Final Report

on

Development of a cost effective, user friendly and efficient dryer for different types of rubber

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Executive summary of the project

Sri Lanka processes natural rubber latex into a semi industrial raw material in two forms namely dry form and liquid form (concentrated latex). Natural rubber produced in dry form contributes to approximately 75% of the local rubber production. Ribbed Smoked Sheets (RSS) and Crepe Laces (CL) are the major dry raw rubber forms while there are few other forms such as yellow fraction rubber (YFR), brown crepe laces (BCL) and skim rubber laces (SKLC) which are produced as by products at relatively small quantities.

The drying process is the longest production step of the manufacturing processes of all the above dry rubber forms. RSS is dried at 48-54 ^{0}C for 5 days in a traditional smoke house and at 55 - 65 ^{0}C during a single day in a newly introduced single day smoke drying units. CLs are dried conventionally in heated hot air chambers at 34 ^{0}C for 3 days. In this system, energy content of flue gas is not utilized. Other forms of rubber are dried at ambient air at uncontrolled drying conditions for prolong periods. Traditional drying operations of rubber, therefore, require a huge space for drying chambers and are carried out in multi-story buildings. Some of the other drawbacks of these drying systems are energy wastage due to interrupted drying process, low drying efficiency, obnoxious operational practices, delayed cash flow and down grading of rubber dried at ambient conditions particularly in overcast weather conditions. Diversification of the type of product could not also be done at once to absorb the advantages of the price fluctuations of RSS and CL with the presently available drying systems as they are designed for drying only a particular form of rubber.

In this scenario, this project was carried out to develop a drying system with a reduced drying period, lesser firewood consumption and improved working conditions while keeping provisions for drying of different forms of dry rubber in a same drying system.

As the output of the project, a user friendly, efficient and accelerated dual unit drying system which could be used for drying of different forms of rubber simultaneously or separately was designed and constructed. Drying performance of different grades of rubber at different operational conditions was studied.

Report in detail

1. Introduction/Background

Sri Lanka produces different types of natural rubber more than 100,000 MT/year mainly in the following forms.

(i). Ribbed Smoked Sheet (RSS)

(ii). Crepe rubber (Pale crepe and Sole crepe)

(iii). Technically Specified Rubber (TSR)

(iv). Brown Crepe Laces (BCL)

(v). Skim Crepe Laces (SKL)

(vi). Centrifuged latex (CL)

In addition, Air Dried Sheets (ADS) which are processed similar to RSS but dried in hot clean air is also produced at minor quantities. All the above mentioned forms except centrifuged latex are presented to the market in dry form. The reported production figures of each of the above types for last ten years are shown in the Table1.

Table1: Raw rubber production (MT) (2004-2013)

Year	RSS	Crepe rubber		BCL	CL	SKLC*	TSR
		PCL	SCL				
2004	46500	12500	2000	3900	26000	1820	3800
2005	50100	12900	2700	2900	29800	2086	5900
2006	52500	20200	3900	1600	28100	1967	9000
2007	48900	21800	4000	1700	31200	2184	9600
2008	55000	21000	3900	2700	35600	2492	11000
2009	54600	31700	5400	3500	29900	2093	11800
2010	59300	52500	6700	1800	24300	1701	8300
2011	60700	59900	3400	1300	24900	1743	8000
2012	59200	36500	1900	1300	44400	3108	8700
2013	62800	15400	2400	2400	37900	2653	9600

*Estimated figure of 7% of the centrifuged latex production

It can be seen from the production figures presented in Table 1 that RSS, crepe rubber BCL and SKCLs contribute to more than 75% of the annual rubber production in dry form. RSS and crepe laces are manufactured from deliberately coagulated latex. BCL is produced from the unintended coagulated latex in the field and SKLC is manufactured from deliberately coagulated skim latex, a by-product from the centrifuged latex manufacturing industry. Manufacturing processes of RSS, crepe laces and SKCL include coagulation of latex, milling into sheet or lace form and drying of laces.

The drying process which is the longest production step plays an important role in the manufacture of rubber since it has a significant impact on the production cycle and on the quality.

In RSS drying, the rubber is dried at 48-54 ^{0}C for 5 days in a smoke house where direct smoke with heated air is used for drying. A typical smoke house comprises a multi-story building which could accommodate 4-5 days crop and a firewood fed furnace. Recently introduced Single day Smoke Drying units are designed to accommodate a single day crop and sheets achieve complete dryness in one day drying period at 55 65 ^{0}C. In contrast, PCL and SCL, a more pale coloured and thinner rubber laces than RSS is dried conventionally in heated air chambers known as drying towers which are made of brick/concrete at 34 ^{0}C for 3 days In crepe rubber drying units, in built hot water radiators are installed on the ground floor. A firewood fed external boiler produces hot water and this is circulated through the radiators by natural circulation, warming the air inside the drying tower through buoyancy forces. Flu gas which contains high energy content is exhausted to the environment without use. The warm air is then carried upward by natural convection and removes the moisture. The normal operating practice is to load and unload the drying towers during day light hours. The smokehouses and dying towers are heated late afternoon and continue through the night. The drying periods could be even longer in overcast weather. In these both traditional drying systems, energy generated are wasted to the environment during the drying interruption period for loading and unloading of the rubber.

BCL and SKCL, there are neither established controlled drying system nor established drying characteristics so far, since the inception of rubber industry in Sri Lanka. Due to the high investment, economic and technological reasons, the conventional hot water-boiler-radiator crepe rubber drying system is not used for drying of these two forms. They are dried at natural air with no heat.

Operational characteristics of present drying methods of different rubbers are briefly summarized in the following Table 2.

Table 2: Present operational characteristics of present drying methods of different rubber

Rubber type	Initial moisture content (%)	Final moisture content (%) (max.)	Drying temperature (°C)	Drying period (Days)	Present drying system
Crepe rubber	12	0.2	34	3	Drying towers heated through hot-water boiler-radiator system
Ribbed smoked sheet rubber	30	1.0	(48-54) (at conventional smoke houses 55-65 (at SS drying units)	5 1	Firewood furnace fed smokehouse
Air dried sheet rubber	30	1.0	34	6	Drying towers heated through hot-water boiler-radiator system
Brown crepe rubber	20	1.0	28-30	4-10	Open space ambient air drying
Skim crepe laces	25	1.0	28-30	3-5	Open space ambient air drying

The drying of RSS rubber in a conventional smoke house requires about 1- 1.2 kg of firewood to dry one kg of sheet rubber from an initial moisture content of about 25 - 30% to a required moisture content of 1.0% while drying of crepe rubber in a conventional drying tower requires about 0.2 kg (minimum) of firewood to dry one kg of crepe rubber from an initial moisture content of about 14% to a required moisture content of 0.2%. Therefore, Rubber factories consume approximately 100,000 MT of firewood mainly derived from uprooted rubber trees are used for drying of natural rubber annually.

In recent years, it has been recognize that treated rubber timber could be used for furniture manufacturing Industry. Therefore, savings in rubber wood consumption generate additional income for the rubber plantation sector. This had led to investigate the possibilities of adopting energy efficient drying systems or alternative drying systems to reduce the fire wood consumption in the raw rubber processing industry.
With regard to the drying of crepe rubber it was found out by Walpita et. al. that the efficiency of the conventional drying towers is only 13.29% which is a very low efficiency and results in consuming more rubber wood than is required. As mentioned above, flue gas emitted for the chimney of the boiler which has a very high content of energy is completely unutilized in the conventional drying towers. Forced air drying system introduced by RRISL also uses hot water radiator system and huge existing drying towers making this system also not a highly energy efficient system. Various studies have been carried out to utilize the solar energy for drying rubber work. The results of the studies carried out have shown that utilization of solar energy could be effective, only if the operational practices of drying of crepe laces are changed to avoid drying interruptions and to carry out the operation continuously in the day time during which solar energy could be utilized effectively. Flat plate air collectors have been used in RSS drying in Malaysia and Indonesia (Mohd. 1991; Breymayer, 1993). In each system, collectors have been used to produce heated air and then this is passed to the drying chamber. However, these systems have not been industrially yet accepted due to their operational complexity and high investment cost with compared to the low grade heat requirement (below 100 ^{0}C) in rubber drying industry.

BCL and SKCL, there are neither established controlled drying system nor established drying characteristics so far, since the inception of rubber industry in Sri Lanka. Due to the high investment, economic and technological reasons, the conventional hot water-boiler-radiator crepe rubber drying system is not used for drying of these two forms. They are dried at natural air with no heat. Ambient air drying of BCL and SKCL also has many inherent disadvantages. It takes about 3-4 days during dry weather and 10 14 days during wet weather for drying of laces and laces are subjected to downgrading due to mould growth, discoloration and dirt contamination. In addition, prolonged drying period causes a prolonged production cycle and therefore, restricts the cash flow of the business while requiring a huge space for hanging laces and making drying process a very labour intensive operation. Quality inconsistencies of laces are frequently observed due to the uncontrolled drying process particularly during rainy season. If a drying system is introduced to shorten the drying period at a considerable level, attempts could be taken to produce thicker laces or mat reducing the electrical power consumption in the rubber mills with simultaneous increase in the output of the mills, ie improved productivity. Preliminary investigations of smoke or hot air drying of BCL and SKCL has revealed that drying could be completed within 48 hours and 18 hours, if the warm air or smoke is used for the purpose of drying at correct temperature.

In addition to the above mentioned drawbacks in the drying systems, an improved working environment and user friendly systems have become a must in the face of growing public concern on the environment and stringent labour regulations apart from the effective utilization of energy.

In recent years, the prices of RSS and crepe have fluctuated significantly. The average monthly prices of the best grades of RSS and crepe rubber are given in Figure 1. It could be seen that the prices of sheet rubber and crepe rubber have exceeded each other in most of the occasions. Cost of manufacture of crepe is approximately twice of the cost of manufacture of RSS. However, sudden diversification of the type of product (crepe or RSS) could not be done to absorb the advantages of the price fluctuations to of the crepe rubber and RSS as the existing drying systems for both grades are different and could not be used commonly.

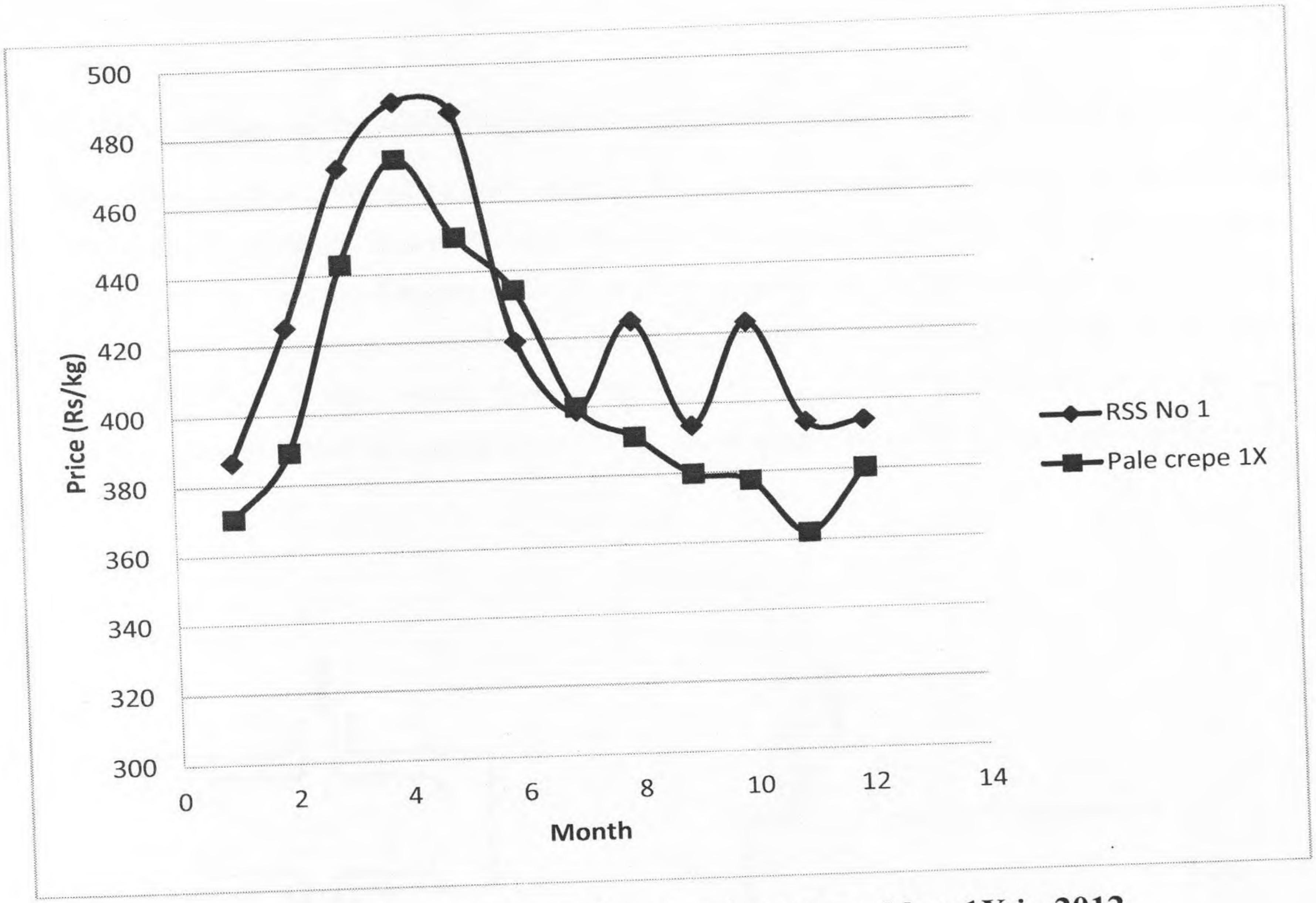

Figure 1: Average prices of RSS no 01 and pale crepe rubber 1X in 2012

Therefore, development of a single user friendly, efficient and accelerated drying system which could be used for drying of different grades of rubber simultaneously or separately using the same heat source would be useful to the raw rubber industry in many ways.

2. Objectives

Overall objective

To develop a user friendly, accelerated and efficient single drying system for drying of different grades of rubber simultaneously or separately.

Specific objectives

(i). Reduction the conventional drying period of natural rubber by at least 50%

(ii). Reduction the firewood consumption for drying of natural rubber by at least 20%

(iii). Reduction the carbon dioxide emission per kg of natural rubber being dried

(iv). Improvement of the working environment and operational practices

(v). Minimization of quality degradation of natural rubber during the drying process

3. Description of the work (against the proposed project design, work plan etc.)

A new drying system comprising two separate drying chambers was designed. A biomass fed furnace was also designed to generate hot clean air with provision to collect the hot smoke (flue gas) separately. Schematic diagram of this hot air generating unit is shown in annexure 1. One drying unit is heated through clean hot air and has a capacity to accommodate 500 kgs of crepe laces or 1,000 kgs of sheet rubber (drying chamber 01). This unit is provided with a hot air distribution system which is mainly used to dry rubber irrespective of the type of rubber being dried.

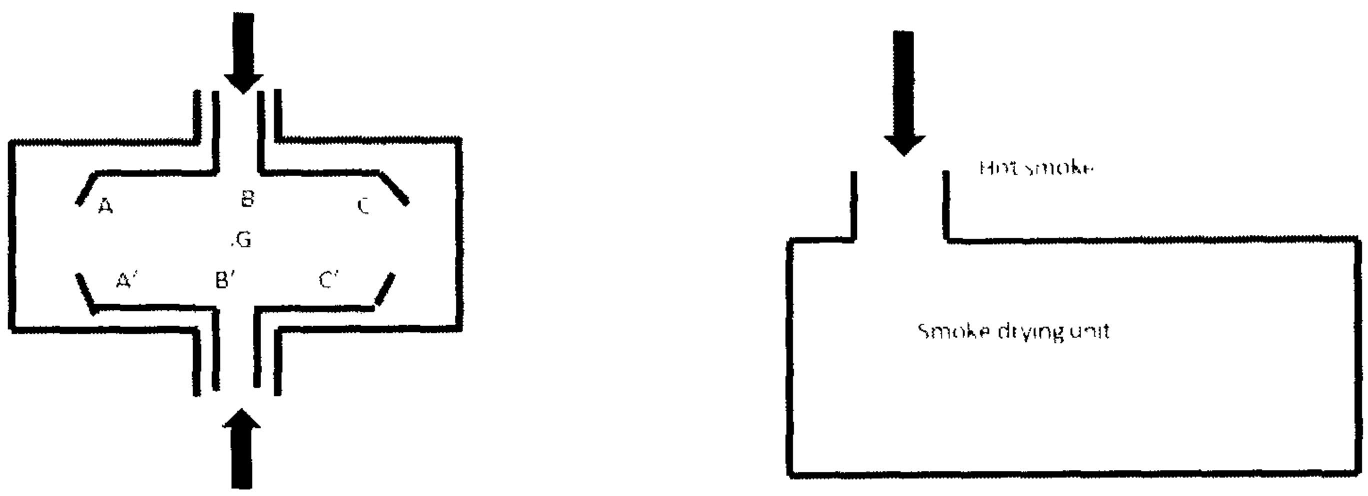

Figure 2: Circuit diagram of the drying units and air flow distributing system.

