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Design and Development of a Crop Residue Crushing Machine

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ABSTRACT: *Crops residues (CRs) are roughages that become available as livestock feeds after crops have been harvested. They are distinct from agricultural by-products (such as bran, oil cakes etc) which are generated when crops are processed. Generally any plant materials that remain after food crops have been harvested are classified as a crop residue. Apart from being a source of animal feed, residues are used as building, roofing and fencing materials, as fuel or surface mulch in crop land. (De LEEUW P. N. 1997).*
Farmers use crop residues mainly in two ways, e.g.: for fuel as firewood and minor constructions, especially maize and sorghum stovers; for roofing local houses, in the case of wheat, oath or barley straws; as building material for walls of local houses, especially teff straw. But the major use is for livestock feed particularly for draught oxen during dry season. Animals feed on crop residues mainly in two ways. The residues are pilled in stacks near homesteads and animals are left to eat from the stacks or given small quantity in the morning and evening, or for working oxen before and after work. Alternatively the residues are left in the threshing ground and consumed by animals together with the standing straws which are left for aftermath grazing.(KEFTASA 1987).Farm residues produce fifty eight percent of dependable livestock feed in the raining season. In the peak of the dry season, stubble pasture supplies more than ninety percent of livestock food. On these remnants, the herds spend about seventy-one percent of their time grazing. (IRO ISMAIL 2004).
Population growth, urbanization and income growth in developing countries are fuelling a substantial global increase in the demands for food of animal origin, while also aggravating the competition between the crops and livestock. (Increasing cropping areas and reducing range lands) This increasing pressure on land and the growing demands for livestock products makes it more and more important to ensure the effective use of food resources, including crop residues. (LIVESTOCK THERMATIC PAPERS 2010).As more and more land is put under crop production, livestock feed becomes scarce and crop residues particularly cereals straw remain the major feed source for the animals particularly during the dry period of the year (which spans November to May period). (KEFTASA 1987).An appreciable increase in the provision of livestock feeds shall be guaranteed when crops residues especially the hitherto poorly utilized stalks and stovers of cereals are crushed to admissible sizes to be taken by livestock as crushed or beefed with nutrients.
At the 2011 Kano international trade fare, many visitors who came to the stands of Technology Incubation Centre and Hydraulic Equipment Development Institute, especially Fulani herdsmen, apart from inspecting the displayed product of the two institutes prayed them to develop a modest, portable and affordable equipment to crush crop residues into livestock feeds. This project is predicated on this request, to ensure the enhancement of agriculture in Nigeria.
KEY WORDS: *CROP RESIDUE, CRUSHING, HERDSMEN, INSTITUTE, TECHNOLOGY*

I. INTRODUCTION

Crop residue has become the used term in tropical research and development circles for describing the fibrous by-products of cereals, sugarcane, roots and tubers, pulses, oilseeds, oil plants, vegetable and fruits. With notable exemptions e.g. sugar beet pulp and citrus pulp, utilization of residues as feed has been the subject of intense research and development since the mid-1970s. (OWEN E AND JAYASURIYA M. C.N 1989)
All ruminants depend on two major feed resources. These are crop residues and agro-industrial by-products and they play significant role in the nutrition of ruminant animals. (ONYEONAGU AND NJOKU 2010).

There is an acute shortage of animal protein in Nigeria, a minimum intake of 34gm of protein is recommended per capita per day. The national estimated daily per capita intake by 1993 was 3.9gm, allowing for fish and wildlife contributions and 3.2gm without. All factors considered, it has been estimated that average daily per capita protein intake by 2010 will be only 5.3gm still far below the food and agricultural organization (FAO) recommendation of 34gm. (PHILIP et al 2009).The quest to increase the agricultural production in all facets, have intensified crop production by way of increasing cultivated areas thereby reducing the grazing areas. Livestock farmers especially in the sector of goats, sheep and cattle are constantly faced with problem of feed shortage during the dry season. The herd constantly relies on crop residue, but these are usually in short supply. Hence ruminants experience seasonal weight gain/loss during the wet/dry periods respectively during the year. **(PHILIP et al 2009).**

In Nigeria, the production growth rate and demand for food is over 3% while growth rate of food production is between 1.0 – 1.5 %, leaving a short fall of 1.5 – 2%, in annual food supplies. It is important to note also the imbalance in these food supplies, between plant and animal sources; the former contributing over 75% and the latter accounting for the remaining 25%. This is mainly due to improper development of the livestock industry. **(IKHATUA 2000)**

