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Evaluation of the Curing Efficiency of the Rocket Barn in Zimbabwe

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Abstract – **A research to evaluate the curing efficiency of the rocket barn in Zimbabwe was carried out at Kutsaga research station. The main objectives were to assess the wood fuel consumption and the total time taken to complete curing in a rocket barn (trial) in comparison to the conventional barn (control). Tobacco leaves collected from the same field at the same time was loaded into the barns. Same quantities of fuel wood, with similar moisture content, were loaded into the barns at the same time. Curing also started at same time. Wood fuel quantity consumed were recorded as well as the total time to complete the curing cycle .The results indicated that the rocket barn consumed about 47 -50% of the wood fuel quantity used in the conventional barn to complete curing. There were no significant differences (p>0.05) in total times taken to complete curing by both barns. The rocket barn is, hence, more efficient in wood fuel consumption and, can be recommended for adoption in the smallholder tobacco growing sector in Zimbabwe in order to reduce the rate of tobacco production related deforestation.**

Keywords – **Curing Efficiency, Deforestation, Rocket Barn, Smallholder Sector, Wood Consumption.**

I. Introduction

Tobacco curing accounts for 5% of Africa's total deforestation 12% of deforestation in Southern Africa, and 200 000 hectares of forest are cut down each year for tobacco production [1]. The majority of this (69%) is used as fuel, whilst the remainder (15%) is used for constructing barns and racks, including those used for air cured tobacco which does not require fuel [1]. The total annual consumption of wood fuel by the tobacco industry in the Southern Africa countries represents 0.7% of all fuel wood consumed for all purposes in these countries and equates to 6.4 million m^3 per annum [2].

Zimbabwe is the fourth leading producer of high quality flue-cured tobacco which constitutes 64% of all tobacco grown worldwide [2]. The year 2005 marked an increase in the price of coal and the cost of transporting it from its reservoirs to the farms. The collapsing of the country's railway system and the cost of electricity bills also made it difficult for farmers who relied on coal as their fuel for curing tobacco. Most tobacco growers resorted to wood fuel as an alternative.

The tobacco based deforestation in Zimbabwe accounts for 15.9% of the total deforestation ([3]-[1]. This rate of deforestation is high above the time taken by small plant to fully mature for use as wood fuel. These large amounts of deforestation have been attributed to the inefficiency of the current conventional barns in use. On average, 9 kg of wood fuel is used to produce 1kg of cured tobacco [4]. Although the government of Zimbabwe through the ministry of environment and natural resources has been implementing reforestation programs, their efforts are failing to sustain the fuel wood demand especially with the current increase in tobacco production and inefficient use of wood by conventional barns.

Before the land reform program, the Zimbabwean tobacco industry was dominated by 4000 white commercial farmers who had their own woodlots reserved for tobacco curing [5]. After the land reform program, the number of tobacco growers increased from 65000 in 2011 to 105 000 in 2013 [6].Of all tobacco growers, 80% are small scale farmers who do not have their own woodlots and are not connected on the electricity grid and therefore rely on wood fuel as their source of energy in curing tobacco[6]. This factor has accelerated the rate of tobacco based deforestation in Zimbabwe. Efficient curing systems are therefore required to minimize the inefficient use of fuel wood by tobacco barns.

The rocket barn is a structure designed to arrest the inefficient use of fuel wood in tobacco curing [4].The most unique design of the barn is its double exhaust chimney which exhausts both smoke and barn moisture thus maximizing the drying rate of the tobacco leaf..

The advantages of the rocket barn design were summarized by reference [12].Due to its smaller furnace diameter, the rocket barn uses smaller pieces of fire wood thus allowing the farmer to stop cutting down the entire stem of the tree but the branches for curing. The barn also allows a farmer to use his own wood lot on rotational basis for many years without going outside the farm for firewood. There are no special or complex materials to be used in building the rocket barn as the bulk of its components are made from farm brick which can be easily made by a small scale farmer from his own farm. Other advantages of the rocket barn include: better quality, heavier and uniform color tobacco which grading time [6].