The other drying chamber is heated through flue gas and is used to dry/smoke sheet rubber or brown crepe rubber (drying chamber 02). The dimensions of the drying system are given below.

Hot air fed drying unit (drying chamber 01)	12'(width); 24' (length); 7' (height)
Flue gas fed drying unit (drying chamber 02)	6'(width); 24' (length); 7' (height)
Hot air generating unit	5' (External Diameter); 6' (height)

Figure 2 shows the circuit diagram of the drying units and heat distributing system. A, A', B, B', C and C' are the hot air inlets into the hot air chamber G is the central point of the air outlet points of the dryer. Temperature at this point considered as the Dryer temperature.

Schematic diagrams of drying units. and hot air generating unit are shown in Annexure 2. Trolleys are introduced to hang laces or sheets to make the system more user friendly and to make loading and unloading operations are easier and faster. Schematic diagrams of trolleys are shown in Annexure 3.

The dryer design was validated against the expected drying performance of crepe rubber and sheet rubber. Validation results are attached in annexure 4. Fabrication of two drying chambers was then completed. Heat distribution system was studied using temperature development as the indicator. Few trial runs were carried out using brown crepe rubber. Based on the observations of the preliminary trials, internal duct arrangement was modified to assure uniform heat distribution

Table 3: Operational modes studied for drying of different rubbers

Operational mode	Product being dried	Remarks
Operational mode 01	Brown crepe	Brown crepe dried at hot air drying chamber (Chamber 01) at three different drying temperatures
Operational mode 02	Crepe rubber	Pale crepe laces were dried at hot air drying chamber (Chamber 01) at three 34 ^{0}C
Operational mode 03	Sheet rubber	Sheet rubber was dried in hot air drying chamber (Chamber 01) at 35-40^{0}C for two days and subsequently they were dried in flue gas heated drying chamber (drying chamber 2)
Operational mode 04	Skim rubber laces	Skim crepe laces dried at hot air drying chamber (Chamber 01) at three different drying temperatures
Operational mode 05	Simultaneous drying of crepe rubber and sheet rubber	Pale crepe laces were dried at hot air drying chamber (Chamber 01) at three 34 ^{0}C while smoke sheets was dried in flue gas heated drying chamber (drying chamber 2)
Operational mode 06	Simultaneous drying of crepe rubber and brown crepe rubber	Pale crepe laces were dried at hot air drying chamber (Chamber 01) at 34 ^{0}C while brown crepe was dried in flue gas heated drying chamber (drying chamber 2)

(Temperature development). Air flow rate through the hot air generator was also reduced to reach the air flow rate through dryers and heat loss through the flue gas. Temperature control systems at the drying unit one was then designed and introduced. Drying performances of the dryer at the operational modes given in Table 3 was then studied.

Raw rubber properties of rubber were evaluated against the control samples to assess the quality of rubber being dried at the new dryer. Introduction of the new drying system and its preliminary results were briefly presented to the planters at a scientific committee meeting organized by the Rubber Research Institute.

4. Objectives achieved to date

Major:

An industrial scale single drying system for drying of different types of rubber (sheet rubber, ribbed smoked sheet rubber, crepe rubber, and brown crepe rubber and skim laces) to be used in the field was developed

Specific objectives achieved

(i). Reduction of conventional drying periods of rubber was achieved

Ribbed Sheet rubber by	20%
Crepe rubber by	33%
Brown crepe rubber	50% minimum
Skim laces	75% minimum

(ii). Reduction of firewood consumption

When simultaneous drying of crepe rubber and sheet rubber - reduction approximately 50%

When only sheet rubber is drying - reduction approximately by 32%

When only crepe rubber is drying reduction approximately by 12.5%

(iii). Reduction the carbon dioxide emission per kg of natural rubber being dried

(iv). Improvement of the working environment and operational practices

(v). Minimization of quality degradation of natural rubber during the drying process

5. Discussion results and observations

5.1 Drying performance of rubber

Operational mode 01: drying of brown crepe rubber

As an initial trial, three batches of brown crepe rubber laces (340 kg of dry rubber) manufactured at Sorana rubber factory were charged into the hot air drying chamber. They were dried at three different temperatures as follows

Experiment A: (28 – 31 ^{0}C) ambient temperature

Experiment B : 30 – 35 ^{0}C

Experiment C : 35 – 40 ^{0}C

Average air flow rate through the drier (Middle flap of the dryer) was maintained at 0.162 m^3/s. A control batch was also dried at the loft of the factory following traditional operational factory practices. Time taken to achieve complete dryness and visual assessment of quality of rubber were studied. Results obtained and observations are as follows (Table 4).

Table 4: Results and observations of the initial trial of operational mode 01

Experiment	Drying period (days)	Visual assessment of the quality of rubber
Control	7	
Experiment A	5	Colour of the laces is similar to the colour of the control samples.
Experiment B	3	Colour of the laces is similar to the colour of the control samples.
Experiment C	3 ½	Colour of the laces is similar to the colour of the control samples. However, laces showed tackiness. Most of the laces got melted and fall down to the chamber floor.

Above results and observations revealed that maximum temperature that could be recommended for drying of brown crepe is 35 ^{0}C.

As the second set of experiment, two batches of brown crepe manufactured at Sorana rubber processing factory were dried at the same dryer at 30-35 ^{0}C. Time taken to achieve the complete dryness and firewood consumption were studied. As in the first trial, two control samples were also dried. The results are tabulated in the Table 5 and Table 6.

Table 5: Raw rubber properties of brown crepe rubber

Property	Brown crepe laces dried at the dryer		Ambient air dried brown crep rubber	
	Trial sample 01	Trial sample 02	Control sample 01	Control sample 02
% Dirt content (w/w)	0.71	0.62	0.820	0.601
% Volatile Matter (w/w)	1.46	0.95	1.36	0.93
% Nitrogen content (w/w)	0.44	0.39	0.48	0.40
% Ash (w/w)	0.95	0.82	0.92	0.86
Initial plasticity number (Wallace units)	42	45	46	46
Plasticity Retention Index (PRI)	47	43	52	54
Mooney viscosity ML 1 + 4 @ 100 °C	82	90	86	88
Visual assessment of the color of the laces	Same as the colour of the control samples			

Table 6: Firewood consumption and drying period of the samples

Trial no	**Firewood consumption Kg/kg of rubber dried**	**Drying period (days)**
Sample 01	0.21	3.5
Sample 02	0.22	3
Control sample 01	Not used	6.5
Control sample 02	Not used	6.5

It was observed that brown crepe laces hung closer to the hot air inlets have got melted. There were only six hot air inlets and the temperature of the air flow at the inlets is around 43-45 ^{0}C which is above the maximum allowable temperature concluded from the previous experiment. It was concluded that these lace got melt due to exposure of these laces to high temperature. Therefore, hot air distribution system was modified to give uniformly scattered large number of smaller air inlets to provide hot air flow into the drying chamber. Few sets of brown crepe laces were again dried at the same temperature range 30 – 35 ^{0}C after the modification and the representative results on the raw rubber properties were given in Table 7. Firewood consumption is given in Table 08.

Table 7: Raw rubber properties of brown crepe rubber dried at the modified dryer

Raw rubber property	Trial sample	Control sample
% Dirt content (w/w)	0.725	0.800
% Volatile Matter (w/w)	1.36	1.40
% Nitrogen content (w/w)	0.48	0.39
% Ash (w/w)	0.90	0.94
Initial plasticity number (Wallace units)	45	48
Plasticity Retention Index (PRI)	48	54
Mooney viscosity ML 1 + 4 @ 100 °C	85	88
Visual assessment of the color of the laces	Same as the colour of the control samples	

Table 8: Firewood consumption and drying period of the samples

Trial no	Firewood consumption Kg/kg of rubber dried	Drying period (days)
Sample	0.20	**3**
Control sample	Not used	7

Drying temperature inside the dryer

Temperature maintained inside the dryer throughout the drying period of brown crepe rubber, and temperature of the hot air at the source (near the hot air generator and the ambient air are shown in Figure 3. Drying temperature recorded at the temperature air flow exit at the central ventilators installed at the dryer roof. A drying curve derived from the results obtained for brown crepe rubber is presented in Figure 4.

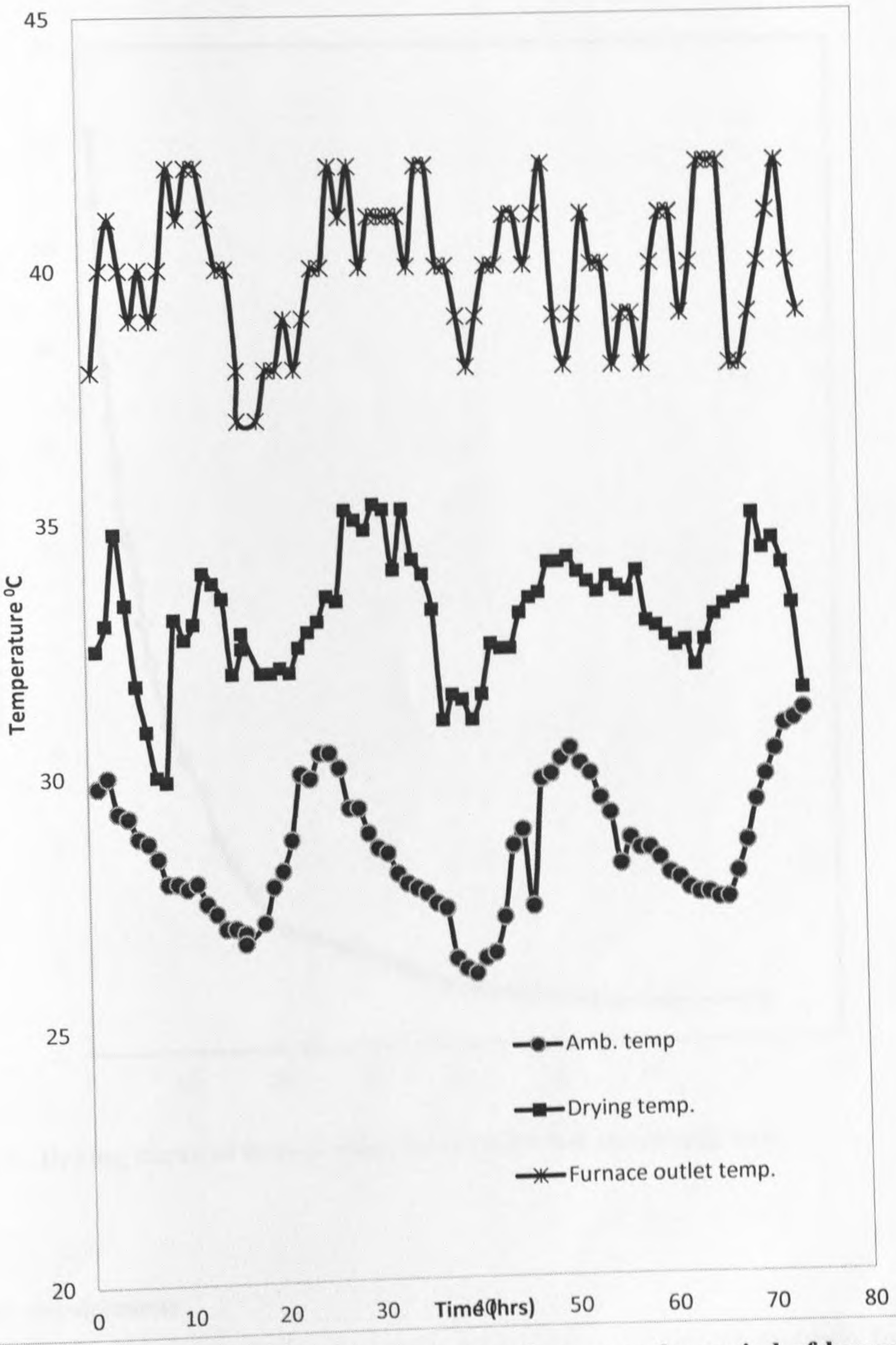

Figure 3: Temperature profile of different locations over the period of brown crepe drying (Max 35.3 ^{0}C, min 29.9 ^{0}C, average drying temp.: 33.08 ^{0}C).

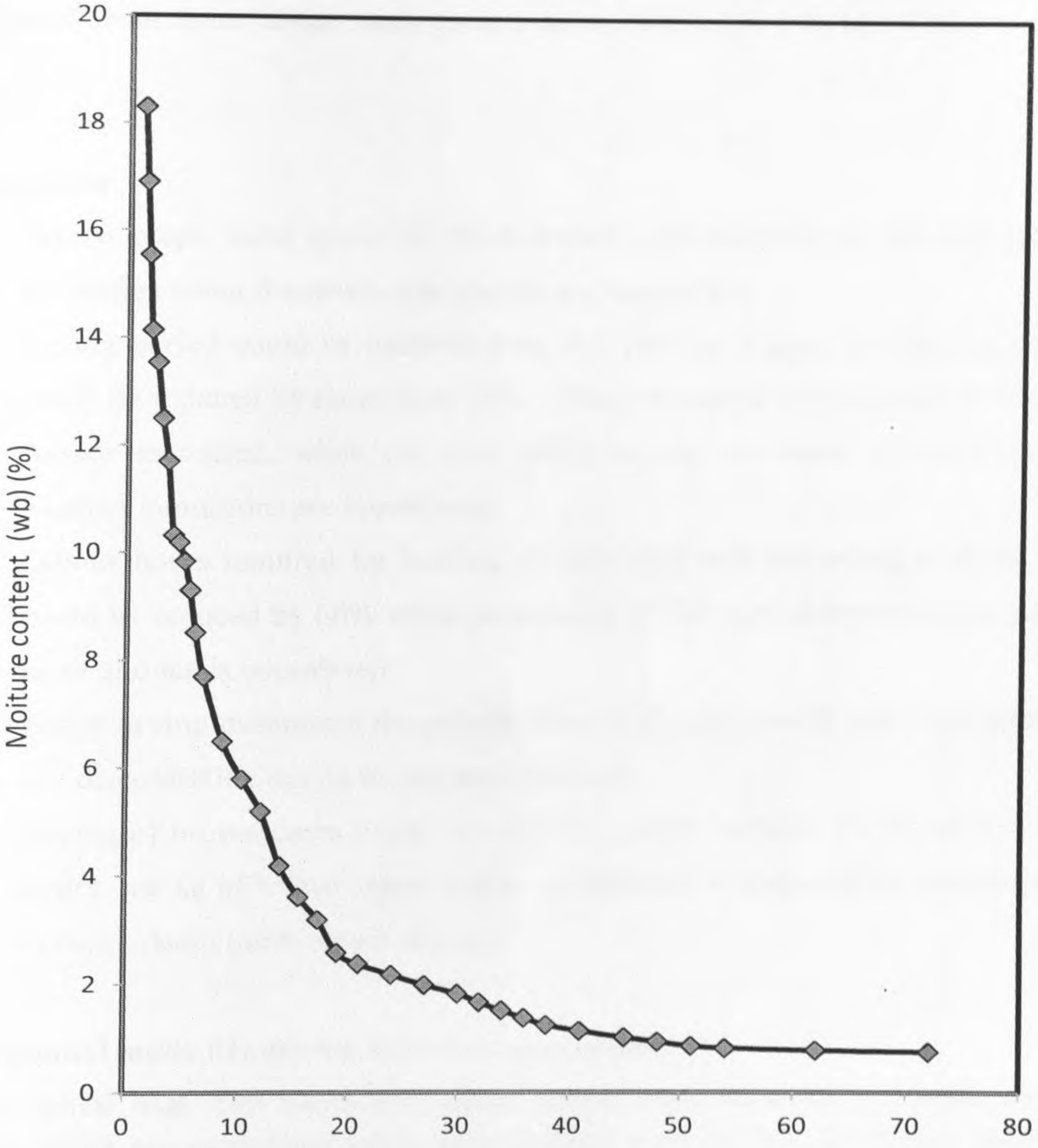

Figure 4: Drying curve of Brown crepe laces in the hot air drying unit

Labour requirement

Wet laces manufactured at the ground floor at the factory are moved manually by the workers to the first floor or second floor of the factory which is known as the loft in the conventional drying process of brown crepe. After completion the drying process, they are again moved to the ground floor for further processing (dry blanketing process). In the present system, wet laces are directly hung on the movable trolleys and they are entered to the dryer. Drying operation is carried out by factory security officer after given training on the dryer operation without incurring additional cost. Therefore, it was estimated that labour requirement could be reduced from three labour hours to one labour hours per 340 kg of brown crepe laces.