The unavailability of sufficient pasture forage during the dry season in the tropical and sub – tropical regions is a major problem in ruminant livestock production. During this period, grazing ruminants lose weight and in extreme cases some deaths do occur. This is the plight of herdsmen in the semi-arid and arid zones of the country **(IKHATUA 2000).** Utilization of stalks and stovers of cereal crops is sure to improve the availability of the product. Ruminants despite their unique and highly efficient digestive system are not able to extract sufficient energy to grow and produce milk from low quality or high lignified residues. Hence these must be properly processed or treated in some way to make them useful for production. Historically, many fibrous crop by-products have been used as energy sources for ruminants in China. The ancient processing and feeding includes particle reduction and reconstitution of roughages with wheat or millet brain. Chopping stalks and soaking in water are popular practices for crop residue feeding throughout the Republic of China. Although they do not always result in constituents improvements in animal performance, they defiantly result in reduced diet wastage and diet selection. **(QINGXIANG 2002)**.

Also in some cases, availability of crop residue varies with season and region. In some regions there is a deficiency of crop residue only in certain seasons, in others a perennial deficiency may prevail, while in some other region and in particular seasons they are available in abundance but are largely wasted. These straws worth millions of naira are burnt in the fields in these places after the grain harvest. Improvement in the management of crop residue enables efficient utilization of this potentially useful feed resource. It is thus clear that the intention of the Nigeria Fulani herdsman is a technology to improve the residue utilization and by so doing enhance meat and milk production.

In most tropical regions, the majority of bovine feeds available are the poor quality crop residues and agro-industrial products. Improper management of feed resources, especially those of the bulky and fibrous crop residue is a contributing factor to low productivity of ruminant livestock in the tropical regions. Crop residue management should include the use of processing technologies for the manufacture of balanced complete straw-based feed for ruminants. **(WALLI et al 2012).**

The quality of crop residues and roughages are improved by both chemical and physical methods. Physical treatment of residues prior to chemical treatment improves materials acceptance of chemical treatment. Physical treatment includes, chopping, shredding, grinding and pelleting. The indications are that grinding and pelleting of fibrous materials increases the surface area exposed to microbial attack and accelerates the rate the flow of digesta through the gastro-intestinal track. This grinding and/or pelleting results in higher intake, up to 30% more.Studies in Sudan also showed that physical treatment of bagasse was more feasible than chemical treatment. However the process of grinding and pelleting of roughages is hardly practised in West African animal production. This may be connected with the non-availability of electricity and tractor power for grinding and pelleting. **(MATHERS AND OTCHERE 2012).**

The scarcity and lack of such a technology for the processing of cereal stovers in the West African sub-region and the need to solve the utmost problem in livestock production appear to have compelled the Fulani herdsman in Kano city area to request the development ofan equitable technology.

II. PROJECT JUSTIFICATION

The expected gains from a successful development of this equipment are enormous and justify financial input and research work towards the realization of the project. These gains include:

1. Enhancement of agricultural production in the livestock industry.
2. Savings in the deaths and sufferings of many a livestock during the hitherto usual dry-season feeds drought.
3. Enormous satisfaction to Fulani herdsmen as much manual labour occasioned by forced long distances drift to places of greener pastures during drought is drastically reduced.
4. Successful project development shall ultimately ensure the proper management of crop residues.

III. OBJECTIVES

It is intended to develop a crop-residue crusher for use by Fulani herdsmen in the mandate areas of Northern Nigeria. Equipment shall be powered by conventional petrol or diesel engines that are widely used in Nigeria for domestic grinding purposes. The power ratings do not usually exceed 12kw. Development of a crusher with such power consumption makes adaptation to the Fulani herdsmen easy.

Specific objectives include:

1. To design a crop residue crusher to accept feed materials of corn, millet, wheat and other cereal stovers.
2. To fabricate the designed prototype machine which power rating shall not exceed the 12 kW power upper rating of conventional domestic diesel and petrol engines.
3. To test the performance of the newly constructed machine.

IV. LITERATURE REVIEW

4.1: HISTORY OF GRINDING

Grinding of foodstuffs can be said to have started from Adam. Records however show that during the Stone Age (About 6700BC) man ground grains of wheat with rocks to make flour. By 5500 BC came the mill stone which consists of two large individual stones between which the wheat is ground to flour. **(MILLING AND BAKING INFORMATION SHEET V (2010)**. T

The industrial revolution ushered in the Buhrstone mill and the Roller mill. The buhrstone mill is probably the oldest type of grinding machine still in use today. This consists of one stationary disc of stone. Much like the millstone, though the stones grind at the interface of their mating faces. Modern Buhrstone mills have stones constructed in cast iron with faces cut in grooves and ridges. Modern horizontally shafted buhrstone mills are the conventional domestic mills used to grind tomatoes and foodstuffs.