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Research on the tobacco curing efficiency of the new rocket barn in Malawi showed that it is an appropriate, affordable and easy-to-build barn that reduces fuel wood consumption, while improving the quality produce [4].It has been regarded as the most suitable for the smallholder farmers where wood fuel is now scarce .This new barn was to be introduced in Zimbabwe, and this project was carried out to assess the rocket barn performance in terms of wood fuel consumption and the time taken to complete the stages of curing before it was adopted in the tobacco sector as a way of reducing tobacco based deforestation.

II. Materials and Methods

2.1 Study site

The study was carried out at Kutsaga Research Station which is in Harare, Zimbabwe, from 2012 to 2014. Kutsaga is located in Natural Region IIA of Zimbabwe; with geographical coordinates of 17˚ 54′ South and 31˚ 08′ East and at an elevation of 1496 m above sea level. In summer and winter the average temperatures are 32˚C and 18˚C respectively. The average annual rainfall for the station is 800 to 1000 mm.

2.2 Experimental set up

Three 3 rocket barns and two conventional barns were used in this research. All the barns used in the experiment had different design features (Table 1)

Table 1: Details of the barns in which tests were conducted

Barn	Design features	Fuel
Rocket 1 (R1)	Brick firebox channel with metal surface (0.3 m wide, 0.4 m high and 15 m long) with fins along the inside and outside; furnace with dimensions 0.4 m diameter × 3.5 m; floor area 4.1 m × 4.5 m; gable roof (4.0 m high at apex and slanting to 3.6 m at the walls); tobacco carrying capacity 264 clips.	wood
Rocket 2 (R2)	Metal flue pipes (0.3 m diameter and 23.5 m long) arranged in a T configuration; furnace with dimensions 0.4 m diameter × 2.3 m; floor area 4.1 m × 4.5 m; gable roof (5.0 m high at apex and slanting to 4.2 m at the walls); tobacco carrying capacity 352 clips.	wood
Rocket 3 (R4)	Brick firebox channel with metal surface (0.3 m wide, 0.4 m high and 15.5 m long) with fins along the inside and outside; furnace with dimensions 0.6 m diameter × 1.8 m; floor area 4.0 m × 4.4 m; flat roof (4.0 m at the walls); tobacco carrying capacity 480 clips.	wood
Conventional 1 (test)	Brick firebox channel with metal surface (0.4 m wide, 0.5 m high and 17.1 m long) with fins along the inside and outside; furnace with internal dimensions 0.5 m × 0.6 m × 2.3 m; floor area 4.0 m × 4.4 m; gable roof (4.9 m high at apex and slanting to 3.8 m at the walls); tobacco carrying capacity 432 clips.	wood
Conventional 2 (standard)	Metal flue pipes (0.3 m diameter and 10 m long) arranged in a T configuration; furnace with dimensions 0.5 m diameter × 2 m; round barn with diameter 2.4 m (floor area 6.2 m^2); grass thatched roof (8.5 m high at apex and slanting to 6.5 m at the walls); tobacco carrying capacity 564 clips.	wood

The total land area of tobacco for use in the project was calculated using the formula:

$$y = \frac{pnt}{lsr} \quad [7]$$

where y is the number of barns/hectare, p the number of plants/hectare, n the number of leaves/plant/reaping, t the barn turnaround time in days, s the number of clips/barn, l the number of leaves/clip and r the reaping interval in days.

2.3 Procedure

Ripen tobacco leaves from the set aside section of a commercial crop were randomly picked and loaded into the barns at the same time, and the barn temperatures at the time of loading were recorded.

The wood (eucalyptus camaldulensis at 12 % moisture content) was used as the fuel. The amount of wood used for each of the three curing stages; the colouring, lamina drying and midrib drying, in each barn was recorded. Also recorded was the time taken to complete each stage of the curing process. The experiments were repeated 4 times.

2.4 Design

The experiment was set up in a randomised complete block design, with five treatments in 4 replicates.