Conclusions

(i). Brown crepe laces could be dried without deterioration of the raw rubber properties using the newly introduced drying process

(ii). Drying period could be reduced from 6-7 days to 3 days, ie. Drying period could be reduced by more than 50%. This percentage of reduction in may be further increased, when the time taken to dry the laces at unfavourable weather conditions are considered.

(iii). Labour hours required for loading of wet laces and unloading of dried lace could be reduced by 66% when processing of 340 kgs of brown crepe rubber laces at once is considered.

(iv). Faster drying minimizes the possibilities of mould growth and development of discoloration due to enzymatic reactions

(v). Drying of brown crepe using new drying system requires 0.2 kg of firewood to dry one kg of brown crepe, where no firewood is required for conventional drying system (ambient air drying)

Operational mode 02: drying of pale crepe rubber

As an initial trial, two batches of crepe rubber manufactured at Sorana rubber factory using pre-coagulated latex were charged into the hot air drying chamber. They were dried at 30 35 ^{0}C. Average air flow rate through the drier (Middle flap of the dryer) was maintained at 0.162 m^3/s.

Two control batches were also dried at the conventional drying tower at the Sorana factory following traditional operational factory practices. Time taken to achieve complete dryness and raw rubber properties were studied. Results obtained and observations are as follows (Table 09).

Table 09: Results obtained and observations of the initial trial of operational mode 02

Experiment	Drying period (days)	Visual assessment of the quality of rubber	Firewood consumption kg/kg
Control sample 1	3	Discoloured samples as they were made out of already pre-coagulated latex	0.2*
Control sample 2	3	Discoloured samples as they were made out of already pre-coagulated latex	0.2*
Sample 01	2	Colour of the laces is similar to the colour of the control samples.	0.45
Sample 02	2	Colour of the laces is similar to the colour of the control samples.	0.5

* Obtained from Sorana rubber processing factory and this value is assumed to eb the minimum value reported in the filed.

Raw rubber properties of the trial samples and control samples are tabulated in the Table 10.

Table 10: Raw rubber properties of crepe rubber (trial samples and control samples)

Property	**Crepe rubber dried at the dryer**		**Crepe rubber dried at drying tower**	
	Trial 01	Trial 02	Control 01	Control 02
% Dirt content (w/w)	0.015	0.018	0.02	0.016
% Volatile Matter (w/w)	0.37	0.39	0.38	0.32
% Nitrogen content (w/w)	0.48	0.50	0.45	0.48
% Ash (w/w)	0.1	0.12	0.18	0.14
Initial plasticity number (Wallace units)	54	58	58	57
Plasticity Retention Index (PRI)	79	82	88	86
Mooney viscosity ML 1 + 4 @ 100 °C	78	85	75	82
Lovibond colour	3	3	3	3

It can be seen from the results presented in Table 9 and 10 that fire wood consumption for drying of crepe rubber in the new drying system is significantly higher than that of the conventional drying system. However, drying period has reduced from three days to two days when crepe laces were dried in the new drying unit. Comparable raw rubber properties of all the samples revealed that drying of crepe laces in the new drying system in a shorter period at recommended temperature does not affect the raw rubber of the crepe rubber.

As the second set of experiments, few batches of crepe rubber (500 kg) manufactured at Sorana rubber processing factory were dried at the dryer at 30-35 ^{0}C at different air flow rates (controlling from the blower fixed to the furnace and the top ventilators) lower than the air flow rate of the initial trial (at 0.162 m^3/s). It was found that crepe laces could be dried within two days with the minimum air flow rate of 0.04 m^3/s at 30-35 ^{0}C. Under these conditions, firewood consumption has been reduced to 0.175 kg/kg. Raw rubber properties of a representative sample and the control sample (dried in the drying tower) are given below.

Table 11: Raw rubber properties of crepe rubber

Property	Crepe rubber dried at the new dryer	Crepe rubber dried at the drying tower
% Dirt content (w/w)	0.017	0.018
% Volatile Matter (w/w)	0.38	0.34
% Nitrogen content (w/w)	0.41	0.40
% Ash (w/w)	0.12	0.14
Initial plasticity number (Wallace units)	56	58
Plasticity Retention Index (PRI)	80	84
Mooney viscosity ML 1 + 4 @ 100 ^{o}C	74	75
Lovibond colour	1.5	1.5

Drying temperature inside the dryer

As in the previous study, temperature maintained inside the dryer throughout the drying period of brown crepe rubber, and temperature of the hot air at the source (near the hot air generator and the ambient air are recorded. They are shown in Figure 5. Drying temperature was recorded at the temperature air flow exit at the central ventilators installed at the dryer roof. A drying curve derived from the results obtained for pale crepe rubber is presented in Figure 6

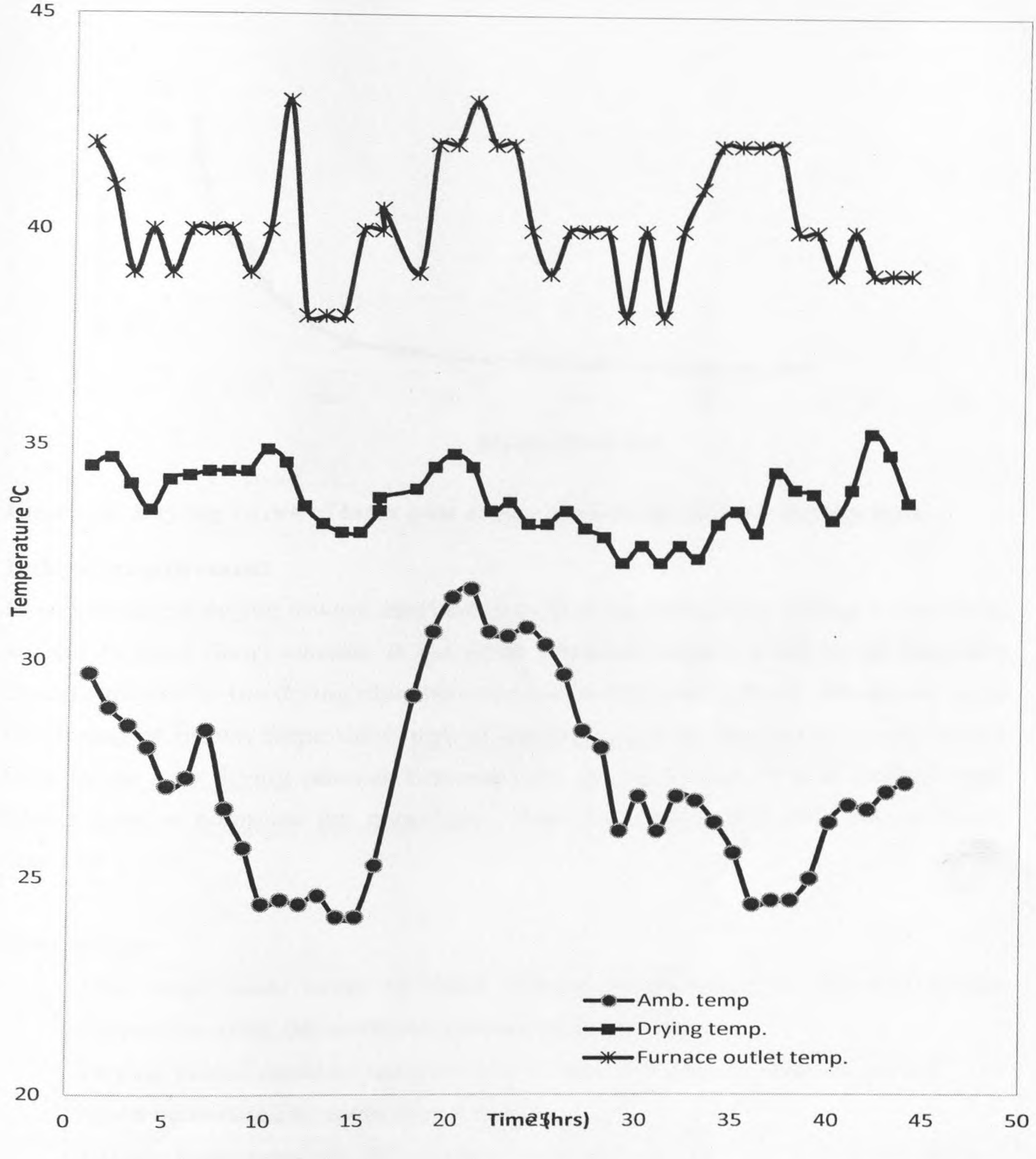

Figure 5: Temperature profile of different locations over the drying period of pale crepe laces (Max 35.3 ^{0}C., min 32.3 ^{0}C, mean 33.74 ^{0}C drying temp.)

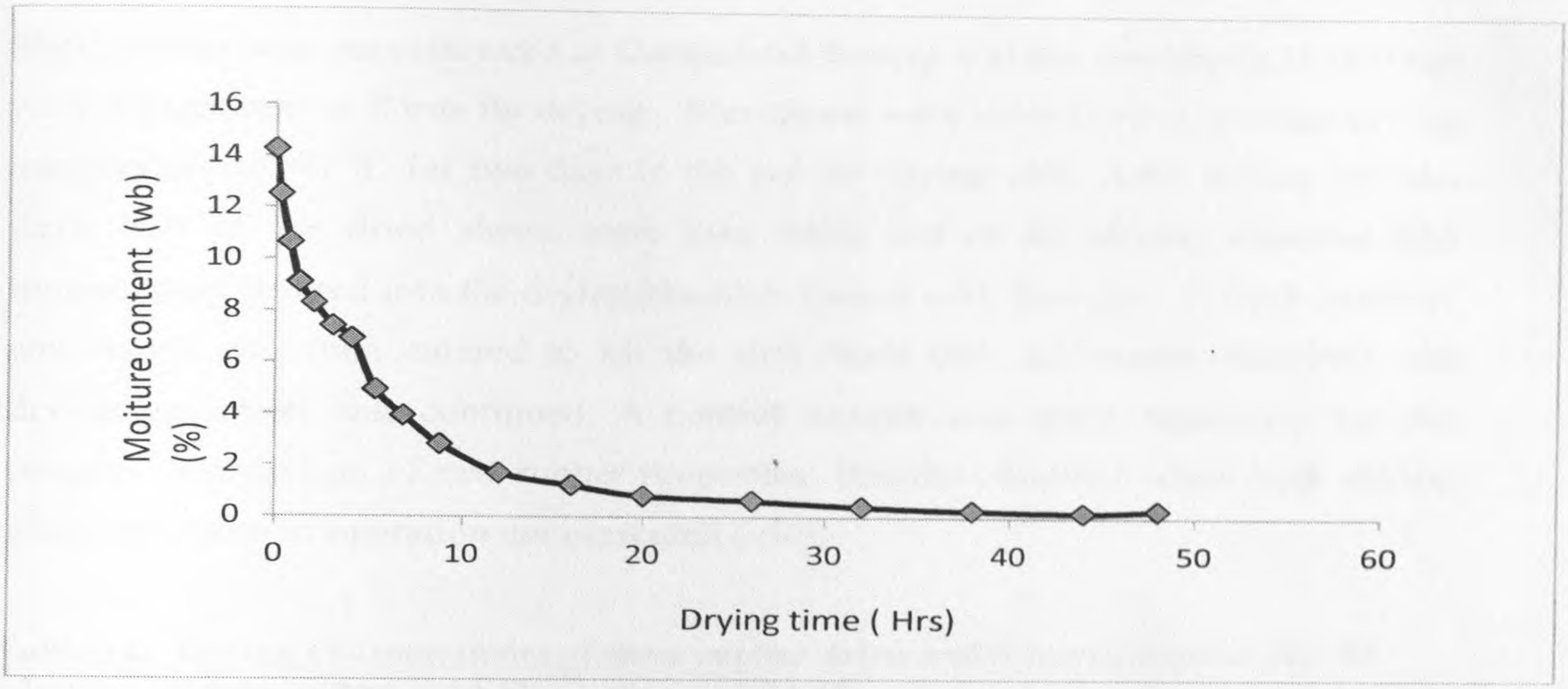

Figure 6: Drying curve of latex pale crepe laces in the hot air drying unit

Labour requirement

In conventional drying towers, laces are moved to upstairs of the drying tower (first, second or third floor) whereas in the present system trolleys loaded with laces are directly moved to the drying chambers located in the ground floor. Therefore, as in the drying of brown crepe laces, task of loading could be completed in one labour hour in the new drying process. Conventional drying system, it is estimated three labour hour to complete the same task. Therefore, more than 60% labour hours could be saved.

Conclusions

	Pale crepe laces could be dried without deterioration of the raw rubber properties using the newly introduced drying process
	Drying period could be reduced from 3 days to 2 days, ie. Drying period could be reduced by more than 33%.
	Labour hours required for loading of wet laces and unloading of dried laces could be reduced by 66% when processing of 500 kgs of brown crepe rubber laces at once is considered.
	Average firewood consumption is 0.175 kg/kg of pale crepe and which is a minimum reduction of firewood consumption by 12.5% against the firewood consumption in conventional drying

Operational mode 03: Drying of sheet rubber

Sheet rubber was manufactured at Dartonfield factory and the wet sheets (1,000 kg) were transported to Sorna for drying. Wet sheets were then dried at average drying temperature of 40 ^{0}C for two days in the hot air drying unit. After drying for two days, half of the dried sheets were then taken out of the drying chamber and immediately entered into the drying chamber heated with flue gas. A fresh batch of wet sheets was then entered to fill the first dryer (hot air heated chamber) and drying operation was continued. A control sample was dried separately for the purpose comparison of raw rubber properties. Results obtained while both drying chambers were in operation are presented below.

Table 12: Drying characteristics of sheet rubber dried under operational mode 03

Initial moisture content (wb) (%)	23.18
Moisture content at the end of the second day (before taking out from the first dryer)	3.92
Temperature maintained at first dryer (^{0}C)	(35 – 40)
Initial moisture content of sheets % (wb) when entered to the smoke drying unit	3.92
Temperature maintained at second dryer (^{0}C)	50 – 55
Time taken to achieve the complete dryness (hours)	Four days (2 days in hot air dryer) (two days in smoke dryer)
Firewood consumption (kg/kg)	0.68

Table 13: Raw rubber properties of sheet rubber dried under different conditions

Property	Sheet rubber dried at the traditional smokehouse	Sheet rubber first dried at hot clean air and subsequently dried using flue gas in chamber 2	Sheet rubber dried at single day smoke house
% Dirt content (w/w)	0.52	0.40	0.43
% Volatile Matter (w/w)	0.40	0.44	0.38
% Nitrogen content (w/w)	0.60	0.58	0.60
% Ash (w/w)	0.28	0.24	0.24
Initial plasticity number (Wallace units)	40	42	43
Plasticity Retention Index (PRI)	78	75	85

It is reported in literature that average firewood consumption in conventional and single day smoke drying units are 1 and 0.8 kg/kg of rubber dried respectively. In the new system, firewood consumption is lower than the firewood consumption in traditional smoke houses. Simultaneously, it has shown that same dryer could be used for drying of sheet rubber.

It can be seen from the raw rubber properties of the sheets, sheet rubber dried using three drying systems possesses comparable properties. It suggests that new drying system does not lead to inferior quality of the sheets. However, lower values of the plasticity index of sheets exposed to smoke only for a day (new system and single day drying system) than that of dried at the conventional smoke house may be probably due to the absorbance of higher content of antioxidant from smoke as sheets are exposed to smoke for an extended period of five days.

No estimation was carried out on labour requirement as it is evidenced that less labour hours are required for new drying system as sheets are moved on trolleys.

Drying temperature inside the dryer

Temperature profile inside the dryer throughout the drying period of sheet rubber, and temperature of the hot air at the source (near the hot air generator and the ambient air are recorded for drying in both hot air and smoke drying units are . shown in Figure 7. Drying temperature was recorded at the temperature air flow exit at the central ventilators installed at the dryer roof. A drying curve derived from the results obtained for pale crepe rubber is presented in Figure 8.