Crushing of crop residues is on the increase with the global quest for sourcing of renewable energy through pre-processing of bio-masses. Physical and mechanical properties of biomasses species and varieties are very important when considering the energy requirements for particle size reduction of agricultural residues. Of the various types of grinding equipment available, hammer mills are the best known equipment used for the shredding/grinding, in which the material fragment are subjected to complex forces and then the resulted particles are used in the following operations from the pellet obtaining technology. **(MOICEANU et al 2012)**

HOQUE et al 2007, in an ASABE paper number 076164 on Review and Analysis of Performance and Productivity of Size Reduction Equipments for Fibrous Materials, recommends the hammer mill; and to accept whole stalks without the need for manual chopping, the large size hammer mill called Tub mill. Various size reduction equipments are available in the market based on the classification of the size reduction equipment done by Scubert et al (2004) and Woldt et al (2004), Miu et al (2006) added an extended layout of this classification and suggested hammer mill, knife mill and disc mill as the proper equipment for biomass pulverization. Due to high size reduction ratio, good control of particle size range with relatively good cubic shape of particles, hammer mills are wildly used and numbers of literature on grinding of different materials are available. Knife mills (or choppers) work successfully for shredding forages under various crops and machine conditions. Disc (or roller) mills produce very small particles if input feed is provided by knife mills or hammer mills. **(HOQUE et al 2007).**

To achieve the project objectives of developing a crusher for crop residues (made up of stalks, straw and leaves), it is evident that a chopping machine or knife mill incorporating a hammer mill is the obvious solution. As the crop stover cannot be conveniently fed directly to a small sized hammer mill, the chopping machine shall input its product directly to the hammer mill chamber.

V. DESIGN METHODOLOGY

Design of grinding or crushing systems are guided by the intended objective. The primary problem to be solved by a crop residue crusher is the crop stalk, which need to be admitted, chopped and then crushed to desired grain size. Whole stalk cannot be admitted into the hammer chamber. Hence the need for a chopping machine, Crop stovers need to be steadied and directed as they enter the chopping machine. Chopped stovers should be within a range of sizes to ensure that hammer mill input material are uniform. Thus stover feeding into the chopping machine should be regulated. The need for a pair of rollers for the feeding of the chopping machine is thus evident.

5.1: EQUIPMENT DISCRIPTION

The equipment is an assemblage of three systems. A pair of rollers horizontally fixed for admission of stovers in the lateral direction, a hexagonal shear cutter with six knifes which motion is synchronized with that of the pair of rollers and a hammer for the final crushing of the chopped stovers.

Figure 1 shows a crop stalk being fed to a chopping machine through the action of a pair of rollers. The motion of the chopping machine is synchronized with that of the roller to ensure that the required sizes are cut from the crop stover. Action is positive when the motion of the top roller and the chopping disc are anticlockwise and that of the lower roller is in the clockwise direction. The chopped pieces of crop stalks fall into the hammer chamber by gravity.

The hammer mill is conventionally a hammer-like projection mounted on a rotating shaft. The hammers are hung in such a way that they can swing either ways depending on centrifugal force or impact on the materials. The hammers revolve at high speed and grind the materials fed into its chamber by beating. The material is ground till it passes the screen holes of the detachable sieve. Hammer size, number and arrangement are very important. Hammers are usually installed on high speed (3600rpm) shafts. The distant between the screen and hammer should be 12 to 14 for size reduction of cereal grains and about 5mm for fibrous material. **(HOQUE et al 2007).**