III. Results

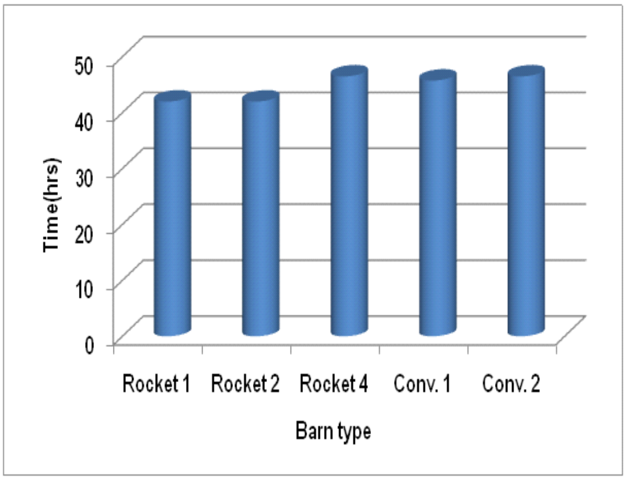

Fig.1. Time taken to complete coloring

The average time taken by all the barns to complete the coloring stage was 44.55 ± 2.3 hrs. The control and rocket barn 4 recorded 46.5 hrs and the test conventional barn recorded 45.75 hrs which were slightly above the average time. Rocket barns 1 and 2 recorded the lowest time (42 hrs). There were no differences in the times taken by both the rocket and the conventional barns at this stage ($p > 0.05$).

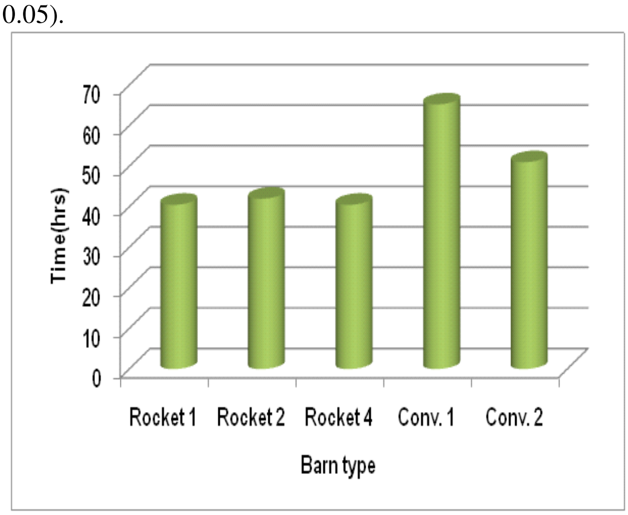

Fig.2. Time taken to complete lamina drying

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The least time taken to complete the lamina drying stage was 40.5 hrs in both rocket barns 1 and 2. The highest time recorded was 65.25 hrs in conventional barn 1. The control barn recorded 51 hrs which was slightly above the average. The average for all the barns in lamina drying was 47.9 hrs. Rocket barn 2 recorded 42 hrs which was lower than the average time. The times taken by the conventional barns were statistical similar ($p > 0.05$), however conventional barn 1 was significantly different from the rockets ($p < 0.05$).