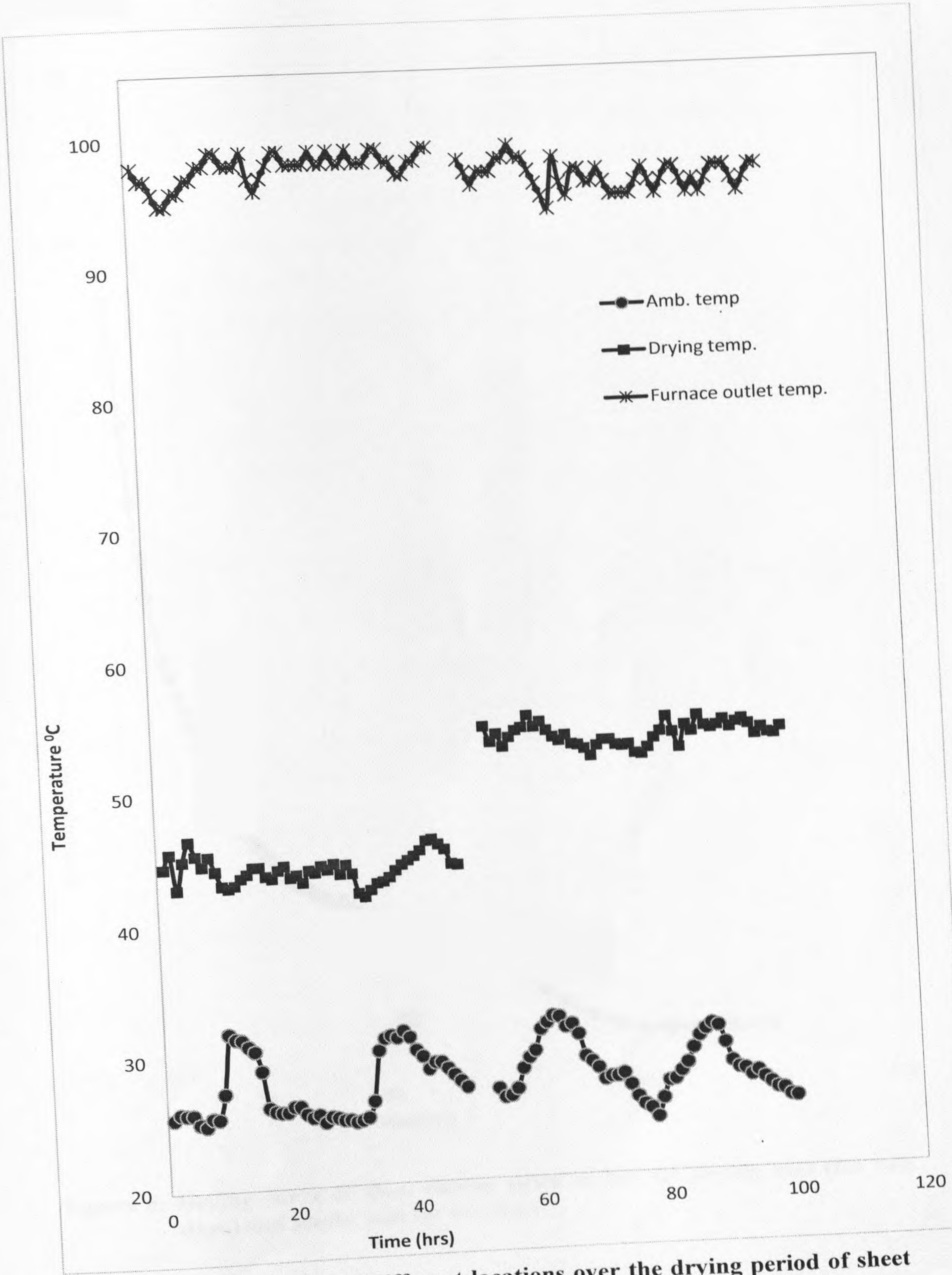

Figure 7: Temperature profile of different locations over the drying period of sheet rubber (Max 55.1 ^{0}C., min 41.0 ^{0}C, mean drying temp. 46.8 ^{0}C)

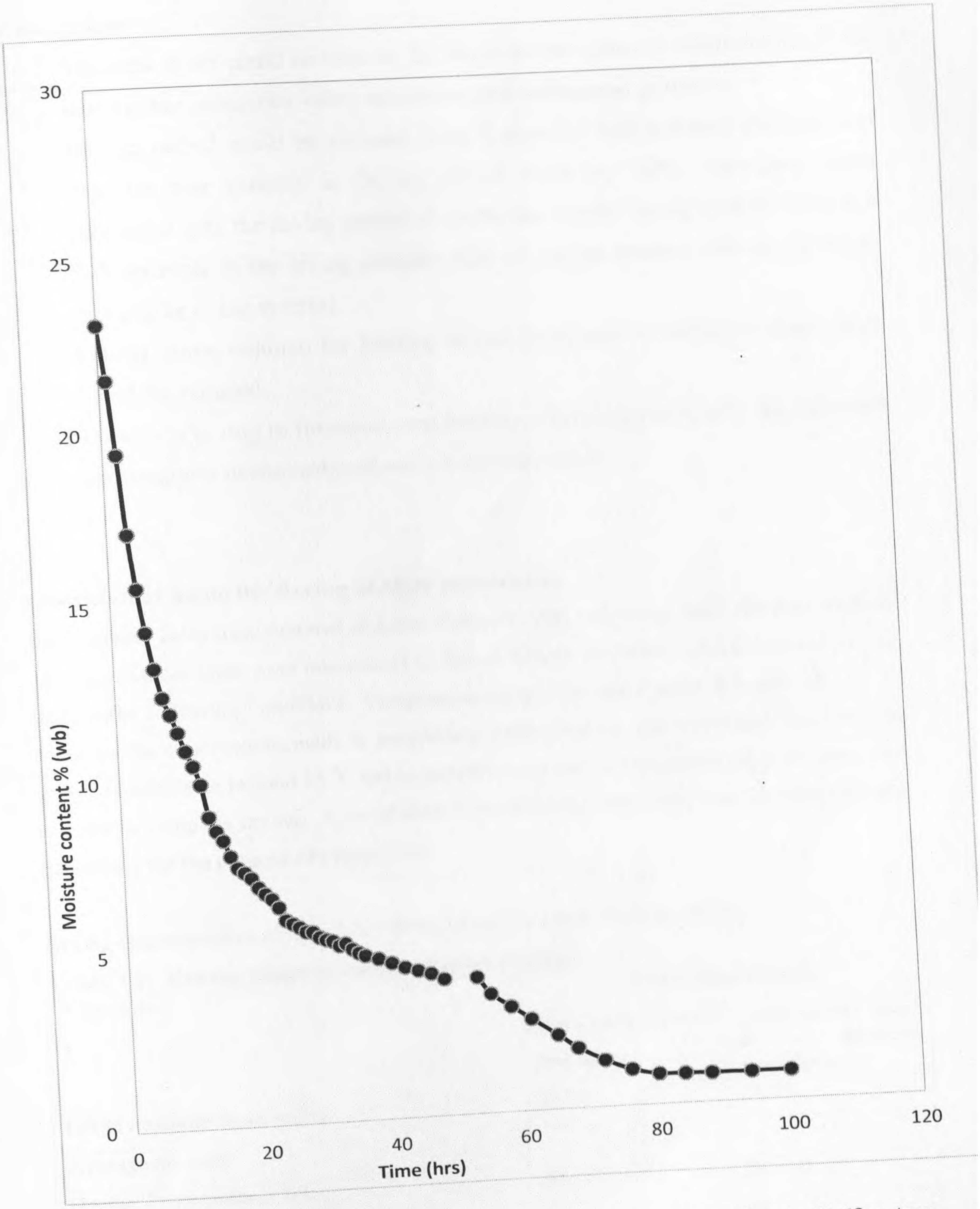

Figure 8: Drying curve of sheet rubber dried in hot air drying unit (for two days) and smoke unit for two days

Conclusions

The new dryer could be used to dry sheet rubber without deterioration of the raw rubber properties using recommended operational practices

Drying period could be reduced from 5 days (in conventional system) to 4 days (in new system), ie. Drying period could be 20%. However, when compared with the drying period of single day smoke drying system, there is a 80% increase in the drying period (4day in present system; one day in single day smoke dying system)

Labour hours required for loading of wet laces and unloading of dried laces could be reduced

There is a saving in firewood consumption when compared with the firewood consumption in conventional and SS drying system

Operational mode 04: drying of Skim rubber laces

Skim rubber laces manufactured at Lalan Rubbers (Pvt) Ltd. using their standard method. 465 kgs of these laces were transported to Sorana factory and were dried in the new drying unit under following conditions. Temperature range was maintained between 30 -35 ^{0}C based on the observations made in preliminary trials where it was found that exceeding of drying temperature beyond 35 ^{0}C led to melt the laces and consequently takes prolong time to achieve complete drying. A set of skim laces from the same batch was dried at ambient conditions for the purpose of comparison.

Drying characteristics of skim laces are tabulated in Table 14 given below.

Table 14: Drying characteristics of skim rubber

Parameter	Batch Identification	
	Skim laces dried at new dryer	Skim rubber dried at ambient conditions
Initial moisture content (%)	22.32	24.34
Average air flow		-
Drying Temperature (^{0}C)	30 - 35	28 - 30
Time taken to achieve the complete dryness (days)	01	03
Firewood consumption (kg/kg)	0.35	Nil

Raw rubber properties of skim laces were presented in Table 15. It should be noted that property variations in skim rubber is significant and values presented in the table are average value of three samples only.

Table 15: Raw rubber properties of skim laces

Property	Skim rubber dried in the new dryer	Skim rubber dried at ambient temperature
% Dirt content (w/w)	0.007	0.008
% Volatile Matter (w/w)*	3.9	3.6
% Nitrogen content (w/w)	1.92	1.94
Initial plasticity number (Wallace units)	53.0	57.0
Plasticity Retention Index (PRI)	51.0	62.0

*Higher than the final moisture content of at the end of the drying process as they absorb moisture from environment rapidly due to the availability of the hygroscopic non-rubber materials

Skim laces dried in the new dryer reached complete dryness within a day whereas sheets dried at ambient conditions took three days for complete drying. It is a 66% reduction in the drying period. However, new drying system requires 0.35 kg of firewood for drying of skim rubber in the new dryer whereas drying at ambient conditions requires no firewood. It should also note that drying period of skim laces dried at ambient conditions takes prolong time with simultaneous deterioration of quality of rubber during the unfavorable weather conditions.

It was also noted that colour of the laces dried in the dryer was superior to the laces dried at ambient conditions. Other raw rubber properties of the laces dried in both systems show comparable properties.

Drying temperature inside the dryer

Temperature maintained inside the dryer throughout the drying period of brown crepe rubber, and temperature of the hot air at the source (near the hot air generator and the ambient air are recorded. They are shown in Figure 9. Drying temperature was recorded at the temperature air flow exit at the central ventilators installed at the dryer roof. A drying curve derived from the results obtained for pale crepe rubber is presented in Figure 10.

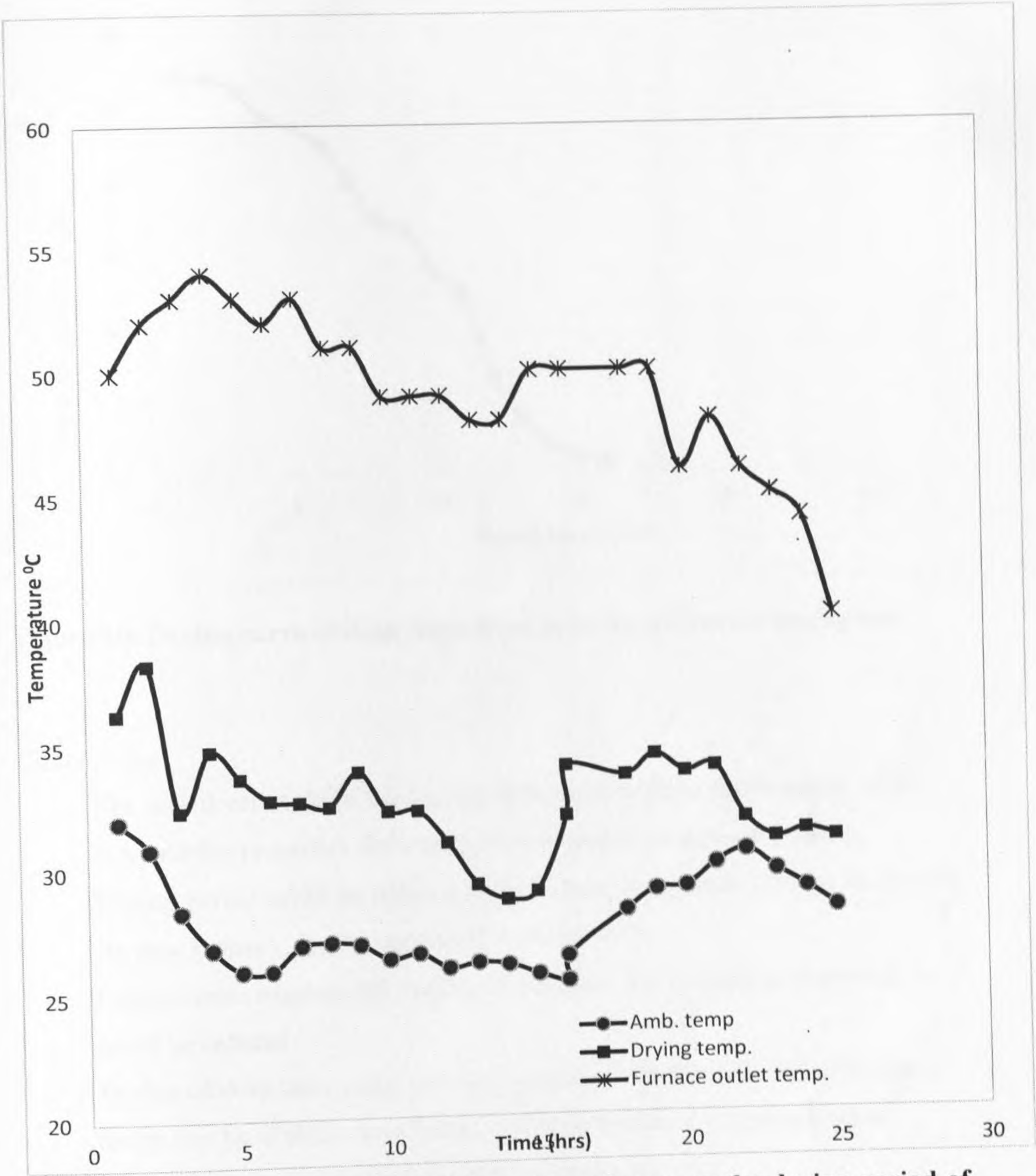

Figure 9: Temperature profile of different locations over the drying period of skim laces (Max. 38.3 ^{0}C, min 28.7 ^{0}C, mean drying temp. 32.67 ^{0}C) .

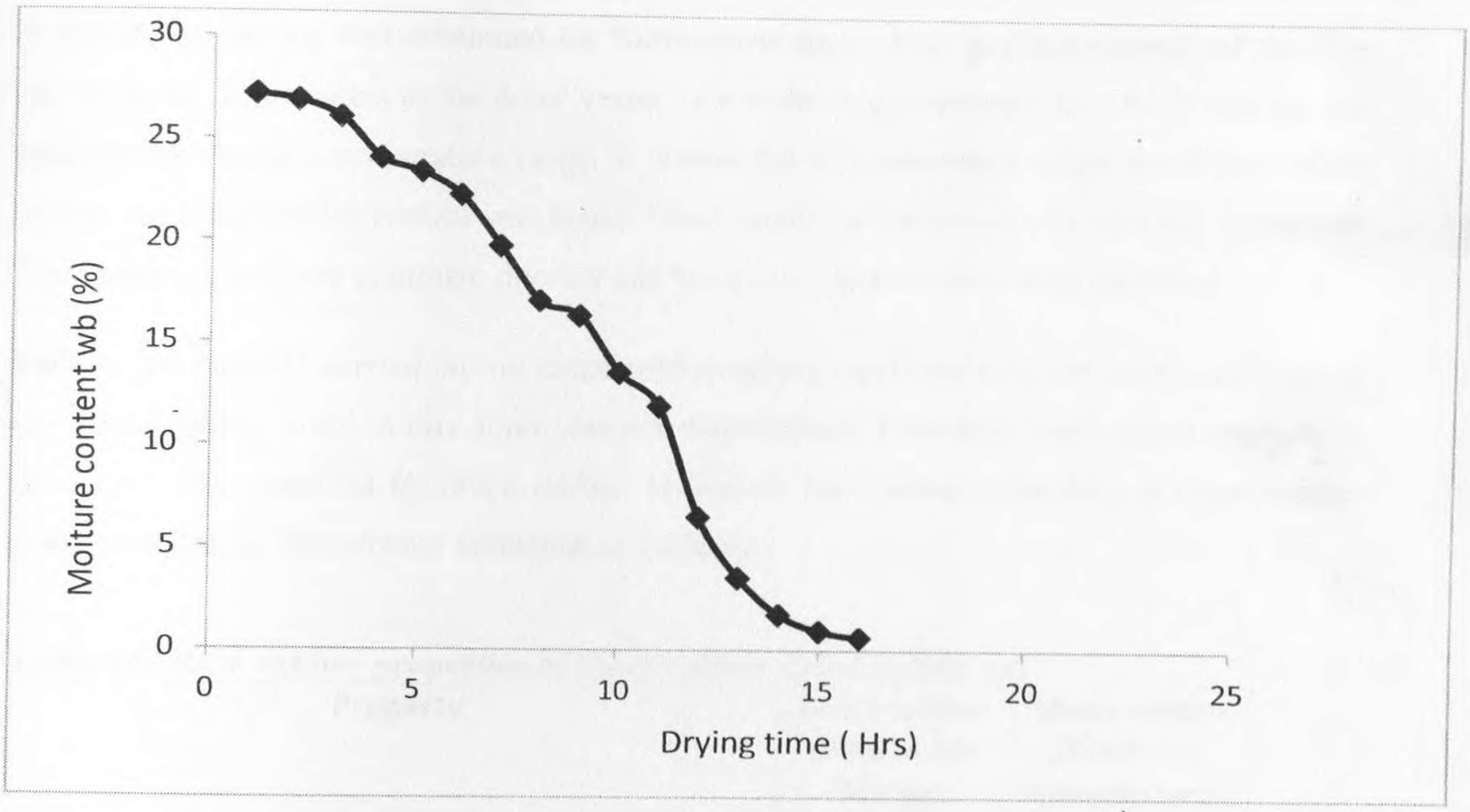

Figure 10: Drying curve of skim crepe laces dried in the hot air drying unit

Conclusions

The new dryer could be used to dry skim laces without deterioration of the raw rubber properties following recommended operational practices

Drying period could be reduced from 7 days (in ambient drying) to one day (in new system) , ie. Drying period could be 85%.

