	250
875	250	250	250
935	250	250	250
1010	250	250	250
1130	250	250	250
1190	250	250	250
1250	250	250	250