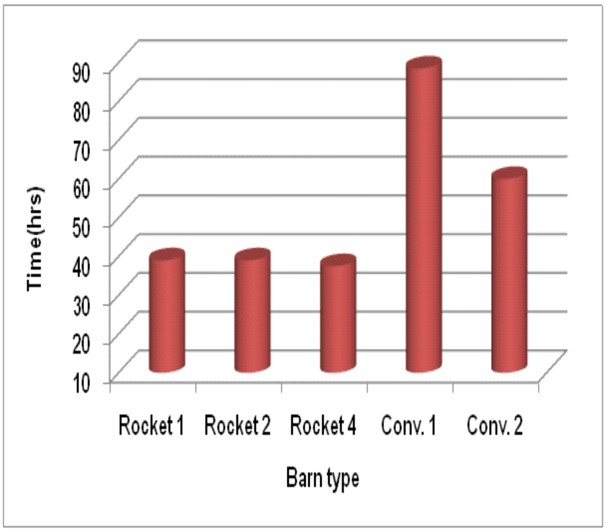

Fig.3. Time taken to complete midrib drying

The least average time taken at midrib drying stage was 37.5 hrs in rocket barn 4. For all the barns an average of 52.8 ± 22 hrs was recorded. The highest time recorded was 88.5 hrs in conventional barn 5. The control barn recorded 60 hrs which was higher than the average time. Both rocket barns 1 and 2 recorded 39 hrs. Midrib drying was significantly shorter ($p < 0.05$) in the three rocket barns as compared to the standard, while the test conventional barn took statistically similar ($p < 0.05$) time as compared to the standard.

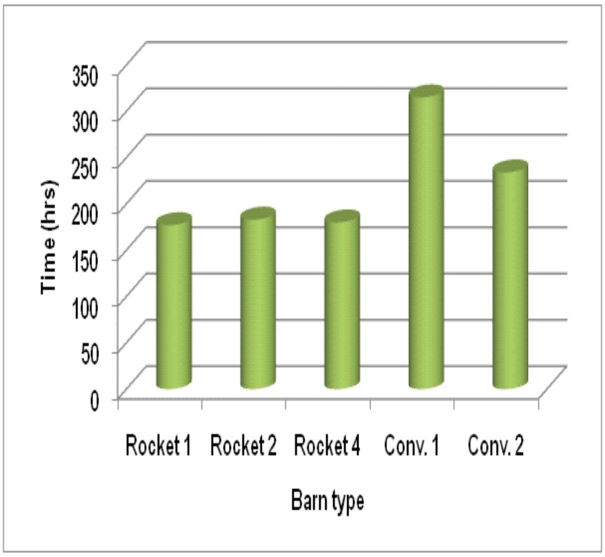

Fig.4. Total time taken to complete curing

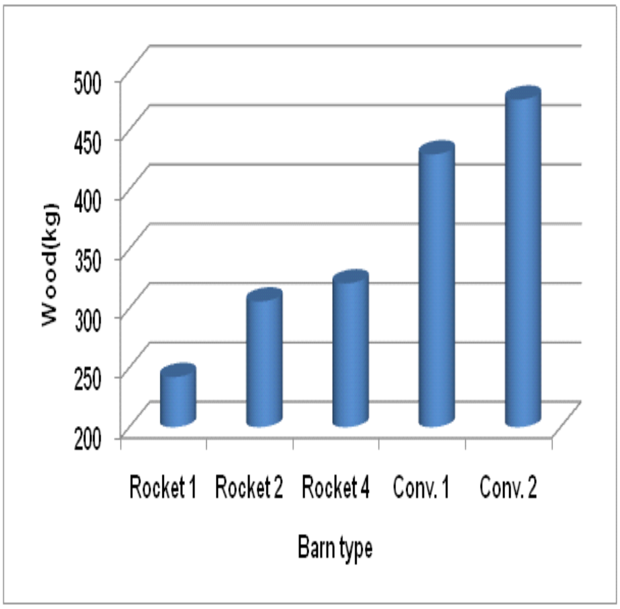

Fig.5. Wood fuel quantity to complete coloring

The average mass of wood consumed during the coloring stage was 354.92 ± 95.5 kg of fire wood. Rocket barns 1, 2 and 4 recorded 242.2, 305.8 and 321.1 kg respectively which were lower than the average. The test conventional barn 1 and the control recorded 429.7 and 475.8 respectively which were higher than the average. Rocket barn 1 recorded the least average mass and the control barn recorded the highest mass. Highly significant differences were observed between the control barn and the rocket barns ($p < 0.05$), however conventional 1 was statistically similar to the control barn ($p > 0.05$).