Labour hours required for loading of wet laces and unloading of dried laces could be reduced

Drying of skim laces using new drying system requires 0.35 kg of firewood to dry one kg of skim crepe laces , where no firewood is required when conventional drying system (ambient air drying) is used

Operational mode 5: Simultaneous drying of crepe rubber and sheet rubber

Crepe rubber (500 kg) manufactured at Sorana rubber factory and sheet rubber manufactured (500 kg) at Dartonfiled rubber factory were simultaneously loaded hot air treated dryer (dryer 01) and flue gas heated dryer (dryer 2) respectively. Temperature of hot air heated dryer was maintained between 32-36 ^{0}C which is the recommended temperature for drying of crepe rubber. Upon completion of drying of first batch of crepe rubber in two days, another batch of wet crepe is entered in to the dryer while sheet rubber in the smoke drying unit continued for further two days. Flue gas temperature of the flue gas received at the inlets to the dryer varies in a wide range between 45 – 60 ^{0}C during the experiment. As this temperature range is within the recommended range for drying sheet rubber, no temperature control was made. Final quality of products was visually inspected. Time taken to achieve complete dryness and firewood consumption were recorded.

Earlier experiments carried out on crepe rubber drying confirms that raw rubber properties of crepe rubber dried in this dryer was not deteriorated. Therefore, only visual inspection on colour was observed for crepe rubber. However, raw rubber properties of sheet rubber dried were tested. Results are tabulated in Table 16.

Table 16: Raw rubber properties of sheet rubber dried in flue gas

Property	sheet rubber dried in the flue gas heated dryer	Sheet rubber dried in a conventional smoke house
% Dirt content (w/w)	0.61	0.52
% Volatile Matter (w/w)	0.46	0.40
% Nitrogen content (w/w)	0.52	0.60
% Ash (w/w)	0.25	0.28
Initial plasticity number (Wallace units)	42	40
Plasticity Retention Index (PRI)	84	78

It can be seen that raw rubber properties are not adversely affected when sheet rubber is dried completely in flue gas heated dryer (dryer 2).

When consider the drying period, it takes four days for complete drying of sheet rubber. Since flue gas generated is used for drying of sheet rubber, no additional firewood is required. Therefore, simultaneous drying of crepe rubber and sheet rubber offers a 100% reduction in firewood consumption when firewood requirement for total rubber (crepe rubber and sheet rubber) is considered. Since both capacity of the dryers and the drying period of RSS is twice as crepe drying the firewood consumption could be estimated as the half of the fire wood consumption in crepe rubber drying alone. ie. 0.09 kgs of fire wood for one kg of rubber (crepe and RSS)

Conclusions

Crepe rubber and sheet rubber could be dried simultaneously and separately in two dying compartments of the dryer. This operation requires zero firewood consumption for drying of sheet rubber as they are dried using waste energy available in flu gas generated during heat generation process for drying crepe rubber.

Operational mode 6: Simultaneous drying of crepe rubber and brown crepe rubber

Crepe rubber (500 kg) and brown crepe (250 kg) manufactured at Sorana rubber factory were simultaneously loaded hot air treated dryer (dryer 01) and flue gas heated dryer (dryer 2) respectively. Temperature of hot air heated dryer was maintained.between 32-36 ^{0}C which is the recommended temperature for drying of crepe rubber. Flue gas temperature of the flue gas received at the inlets to the flue gas heated dryer (dryer 2) bring down to 40 ^{0}C by diluting flue gas with ambient air though adjusted air inlets. Final quality of products was visually inspected. Time taken to achieve complete dryness and firewood consumption were brown crepe rubber dried were tested. Results are tabulated in Table 15.

Table 17: Raw rubber properties of Brown crepe laces dried in flue gas

Property	Brown crepe laces dried in the flue gas heated dryer	Brown crepe rubber dried at ambient temperature
% Dirt content (w/w)	0.82	0.800
% Volatile Matter (w/w)	1.42	1.40
% Nitrogen content (w/w)	0.36	0.39
% Ash (w/w)	0.98	0.94
Initial plasticity number (Wallace units)	43	48
Plasticity Retention Index (PRI)	62	54

It can be seen from the properties presented in the Table that raw rubber properties are not adversely affected when brown crepe rubber is dried completely in flue gas heated dryer (dryer 2).

When consider the drying period, it takes three days for complete drying of the laces. Since flue gas generated is used for drying of brown crepe laces, no additional firewood is required. Since the capacity of the brown crepe loading (in smoke unit) : crepe rubber loading (in hot air drying unit) is 1:2 and drying periods for brown crepe: pale crepe is 3:2, it could be estimated that fire wood consumption is 3/4 of the fire wood consumption of crepe rubber per kg of total rubber (crepe and brown) dried simultaneously.

Conclusions

Crepe rubber and brown crepe laces could be dried simultaneously and separately in two dying compartments of the dryer. This operation requires zero firewood consumption for drying of brown crepe as they are dried using waste energy available in flu gas generated during heat generation process for drying crepe rubber.

5.2 THERMAL STUDIES

(A). Verification of dryer temperature and air flow rates at different locations in the empty dryer

Hot air temperature at different locations (A, G and B) of the empty drying chamber 01 is verified for 50 hours after reaching the steady state. Data obtained were graphically presented in Figure 11. It can be seen that heat enters to the dryer is equally distributed in the dryer as the inlet temperatures at the both points have shown almost similar values. Temperature at G always shows a lower temperature than the inlet temperatures probably may be due to the dilution effect and heal losses.

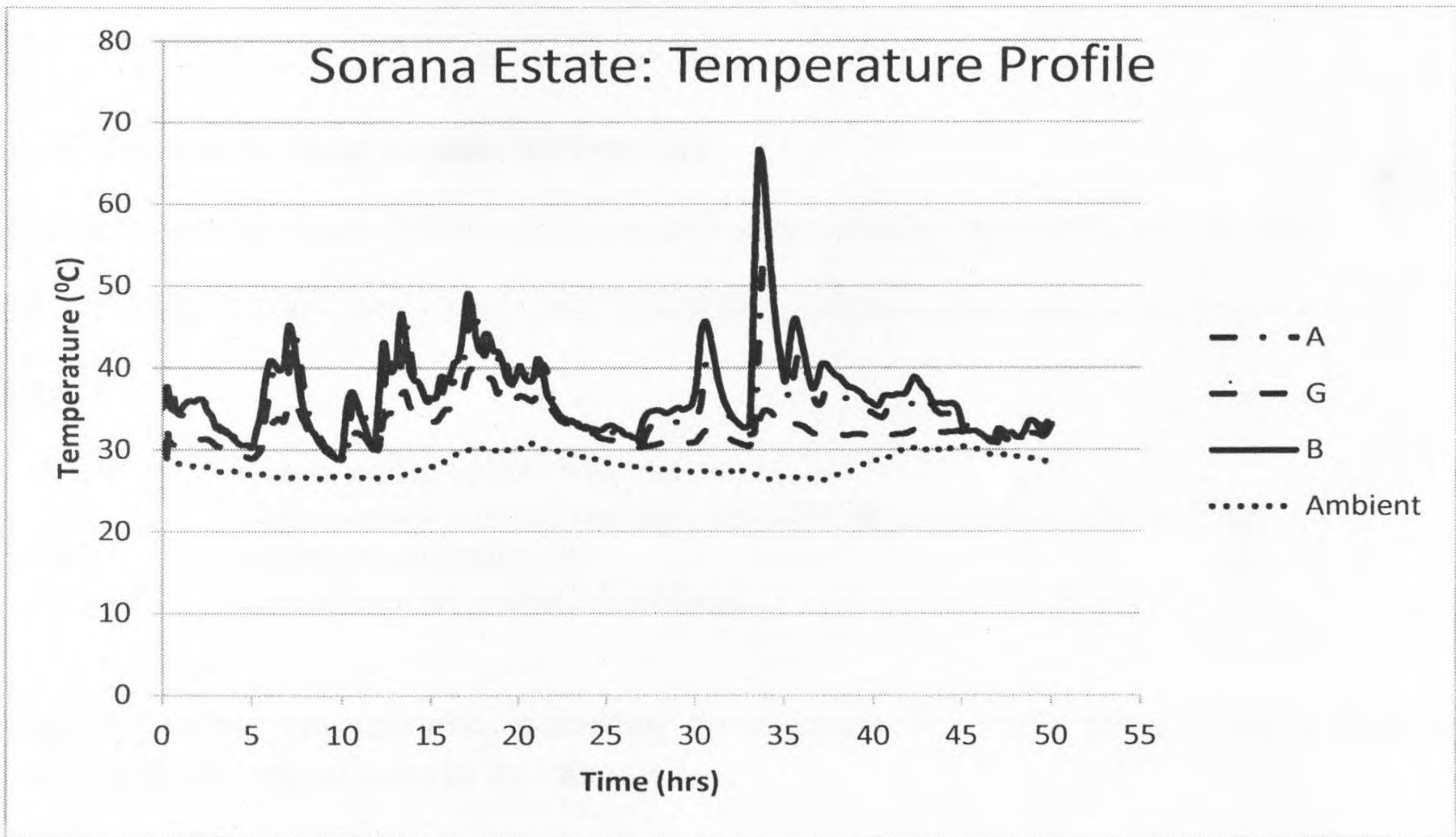

Figure 11: Temperature variations at different locations of the empty dryer

Air flow rates at different locations were also studied. They were shown in the following Table (Table 18). There is a slight difference in the total air out flow and the inflow which may due to the unaccounted air inflows from the surrounding when the total air flow is calculated.

Table 18: Average air flow rates at different locations of the empty dryer

Location	Air velocity (m/s)	Area (m^2) $x10^{-4}$	Air flow rate (m^3/s)
Air inlets			
Right corner of the dryer (A) (No. of out let -02)	3.2	367	0.1176
Middle of the dryer (B) No. of outlets -02	6.4	234	0.1497
Left corner of the dryer (C) No. of outlets - 02	3.2	392	0.1252
Air outlet			
Middle flap of the dryer (G) No. of outlets -5 (half opened)	0.45	3600	0.162

B. Estimation of heat content in firewood

The net calorific value (NCV) of firewood estimated using the following equation.

$$NCV = HEC\,[(100 - MC)/100] - MC/100 * LH_{H20} \quad \text{--} \quad 1$$

where

NCV	Net calorific value of firewood
HEC	High energy content (energy for oven dry firewood) (19 MJ/ kg)
MC	Moisture content (wb)
LH_{H20}	Latent heat of water(2.8 MJ/kg)

Calorific values are estimated according the equation No 1 and given in the following Table with the values used in the calculations.

Table 19: Net calorific value of firewood used

HEC (MJ/ kg)	19
MC	24
LH_{H20} (MJ/kg)	2.8
NCV MJ/kg	14.64

(C). Energy requirement for drying of rubber

The total heat requirement for drying of rubber in a dryer could be expressed by the following equation.

$$Q_{TOT} = Q_{EM} + Q_{HL} + Q_{sr} + Q_{som} \quad (2)$$

Where

Q_{TOT} Total heat requirement.

Q_{EM} Heat requirement to evaporate moisture and to rise the temperature of the moisture to drying temperature.

Q_{HL} Heat required to compensate heat losses from the dryer surfaces

Q_{sr} Heat required to raise the temperature of rubber laces from the ambient temperature to the drying temperature.

Q_{som} Heat required to raise the temperature of other materials such as timber racks from the ambient temperature to the drying temperature.

Q_{som} was not considered in this study as this energy is not used for drying operation and is assumed to be negligible.

(C.1). Energy Requirement to Evaporate Moisture (Q_{EM})

As in other agricultural crops, crepe laces contain surface moisture and internal bound and unbound moisture. The surface moisture is removed first. Internal moisture requires sufficient heat to form water vapour and diffuses it to the surface. When the interior moisture content decreases gradually, the heat required to diffuse internal moisture gradually increases. Therefore, latent heat of free water, often taken from steam tables cannot be used in this calculation. Hall (1962) has increased latent heat by the sorption factor of 1.15 and has used this figure in calculations of removing moisture from agricultural crops. Q_{EM} could be calculated using this value and following formula.

$$Q_{EM} \quad M_W \times [C_p x(T_{dry}-T_{amb})+ (L \times f)] \quad (3)$$

$$M_W \quad M^*[(MC_i /(100-MC_i) - MC_f/(100-MC_f)] \quad (4)$$

Where:

M_W	-	mass of the moisture to be remove
M	-	mass of the dry rubber
MC_i	-	initial moisture content (wb)
MC_f	-	final moisture content (wb)
L	-	approximate latent heat of water (2400 kJ/kg ^oC)
F	-	sorption factor (1.15) (considered same for all grades of rubbers)
C_p	-	Specific heat of the water
T_{dry}	-	drying temperature (^oC)
$T_{amb.}$	-	ambient air temperature

Table 20 shows the heat requirement for removal of water from different rubbers determined using equation 3 and 4.

Table 20: Heat requirement for removal of water from the rubber

Parameter	Crepe rubber laces	Sheet rubber	Brown crepe laces	Skim rubber laces
M (kg)	500	1,250	340	465
MC_i (%)	14.27	23.18	18.3	22.32
MC_f	0.3	0.8	0.72	0.63
Moisture to be removed (kg)	96	439	74	171
T_{dry} (^{0}C)	34	50	33	33
T_{amb} (^{0}C)	28	28	28	28
C_p (M/kg.k)	0.0042	0.0042	0.0042	0.0042
L of water (KJ/kg)	2.26	2.26	2.26	2.26
F	1.15	1.437*	1.15	1.15
Q_{EM} (MJ)	251.92	1467.27	193.08	448.02

* sheet rubber is four times thicker than the laces and hence value L is multipied by a factor of 1.25

C.2 Energy Requirement to Compensate Heat Losses (Q_{HL})

The equation for heat losses from the drying tower over the drying period is

$$Q_{HL} = U \times A \times (T_I - T_O) \times N \qquad (5)$$

Where U – overall heat loss coefficient of the drying chamber including the floor

(See Appendix 5) (kJ/m^{2}hK)

A – total surface area of drying tower including the floor (m^2)

T_I - inside temperature of drying chamber (^{o}C).

T_O - ambient temperature (^{o}C).

N - drying period (hours).

Average ambient air temperature was assumed to be 28 ^{o}C. T_I is equal to the drying temperature. U and A values of the drying chamber differ for the designs depending on the structure and the construction materials of the chamber. The Q_{HL} calculated by using the equation (5) using the parameters given in Table 21 for U and A values.

Table 21: Total heat loss of the dryers during drying of different rubber

Design	Area (A) (m^2)	Heat loss coefficient (U) (MJ/m^2hK)	Heat requirement Q_{HL}			
			Crepe rubber (34 °C, 2)	Sheet rubber (50 °C - 2+2)	Brown crepe laces (33 °C- 3).	Skim rubber laces (33 °C - 1)
Hot air drying unit	46.37	0.0036	48.07	176	60.09	20.03
Smoke drying unit	39.06	0.0036	-	148	-	-
Total	-	-	48.07	364.73	60.09	20.03

( ): average drying temperature inside the dryer and drying period in days
Ambient temperature: 28 °C

D.3 Requirement to raise the temperature of rubber to drying temperature from the ambient temperature (Q_{sr})

The equation to calculate heat losses from the drying tower over the drying period is given by the following equation.

$$Q_{SR} = M \times Cp \times (T - T_{amb}) \qquad 6$$

Where

Q_{SR} Total heat requirement
M Mass of the dry rubber
Cp Specific heat capacity
T Average drying temperature
T_{amb} Ambient temperature

Energy requirement to raise the temperature of rubber inside the dryer to drying temperature from ambient temperature is tabulated in Table 25.

Table 22: Energy requirement to raise the temperature of rubber to drying temperature

	Crepe rubber laces	Sheet rubber	Brown crepe laces	Skim rubber laces
Mass of rubber (kg)	500	1250	340	465
Heat capacity of rubber (KJ/kg of rubber)	1.88	1.88	1.88	1.88
Average Drying temperature (^oC)	34	50	33	33
Ambient* temperature (^oC)	27	27	28	28
Energy requirement (MJ)	6.58	54.05	3.12	4.37

* *Average value of the experimental data on the specific day on which drying of respective dry rubber is carried out.*

C.4 Total Energy Demand

Total energy demands calculated by equation (2) for each design are presented in the Table 22.

Table 23: Total energy demand for drying of different rubber

Type of rubber	Quantity of dry rubber being dried (kg)	Q_{EM} (MJ)	Q_{HL} (MJ)	Q_{SR} (MJ)	Total energy requirement (MJ)	Energy requirement for drying of unit weight of rubber (MJ/kg)
Crepe rubber	500	251.92	48.07	6.58	306.57	0.613
RSS	1250	1467.27	364.73	54.05	1886.05	1.51
Brown crepe	340	193.88	60.09	3.12	257.09	0.756
Skim crepe	465	448.02	20.03	4.37	472.42	1.02

(D). Drying efficiency at each operational mode

Drying efficiency at each operation mode in this study is defined as the ratio,

Total useful energy consumed for drying of rubber
Total heat content of fire wood burnt in the boiler

Data required for determination of drying efficiency were taken from the experimental results reported in earlier sections

Table 24: Drying efficiencies of different operational modes

Operational mode	**Description**	**Energy requirement for drying of rubber (MJ)/kg**	**Fire wood consumption (kg)/kg of (conventional)**	**Energy content supplied from fire wood (MJ)/kg of rubber**	**Energy efficiency % (conventional)**
Operational mode 01	Hot air drying of brown crepe rubber	0.756	0.20	14.64*0.20 =2.928	26%
Operational mode 02	Hot air drying of pale crepe rubber	0.613	0.175 **(0.2)**	14.64*0.175 = 2.562 **(14.64*0.20 = 2. 93)**	24% **(21%)**
Operational mode 03	Hot air drying of sheet rubber for two days and smoke drying in the smoke drying unit for 2 days	1.51	0.68 **(1.0)**	14.64x0.68 = 9.96 **(14.64*01= 14.64)**	15.16 **10%.**
Operational mode 04	Hot air drying of skim rubber	1.02	0.35	14.64x 0.35 = 5.124	20%
Operational mode 05[1]	Simultaneous drying of crepe rubber and sheet rubber	0.91	0. 12	14.64x 0.12 =1.757	51%
Operational mode 06[2]	Simultaneous drying of crepe rubber and brown crepe rubber	0.65	0.131	14.64x0.131 = 1.92	34%

1. *Firewood consumption/kg of rubber (RSS + crepe) being dried = 0.175*2/3 = 0.12*
   *Energy requirement/kg of rubber (RSS+ crepe) = (0.613*2 +1.51*1)/3 = 0.91*
2. *Firewood consumption/kg of rubber being dried (crepe +brown) = 0.175*3/4 = 0.131*
   *Energy requirement/kg of rubber (crepe + brown) = (0.613*3 +.756*1)/4 = 0.65*

5. Conclusions

The hybrid dryer developed for drying of rubber could be used to dry different types of rubber simultaneously or separately in a user friendly manner.

A comparison of average drying efficiencies of the new dryer with respect to different efficiency parameters is as follows

Rubber type	Energy efficiency		Firewood use efficiency		Drying period effciency	
	New system (%)	Conventional process (%)	New system Kg/kg of rubber dried	Conventional process	New system (days)	Conventional process
Crepe	24	21	0.175	0.20	2	3
Sheet	15	10	0.68	1.0	4	5
Brown	26	-	0.175	-	3	7-10
Skim rubber	20	-	0.35	-	1	3.7
Simultaneous drying of crepe rubber and sheet rubber	51%	-	0.91	-		2/4
Simultaneous drying of skim and brown crepe rubber	34%	-	0.13	-		1/3

It could be noted that simultaneous drying where flue gas is used for drying gives higher energy efficiencies showing the advantage of the heat content of the flue gas.

6. Final Conclusion

The hybrid dryer developed for drying of rubber could be used to dry different grades of rubber simultaneously in a user friendly manner with higher or comparable total drying efficiency to the drying efficiency of the conventional drying systems in a shorter drying period.

7. References

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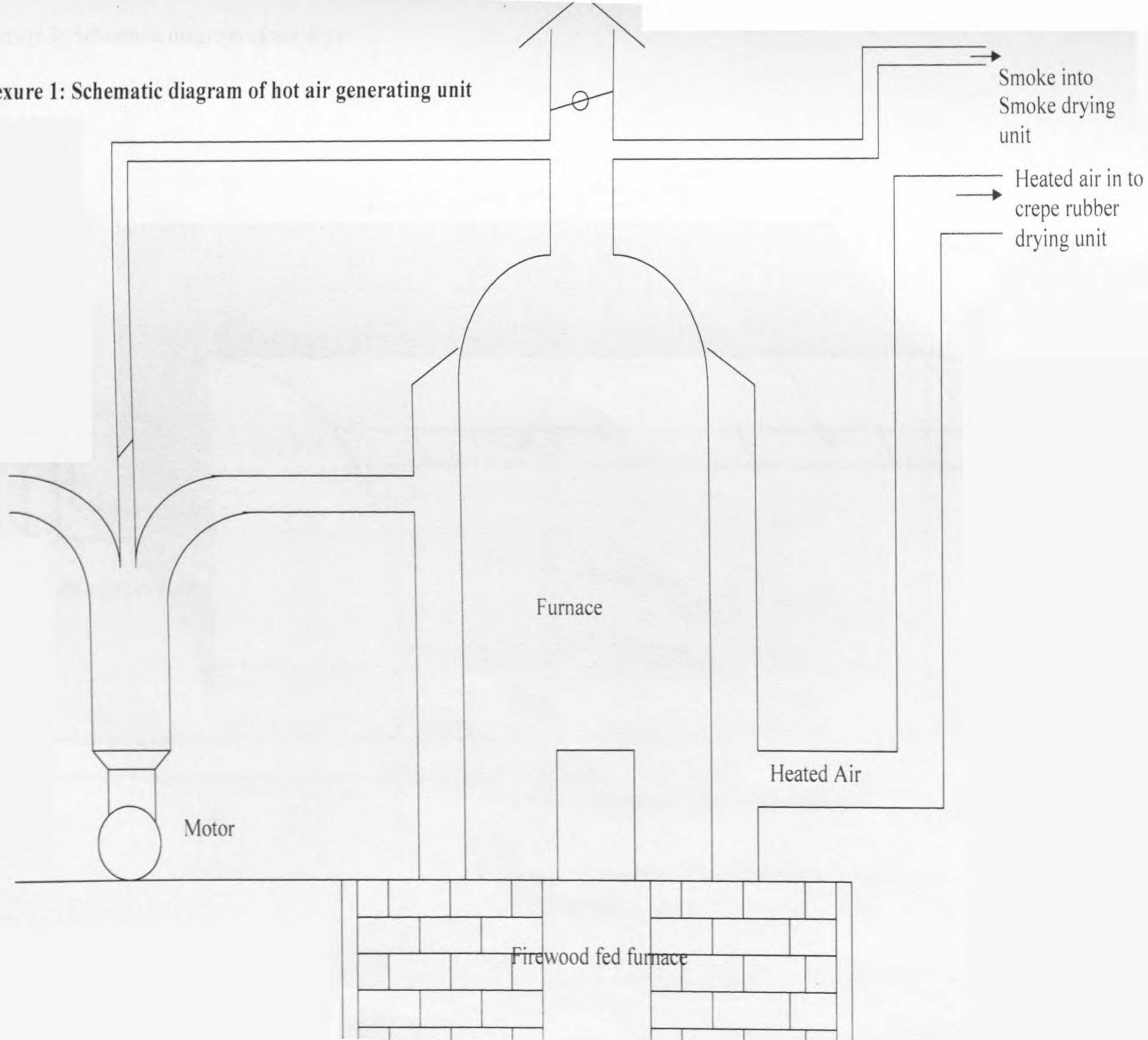
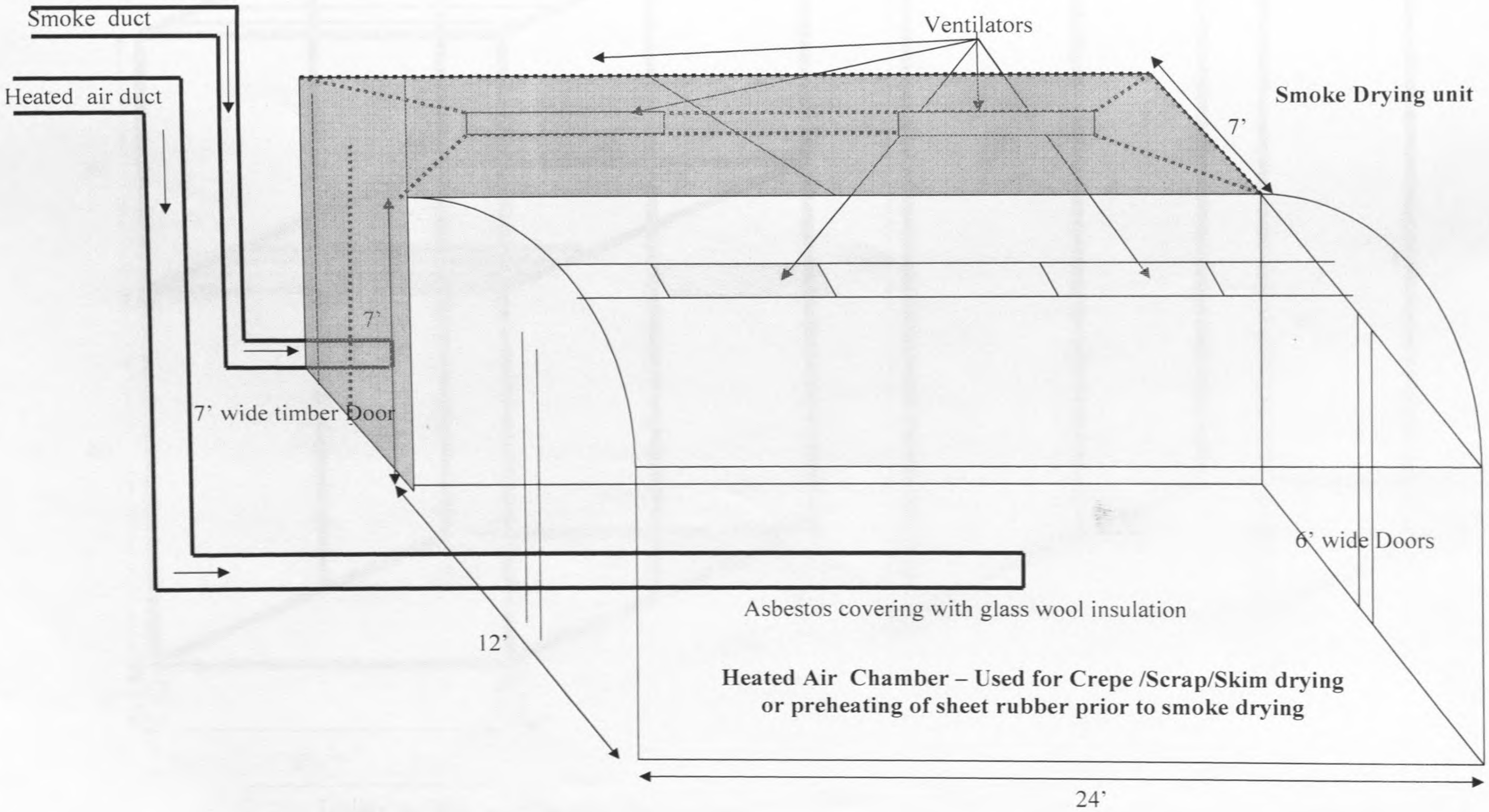
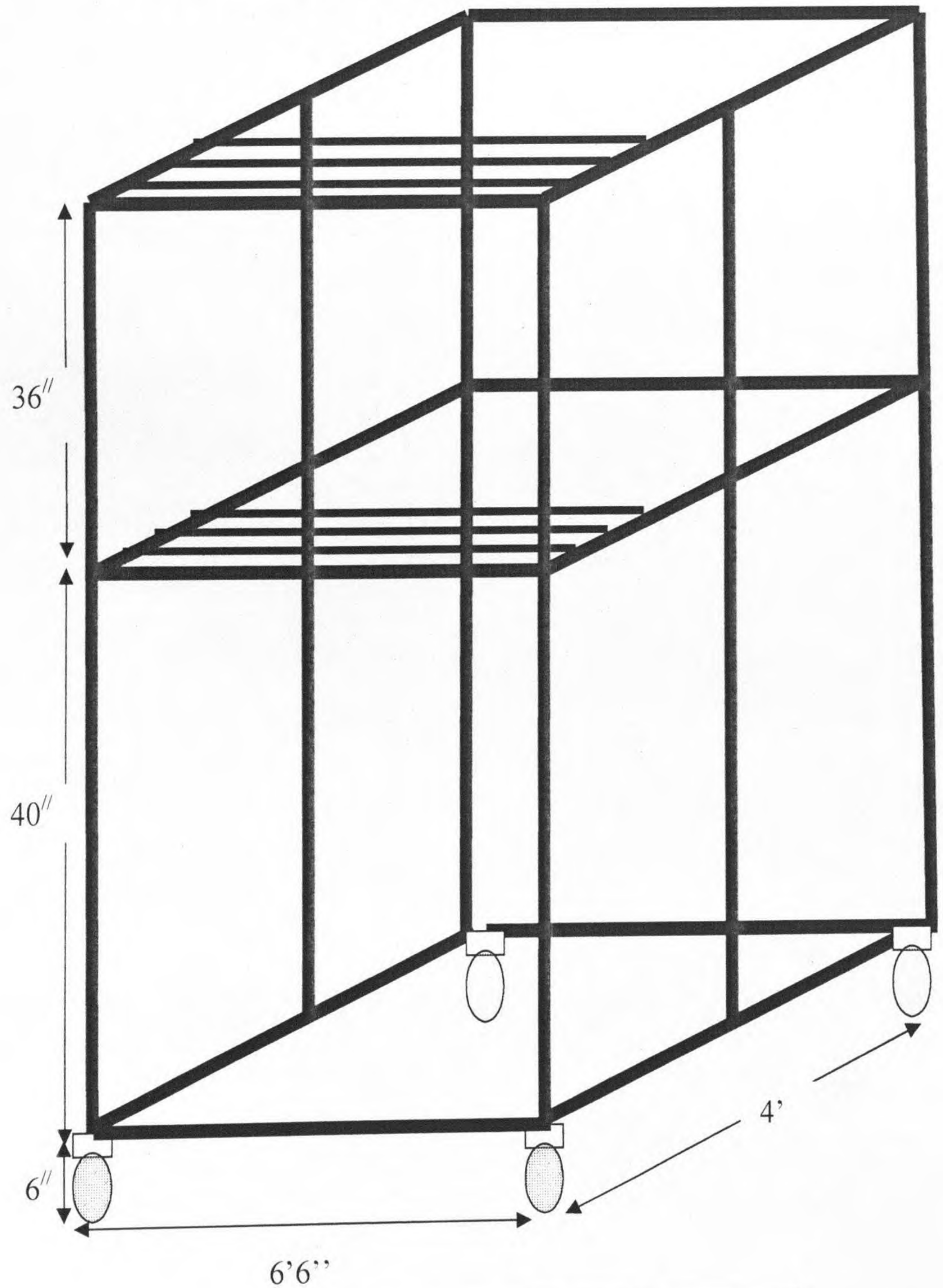
Annexure 1: Schematic diagram of hot air generating unit