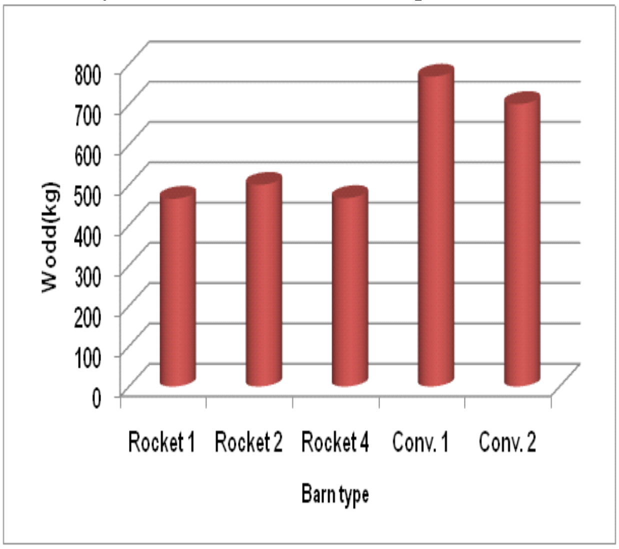

Fig.6. Fuel wood quantity to complete lamina drying

In the lamina drying processes, the least average mass recorded was 465.9 kg in rocket barn 1. The highest recorded mass was in the test conventional barn 1 which recorded 768.9 kg. On average all the barns recorded 580.8 kg ± 143.5 kg. The control barn (convectional 2) recorded a mass of 701kg which was however above average and the rocket barns 2 and 4 recorded 500.5 and 467.5 kg respectively. Although some differences were noted in wood fuel consumptions by the barns, the masses recorded were statistically similar (p > 0.05).

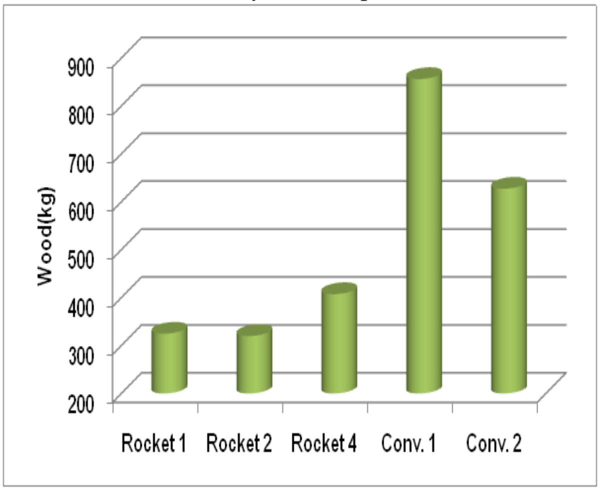

Fig.7. Wood fuel quantity to complete midrib drying

The test conventional barn recorded the highest average mass of wood fuel in midrib drying of 856.3 kg. This was however the above the average for all the barns which was 507.18 ± 231.6 kg. The least average mass was 320 kg in rocket barn 2. The control barn (conventional 2) recorded an average of 627.4 kg which was how ever higher than the average for all the barns. Rocket barns 1 and 4 also recorded 324.8 and 407.4 kg which were less than the average. Highly significant differences were noted between the rocket barns and the conventional barns (p < 0.05). Although the control barn recorded a relatively smaller mass than conventional barn 1, both masses were statistically similar (p > 0.05).