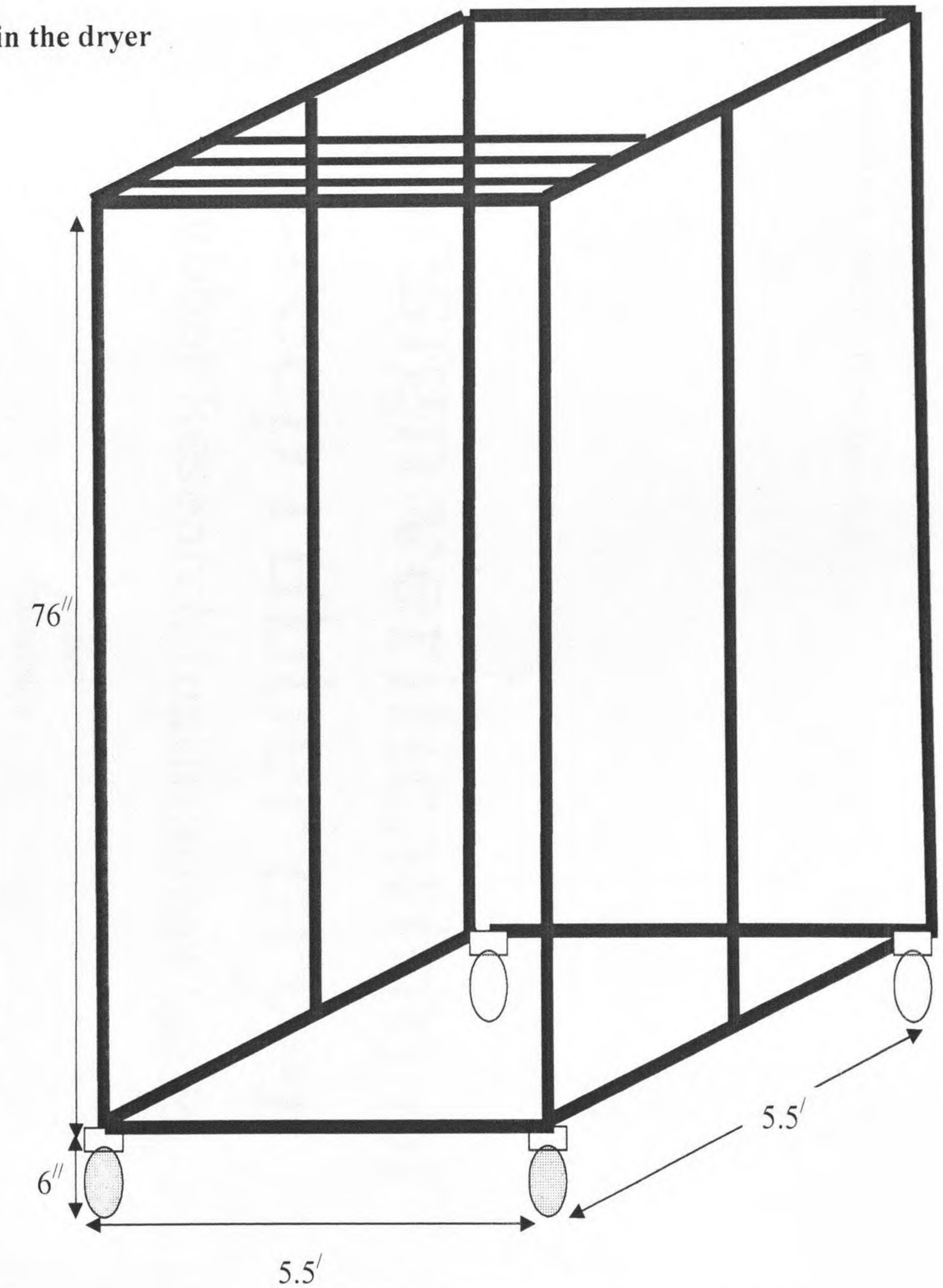
Annexure 2: Schematic diagram of the dryer



Annexure 3: Design of trolleys used to hang the sheets and laces in the dryer



Trolley for RSS – 125kg - 04Nos



Trolley for Crepe – 62.5kg - 08Nos

Design verification of creep rubber dryer

Rubber Research Institute Sri Lanka

Dell

9/1/2013

INTRODUCTION

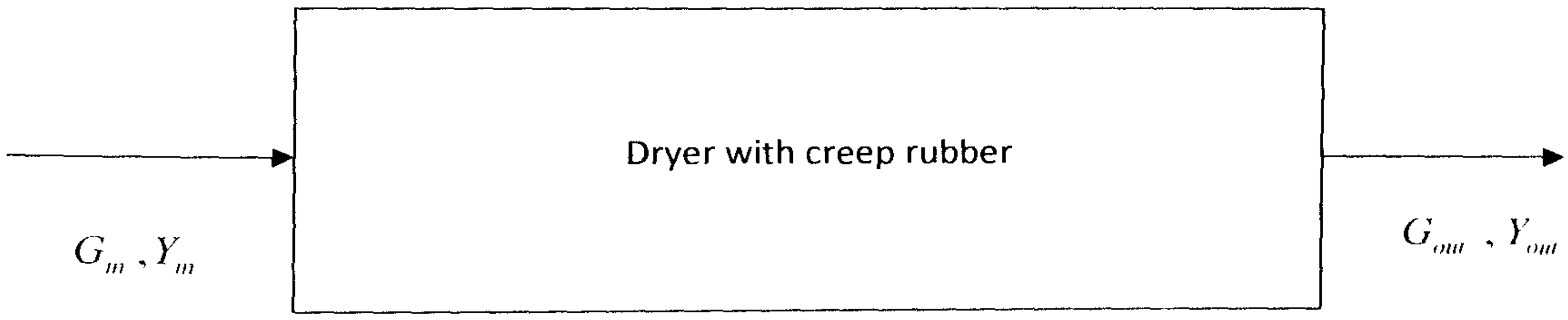
Dryers are used in rubber industry to remove the moisture of raw rubber sheets before it is used in different applications. In this study, currently operating dryer was mathematically modeled for design verifications.

MODEL DEVELOPMENT

Design parameters

Creep rubber	
Moisture content	**12 % (wet basis)**
Final moisture content	**0.2 % (wet basis)**
Drying time	**24 hr**
Batch size	**500 kg**

Material balance



Dry basis initial and final moisture contents per unit weight of rubber

$$12\% = \frac{x_i}{x_i + 1} \times 100\%$$

$$x_i = 0.136$$

$$0.2\% = \frac{x_o}{x_o + 1} \times 100\%$$

$$x_o = 0.002$$

$$\frac{dm}{dt} = \dot{m}_{in} - \dot{m}_{out}$$ For the moisture

$$\frac{dm}{dt} = G_{in} \times Y_{in} - G_{out} \times Y_{out}$$

Where: G_{in} Gas input flowrate

G_{out} Gas output flowrate

Y_{in} Input moisture of gas

Y_{out} Output moisture of gas

$$\frac{dm}{dt} = G_{in}(Y_{in} - Y_{out})$$

Energy balance

$G_{in} H_{g\,in} = G_{out} H_{g\,out} + Q_{ll}$

$Q_{ll} = 0.05 G_{in} H_{g\,in}$ Assumes that heat loss to wall is taken as 5% of the enthalpy of inlet air:

$$H_{g\,in} = (c_{pg} + Y_{in}c_1)T_{g\,in} + Y_{in}\lambda$$

$$H_{g\,out} = (c_{pg} + Y_{out}c_1)T_{g\,out} + Y_{out}\lambda$$

$T_{g\,in} = 40\ ^oC \quad and \quad T_{g\,out} = 34\ ^oC$

$$(c_{pg} + Y_{in}c_1)T_{g\,in} + Y_{in}\lambda = (c_{pg} + Y_{out}c_1)T_{g\,out} + Y_{out}\lambda + 0.05[(c_{pg} + Y_{out}c_1)T_{g\,out} + Y_{out}\lambda]$$

$$(1 + 0.005 \times 4.2) \times 40 + 2370 \times 0.005 = (1 + Y_{out} \times 4.2) \times 34 + Y_{out} \times 2370 + 0.05((1 + Y_{out} \times 4.2) \times 40 + Y_{out} \times 2370)$$

$Y_{out} = 0.0064$

$$\frac{dm}{dt} = \frac{(x_{out} - x_{in}) \times F}{t}$$

$$\frac{dm}{dt} = \frac{(0.002 - 0.136) \times 500}{24 \times 60 \times 60} = -7.75 \times 10^{-4}$$

$$G_{in}(Y_{in} - Y_{out}) = -7.75 \times 10^{-4}$$

$$G_{in} = 0.553\, kg/s$$

Through the mathematical modeling, it was found that the required air flow rate into the dryer is 0.553 kg/s.

Design of combustion chamber

Overall heat transfer coefficient is taken as 8 w/m^2.K

Heat is generated through the combustion of biomass and transferred to the gas via a heat exchange. Heated gas is sent into the dryer after heated up to a temperature of 40 ^{0}C. The rate of heat transfer **Q** can be calculated as follows.

$$Q = G_m C_p \Delta T$$

C_p = *Specific heat capacity of air*
ΔT = *Temperature difference*

$$Q = 0.553 \times 1.01 \times (40 - 30)$$

Room Temperature is 30 ^{0}C

$$Q = 5.59\ kJ/s$$

Heat loss $\mathbf{Q}_L$ by the heat exchanger to the surrounding is taken as 10 % of the transferred heat

$$Q_L = 0.559\ kJ/s$$

Total heat generated by the combustion chamber

$$Q_{Total} = Q + Q_l$$

$$Q_{Total} = 6.15 kJ/s$$

Calorific value C_v of the biomass is 3.5 KWh/kg (12600 kJ/kg)

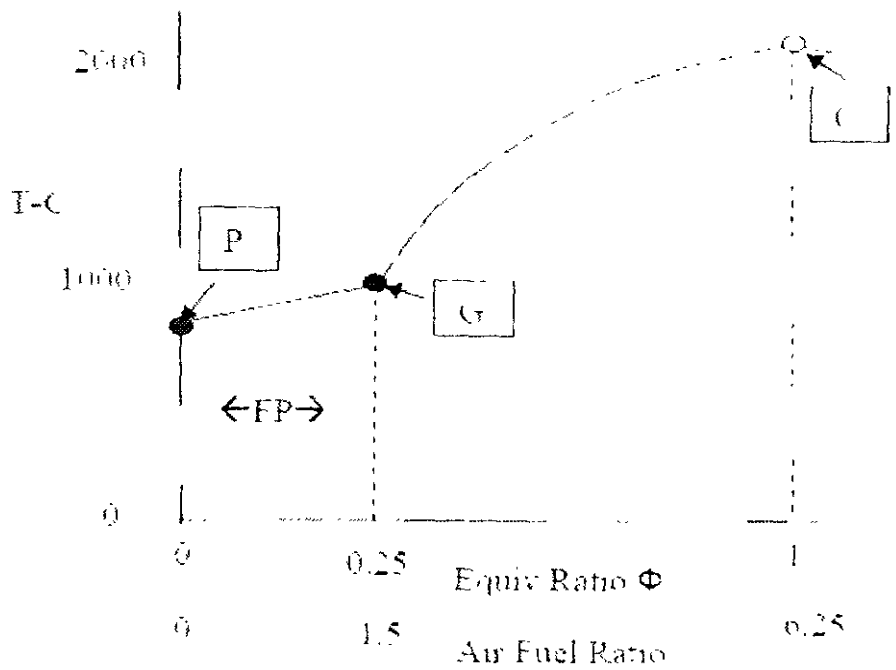
The rate of fuel (biomass) combustion in the combustion chamber $\mathbf{m_f}$

$$Q_{Total} = m_f C_v$$

$$m_f = 1.75 kg/hr$$

Air to fuel ratio for the complete combustion of biomass is 6.3

The equivalent ratio of the combustion is selected as 1.25 and assumed the flame temperature around 1800 ^{0}C



THE EQUIVALENCE RATIO AND AIR FUEL DIAGRAM

(Air/Fuel values shown for biomass)

$$\frac{\left(A/F\right)_{Actual}}{\left(A/F\right)_{Stoic}} = \phi\left(Equivelent\ ratio\right)$$

$$\left(A/F\right)_{Actual} = 1.25 \times 6.3$$

$$m_{air} = 1.75 \times 1.25 \times 6.3$$

$$m_{air} = 13.8\ kg/hr$$

Calculation of heat transfer area

$$Q = U \times A \times LMTD$$

A is the heat transfer area

Assume that heat is transferred until flue gas temperature comes to 600 ^{0}C

$$LMTD = \frac{(1800-40)-(600-30)}{\ln\frac{(1800-40)}{(600-30)}}$$

$$A = \frac{5.59}{8 \times 1056}$$

$$A = 0.66m^2$$

Due to the heat losses to the surrounding, it is recommended to construct the heat exchanger with heat transfer area of 1 m^2.

Design verification of RSS dryer

Design parameters

Creep rubber	
Moisture content	**25 % (wet basis)**
Final moisture content	**0.7 % (wet basis)**
Batch size	**500 kg**

Material balance

Dry basis initial and final moisture contents

$$25\% = \frac{x_i}{x_i + 1} \times 100\%$$

$$x_i = 0.33$$

$$0.7\% = \frac{x_o}{x_o + 1} \times 100\%$$

$$x_o = 0.007$$

$$\frac{dm}{dt} = \dot{m}_{in} - \dot{m}_{out}$$ For the moisture

$$\frac{dm}{dt} = G_{in} \times Y_{in} - G_{out} \times Y_{out}$$

Where: G_{in} Gas input flowrate

G_{out} Gas output flowrate

Y_{in} Input moisture of gas

Y_{out} Output moisture of gas

$$\frac{dm}{dt} = G_{in}(Y_{in} - Y_{out})$$

Energy balance

$$G_{in} H_{g,in} = G_{out} H_{g,out} + Q_{ll}$$

$Q_{ll} = 0.05 G_{in} H_{g,in}$ Assumes that heat loss to wall is taken as 5% of the enthalpy of inlet air:

$$H_{g\,in} = \left(c_{pg} + Y_{in}c_1\right)T_{g\,in} + Y_{in}\lambda$$

$$H_{g\,out} = \left(c_{pg} + Y_{out}c_1\right)T_{g\,out} + Y_{out}\lambda$$

$T_{g\,in} = 40\ ^{o}C \quad and \quad T_{g\,out} = 60\ ^{o}C$

$$\left(c_{pg} + Y_{in}c_1\right)T_{g\,in} + Y_{in}\lambda = \left(c_{pg} + Y_{out}c_1\right)T_{g\,out} + Y_{out} + 0.05\left[\left(c_{pg} + Y_{out}c_1\right)T_{g\,out} + Y_{out}\right]$$

$$(1 + 0.005\times 4.2)\times 600 + 2370\times 0.005 = (1 + Y_{out}\times 4.2)\times 60 + Y_{out}\times 2370 + 0.05\left((1 + Y_{out}\times 4.2)\times 600 + Y_{out}\times 2370\right)$$

$Y_{out} = 0.186$

$$\frac{dm}{dt} = G_{in}\,(Y_{in} - Y_{out})$$

$$\frac{dm}{dt} = \frac{13.8}{3600}(0.005 - 0.186)$$

$$\frac{dm}{dt} = -6.93\times10^{-4}$$

$$\frac{dm}{dt} = \frac{\left(x_{out} - x_{in}\right)\times F}{t}$$

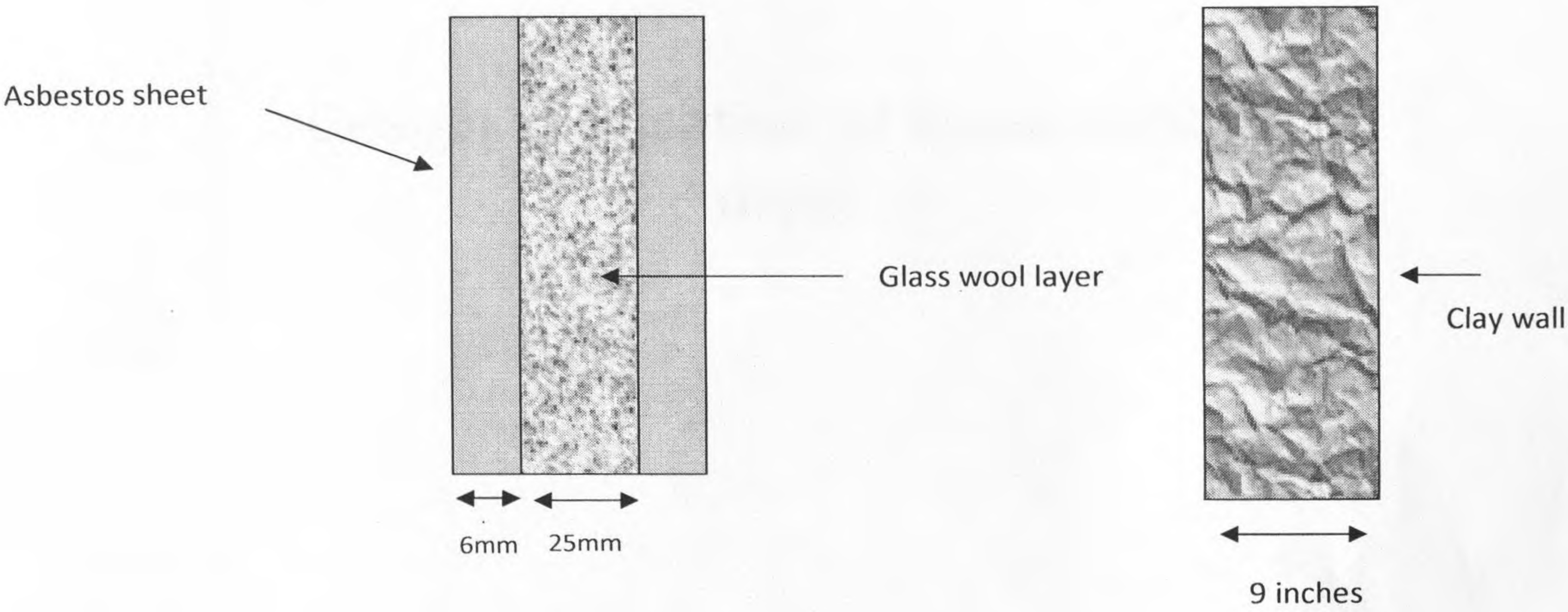
$$\frac{dm}{dt} = \frac{\left(0.007 - 0.33\right)\times 500}{t} = -6.93\times10^{-4}$$

$$t = 2.7\ days$$

Through the mathematical modeling, it was found that the required time to achieve the desired moisture level of RSS is 2.7 days using flue gas.