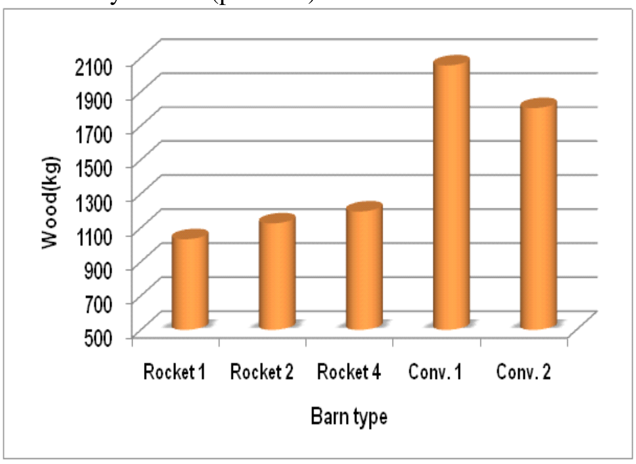

Fig.8. Total wood fuel quantity to complete curing

For the total curing cycle, the least average mass recorded was 1032.9 kg in rocket barn 1 and the highest recorded mass was 2054.9 kg in the test conventional barn 1. The average per curing cycle for all the barns was 1442.9 ± 456.7 kg. The control barn recorded an average of 1804.2 kg which was higher than the average for all the barns. Rocket barns 2 and 4 recoded 1126.3 and 1196 kg respectively which were lower than the average. There were no differences on the masses recorded by the rocket barns (p > 0.05). Highly significant differences were noted between the wood fuel consumptions of rocket barns and the control barn (p < 0.05). The control barn and conventional 1 recorded statistically similar masses (p > 0.05).

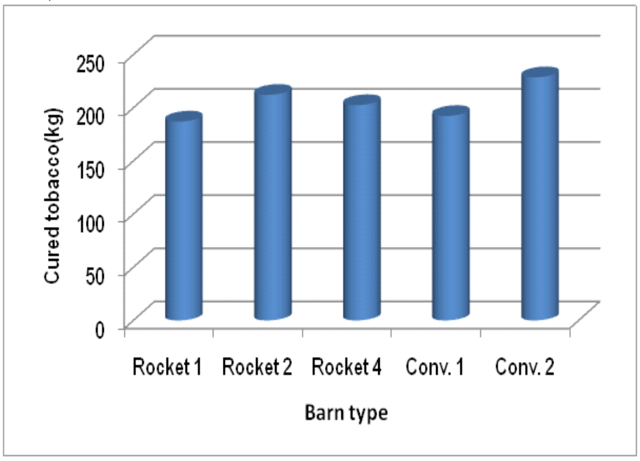

Fig.9. Mass of cured tobacco

On average, all the barns recorded 204.5 +/- 16.6 kg of cured leaf. The least mass recorded was 187 kg in rocket barn 1. The standard barn recorded an average of 228.7 kg which was higher than the average for all the barns. The test conventional barn also recorded 192.3 kg which were lower than the average. Rocket barns 2 and 4 recorded 212.2 and 202.5 respectively.

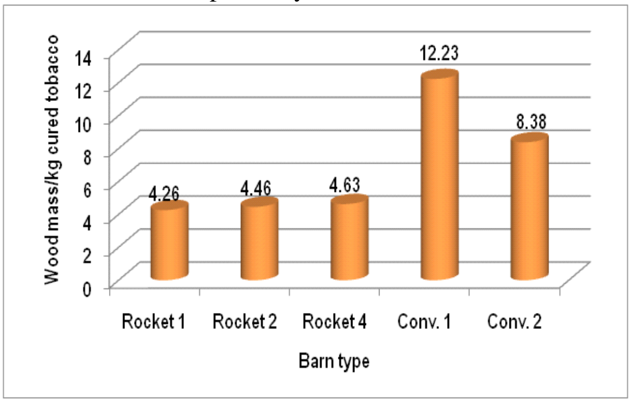

Fig.10. Wood fuel use efficiency

The amount of wood fuel used per unit mass of tobacco cured in rocket barns 1, 2 and 4 were 50.8 %, 53.3 % and 55.3 % of Conventional 2 (Standard).

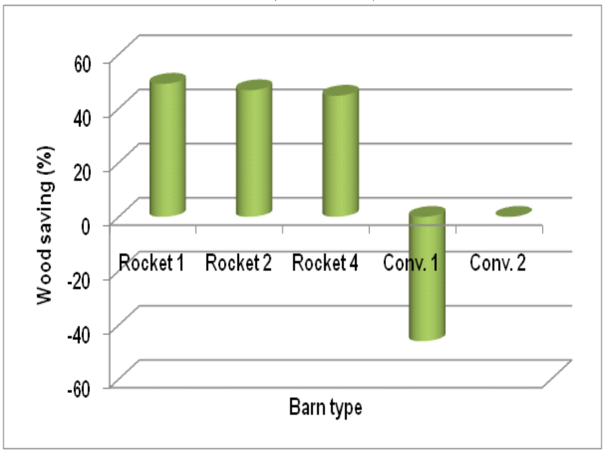

Fig.11. Wood saving

The rocket barns 1, 2 and 4 saved 49.2 %, 46.7 % and 44.7 % respectively of the total wood consumed by the control barn (Conv. 2).

IV. Discussion

The times taken by all the barns were similar during the coloring stage (Fig. 1). According to reference [9], the time to complete the coloring stage is determined by the maturity of the harvested leaf and the position of the leaf in the stem. Reference [10] also mentioned that climatic conditions and barn temperatures have influence on the time taken to complete coloring. Coloring is a biological process in which the tobacco leaf stays alive until it reaches its best chemical balance. While the leaf is alive, respiration, hydrolysis of starch to simple sugars and oxidation of sugar to into carbon dioxide and water continues within the leaf resulting in the color changes of the leaf. Factors determining the duration of this stage includes chemical composition of the leaf, type of tobacco, position of the leaf in the stem, climatic conditions, barn temperature and leaf maturity. Temperature is highly monitored in this stage so as to avoid any premature wilting of the leaf before it has completed the stage. The maximum temperatures of the coloring stage are very low, and can be attained by any barn independent of design. As a result, the prominent factors to the duration of the coloring stage are leaf characteristics and conditions on which the leaf is subjected to. Since tobacco leaves were uniform, i.e.: from the same field, of the same maturity, harvested at the same time and loaded in all the barns at the same time, it is therefore expected that all the barns complete the coloring process at the same time.

In lamina drying, all the barns recorded similar times (Fig. 2). The temperature in lamina drying is advanced on a rule of thumb basis to avoid overheating the leaf before it deteriorates chemically [7]. Since all the chlorophyll depleting enzymes are completely denatured at 50 ^{o}C., the temperature advances in the early stages of lamina drying are advanced in such a way that gives room for the action of these enzymes to ensure that the leaf is dried after it has fully deteriorated chemically. After 50 ^{o}C., temperatures are advanced in such a way that there is chance for moisture clearing in the barn as this may result in tobacco losing lustre and turning brown (sponge) with a lot of black spots on it (moisture runback). Due to the action of the double exhaust chimney of the rocket barns, the chance to clear is limited as the rate of moisture removal is faster than in conventional barns and hence they take a slightly smaller time to complete this stage. However the time differences are insignificant and statistically the times are considered similar.

Midrib drying was shorter in the three rocket barns as compared to the standard, while the test conventional barn took statistically similar time as the standard (Fig. 3). According to reference [8], the maximum temperature at midrib drying is 71 ^{0}C. Reference [4] also mentioned that temperatures in the heat exchanger box of the rocket barn gradually decrease from 850 ^{0}C at the furnace outlet to 150 ^{0}C at the chimney inlet. These temperatures are high above the threshold temperature before the brick starts radiating the heat it would have absorbed from the hot flues.

The midrib drying stage marks an increase in the heat radiating surface of the rocket barn as compared to the conventional barns. On average, 1 m^2 of the heat radiating surface area in rocket was used to heat 3.3 m^3 of the curing room, in the control barn however, the ratio was higher (1m^2 heating 8.9 m^3). According to reference [7], the rate of drying of the tobacco leaves is proportional to the area of the heat radiating surface area. It follows that the rocket barns should take less time compared to the control barn. Since the test conventional barn had the smallest heat radiating surface area, this explains why it recorded the highest times at midrib drying.