Thermal conductivities

Material	Thermal conductivity (W/m.K)
Asbestos	0.08
Glass wool	0.04
Dry clay	0.24



The temperature inside the dryer is taken as 60 ^{0}C and room temperature is 30 ^{0}C.

Calculation

The heat loss through the dryer was calculated by considering only the conduction through the walls. Accordingly heat flux through the walls was calculated

Heat flux through asbestos wall is **38.7** w/m^2.

Heat flux through dry clay wall is **32** w/m^2.

Design verification of creep rubber dryer

INTRODUCTION

This report is consisting of the calculation procedures of the duct line design and simple schematic of the arrangement of dryers and the combustion chamber.

Design calculation of duct area of creep rubber dryer

Data:

The required air flow rate to the dryer = 0.553 kg/s

Air temperature = 40 °C

Air density at 40 °C = 1.127 kg/m^3

Air volume flow rate= 0.553/1.127 = 0.5 m^3/s

The air velocity through the duct line = 4 m/s

$$Duct\ area = \frac{Volume\ Flow\ rate}{Velocity} = \frac{0.5}{4} = 0.125m^2$$

Design calculation of duct area of RSS rubber dryer

Data:

The required air flow rate to the combustion chamber = 13.8 kg/hr

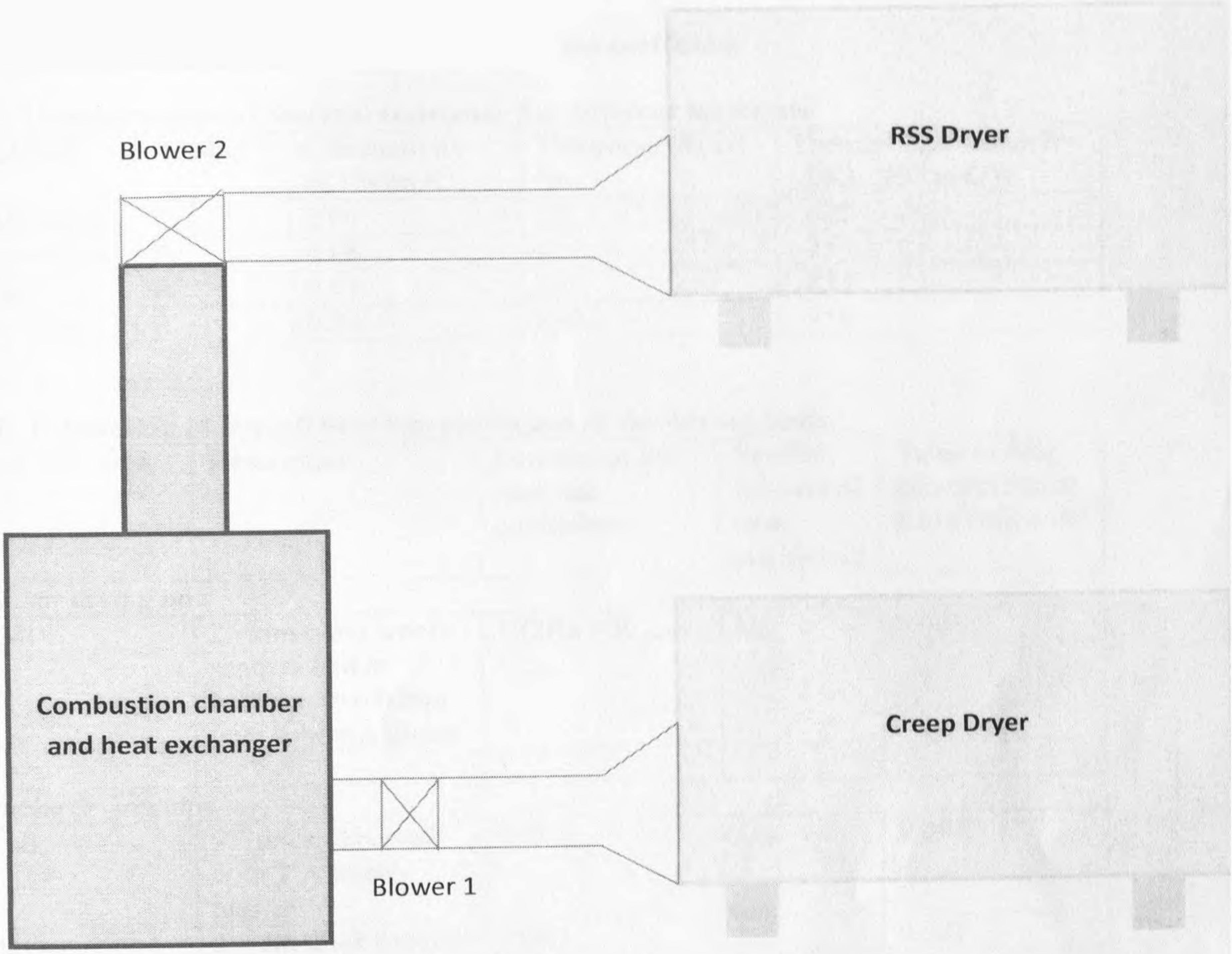
Inlet air temperature = 600°C

Air density at 600°C = 0.4 kg/m^3

Air volume flow rate= (13.8/3600)/0.4 = 0.01 m^3/s (36 m^3/h)

The air velocity through the duct line = 1 m/s

$$Duct\ area = \frac{Volume\ Flow\ rate}{Velocity} = \frac{0.01}{1} = 0.01m^2$$


RSS Dryer
Blower 2
Combustion chamber and heat exchanger
Creep Dryer
Blower 1

Annexure 5: Determination of Overall heat loss coefficient

A1: Determination of thermal resistance for different materials

Material	Symbol 1	Conductivity (K) W/m.K	Thickness (d) 10^{-3}m	Thermal Resistance R= (d/K) 10^{-3} mK/W
Glasswool	R_{gw}	0.04	25	625
Asbestoses	R_a	0.08	6	75
Timber	R_t	0.03	25	833
Dry clay	R_w	0.24	230	958

A2: Estimation of overall heat loss coefficient of the drying Units

Heat loss area	Description	Expression for heat loss coefficient	Symbol for overall heat coefficient	Value of heat loss coefficient $KJ/m^2/h/Kx\ 10^3$
Hot air drying unit				
Wall	25 mm glass wool sandwiched in-between two 6 mm with asbestos plates	$1/(2Ra + R_{gw+})$	U_w	0.001
Smoke drying unit				
Wall	9'' thick clay wall with 1" cement plaster	$1/(R_b)$	U_{cw}	0.001
Timber	2.5 cm thick timber	$1/(R_t)$	U_t	0.001

Overall heat loss coefficients of the drying units were estimated using the following formula.
$U = \Sigma(UiA_i)/ \Sigma A_i$

Where
U heat loss coefficient
A_i area of the i^{th} component

Total area

(a). Hot air drying unit

Walls of the hot air drying unit 46.37 m^2

Smoke drying unit

Walls of the hot air drying unit 34.65 m^2

Timber door area 4.41 m^2

Substituting relevant values

Overall heat loss coefficient of hot air drying unit $\frac{46.37 \times 0.001}{46.37}$

U_{ha} 0.001 **kJ/m²sK**

0.0036 MJ/ **m²hK**

Overall heat loss coefficient of smoke drying unit $\frac{34.65 \times 0.001 + 4.41 \times 0.001}{34.65 + 4.41}$

U_{sh} 0.001 **kJ/m²sK**

0.0036 **MJ/m²hK**

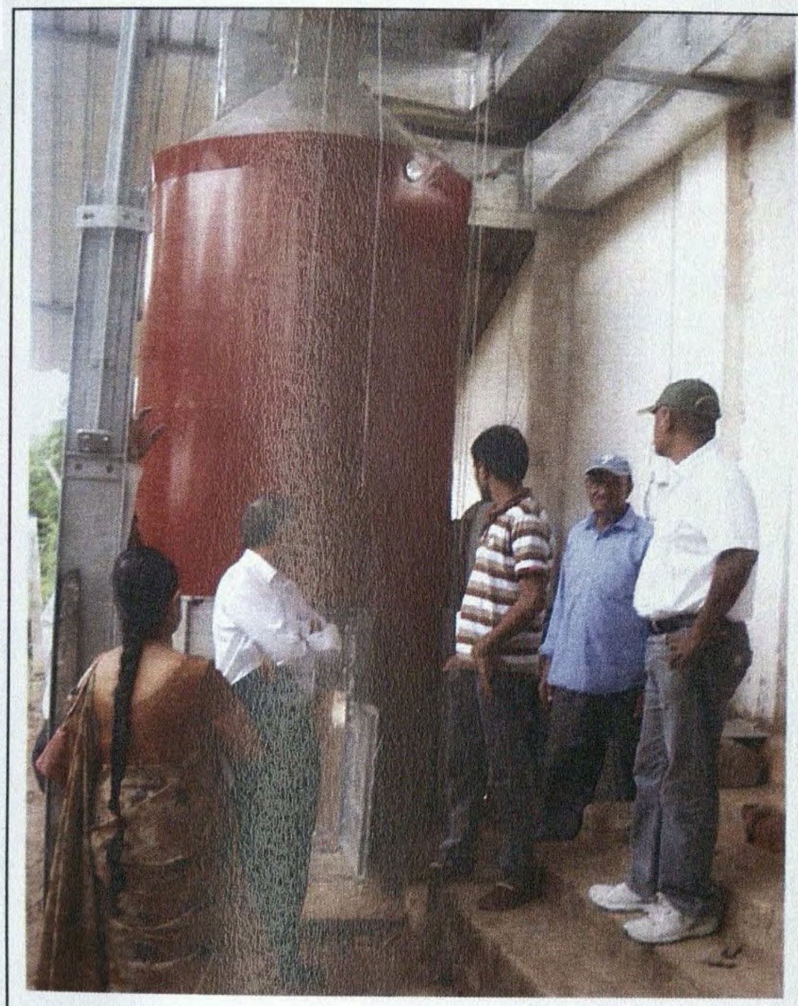


Figure 1: Hot air generator

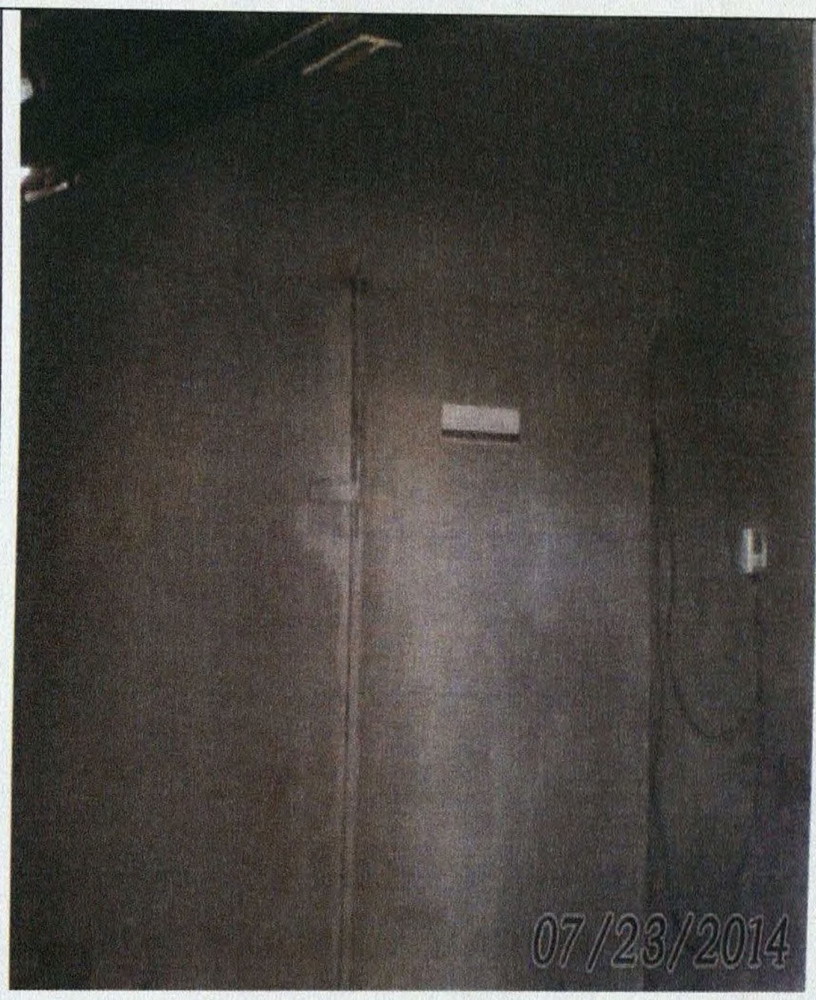


Figure 2: Hot air drying unit

Figure 3: Adjstable ventilator system in inside the hot air drying unit

Figure 4: Laces are hung on the trollyes

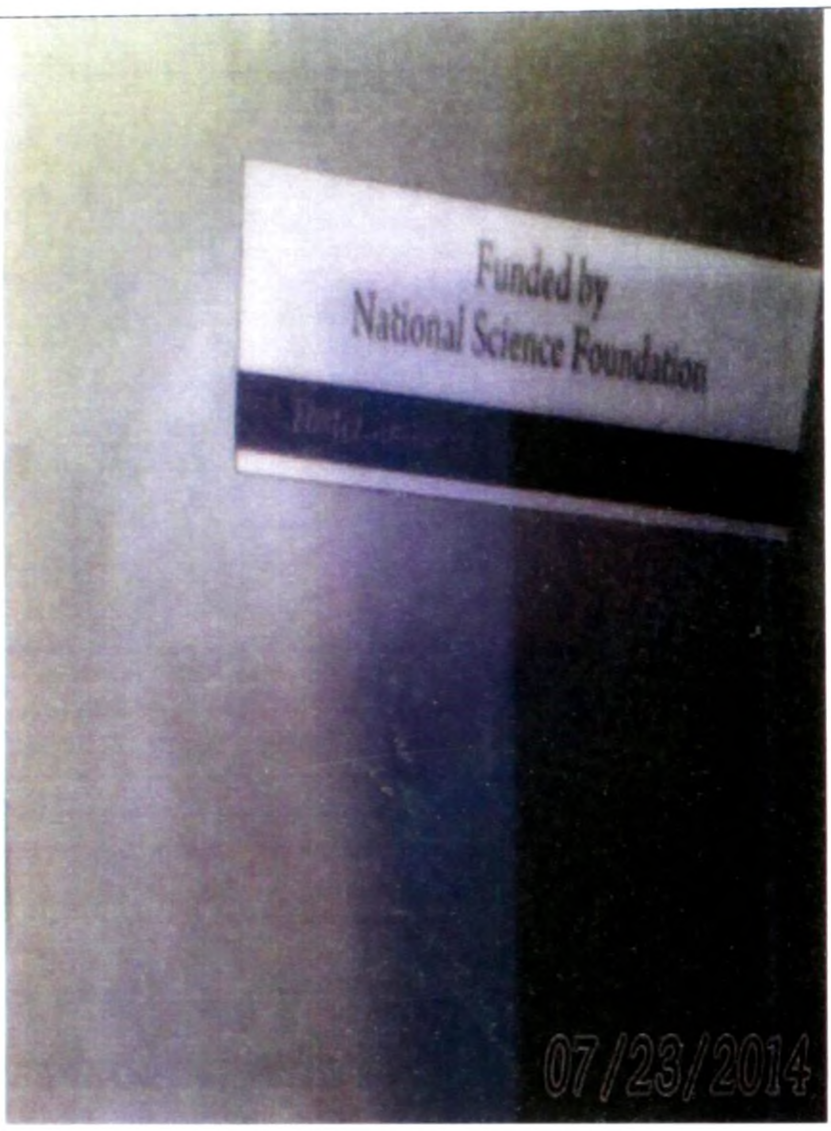


Figure 5: Dryer funded by NSF

Figure 6: Inside the hot air drying unit

Figure 7: Dryer under construction

Figure 8: Smoke drying unit