The rocket barns consumed less wood during coloring as compared to the control barn (Fig. 5). The coloring stage is less energy consuming and is archived by transferring at least 51.4 joules of energy per leaf according to reference [13]. In his law of conservation of momentum, Isaac Newton expressed that for effective work to be carried out; the impulse (the time effect of a force) must be increased. Since work done is analogous to heating, the time effect of hot flues in the barn must increase to ensure maximum use of heat from the hot flues. This is archived by increasing the length of the heat radiating surface before the hot flues are exhausted to the chimney. In the rocket barns, rocket barn 4 had the least heat radiating surface length as shown by the high fuel consumption as compared to other rocket barns. Although rocket barn 2 had the highest flue pipe length, maintaining constant temperatures was difficult as the metal flue pipe would quickly respond to diminishing barn fires and hence recorded higher energy than rocket barn 1. The flue pipe lengths in both conventional barns were smaller and hence recorded the highest energies.

Although some differences were noted in wood fuel consumptions by the barns, the masses recorded were statistically similar at lamina drying (Fig. 6). According to reference [7], the lamina drying process is partly physical and biological. The rule of thumb usually observed at this stage is to move 3 ^{o}C in every 4 hrs with a pause at 50 ^{o}C and 60 ^{o}C. Temperatures are advanced in a way to give room for the chlorophyll depleting enzymes which are denatured at 50 ^{o}C. After this temperature, temperature rise can then move faster as the enzyme that controls the oxidation of sugar is only killed at 60 ^{o}C. The lamina drying stage extracts a lot of moisture from the tobacco leaves than other stages. Instead of adding more heat to the tobacco barn, there must be a balance between the barn moisture, ventilation and temperature. If temperatures are increased while the barn is loaded with moisture, more heat is used in evaporation than in drying the leaf. The barn temperatures cannot rise unless there is a reduction in the amount of moisture present. What is required is to reduce fire enough to allow for more water in the barn to evaporate. Since barn firing at this stage is done with limitations, the wood fuel consumed by all the barns was similar. However, the ratio of the heat radiating surface area in the rocket barns is smaller than in the conventional barns, more energy was required in the conventional barns. This accounts for the small energy differences between the rocket barns and conventional barns at this stage.

At midrib drying, the rocket barns consumed less wood as compared to the conventional barns. Both conventional barns recorded similar masses (Fig. 7). The midrib drying stage is the most energy consuming stage in curing. According to reference [7], most of the wood fuel used in curing is consumed during the midrib drying. Reference [14] also mentioned that drying is a function of air velocity, humidity and temperature. In the rocket barn increasing barn temperatures also increases the air sucking effect of the double exhaust chimney. The induced draft in the air extracts barn moisture and gives room to outside unsaturated air to enter into the barn. On entering the barn, the temperature of the ambient air is quickly heated up by the furnace wall making it less dense and therefore moves at a faster rate, picking up moisture from the leaves before exhausting it to the atmosphere through the large diameter chimney. The enhancement of the rocket barn with a double exhaust chimney increases the air draft from natural to assisted air circulation. Since the drying process is a function of three factors which includes temperature, humidity and air speed, the rocket barn design effectively use these three factors in their correct proportion.

The control barn however uses natural convectional draft as a means of circulating air in the barn. Ambient air entering the barn is at a lower temperature than the barn temperature. To allow for the movement of that air, more time and energy is required to heat up the incoming air before it peaks up the moisture from the leaves and finally exhausted to the atmosphere. Of the three factors of drying, the control barn effectively uses temperature to engage other two factors (air speed and humidity). This therefore results in the high energy consumption as indicated by the large wood consumption as compared to the tested rocket barns during the midrib and lamina drying process.

V. Conclusion

There are no time differences in the curing stages among tested barns. The rocket barns saved from 47 – 50% of fuel wood used by the conventional barns. The rocket barns are hence more efficient in terms of wood fuel use per unit mass of tobacco cured and, could be recommended for adoption by the tobacco sector, as a way of reducing tobacco based deforestation. The study recommends further research and development of bigger energy efficient barns that can be used by all tobacco farmers regardless of the scale of operation. While it can be expensive to make a complete change to the rocket barns, research should also seek to modify current conventional barns in order to improve their curing efficiency.

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