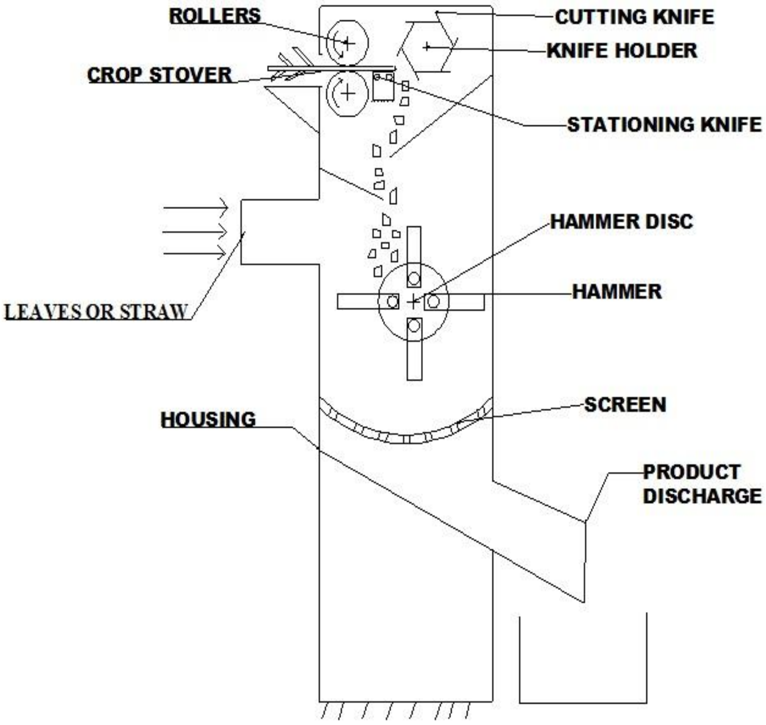

FIGURE 1: SCHEMATIC DISGRAM OF MACHINE

VI. EQUIPMENT DESIGN

Wheat, soybean, broomcorn, millet and corn stovers were studied by LIANG AND GUO 2011. The result of the test showed the shear strength of soybean stalk was the maximal while millet and wheat took second place, the broomcorn and corn are the minimal. The soybean stalk, whose cross section shape is solid, can be regarded as woody material with high stiffness. The core structure of broomcorn and corn stalk can be analysed as circular structure, which has less density and smaller shearing resistance than those of solid structure at the same cross sectional area. **(LIANG AND GUO 2011).**

The critical area of power required by the pair of rollers to admit stovers, the cutting force to be delivered by the rotary cutter and the centrifugal force to be delivered by the hammer are treated in this section.

6.1 ROLLER DESIGN

Crop residue consists of stems and leaves of several cereals. Stem diameters vary from 4mm for wheat **(DEGER et al 2010)** to 18.9mm for corn stover **(WOMAC et al 2005).** A pair of rollers with 4mm gap between them would admit most crop stovers but shall compress the corn stovers and other stalks whose diameter are above 4mm. The bulk density and the porosity of corn stover, 127.32kg/ m^3 and 58.51% respectively **(ZHAN et al 2012)** is an indication that the stalk is soft to compress. Shear strength of the crop stover vary from 3.02N/mm^2 ((least for corn stover) to 21.7N/ mm^2 (maximum for soybean stover). **(LIANG AND GUO 2011)**.

For safe design, assume compressive stress to be delivered by the rollers shall equal the shear stress for corn stover of 3.02N/ mm^2. Hence minimum compressive force

$$F_{MC} = S_C \text{ x Acorn} \quad \text{\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_} \quad (1)$$

Where F_{MC} = Minimum compressive force.

S_C = Shear stress of corn stover. (Assumed compressive stress)

Acorn = Cross-sectional area of corn stover.

$= \frac{\pi D^2}{4}$ (D = Diameter of corn dry stover).

6.2 ROTARY KNIFE DESIGN

From 6.1 the maximum shear force of crop residue = 21.7 N/ mm^2 for soybean. Design value for the shear cutter making 25% allowance for factor of safety, shall be 27.125.

$F_{CUTTER} = S_{CUTTER} \times A_{SOYBEAN}$. ______________________(2)

Where

F_{CUTTER} =Cutting Force.

S_{CUTTER} = Maximum shear stress

$A_{SOYBEAN}$ = Cross-sectional area of soybean stover

$= \frac{\pi D^2}{4}$ (D = Diameter of corn dry stover).

Diameter of highly performing soybean stem = 54.87mm. **(ZHANG et al 2011).**

$A_{SOYBEAN} = \frac{\pi \times 54.87^2}{4}$

= 23.64mm^2.

From equation (2)

F_{CUTTER} = 27.125 × 23.64

= 641N

Force required to cut the stover is given by

$F_{CUTTER} = mw^2$r -------------------- (3) **(NWAKAIRE et al 2011)**

Where

m = mass of cutting knife.

w = Angular velocity of cutting shaft.

= 2πN/60 -------- (4) **(KHURMI AND GUPTA 1979).**

N = revolution per minute of cutter

Hence

r = radius of cutting shaft

Power required for cutting

$P_{CUTTING}$ = Fwr ------------ (5) **(NWAKAIRE et al 2011)**

6.3 HAMMER MILL DESIGN

For assured and effective comminuting of stovers, each hammer in the assemblage of hammers, should deliver at least the shear force required to cut material. Hence by the force of repeated blows, the impact with the walls of the chamber, the screen and each other, the stover is quickly reduced to powder. From 6.2 the design expected hammer force is equal to the cutting force given by:

F_H = shear stress (27.125N/ mm^2) × Area of soybean stover.

The centrifugal force of the Hammers

$F_H = N_H M_H r_h w_{h^2}$ ------------ (6) **(EBUNILO et al 2010)**

Where

F_H = Centrifugal force

N_H = Number of Hammers

M_H = Mass of each hammer

r_h = Radius of hammer

w_{h^2} = Angular velocity of hammer

= 2πN/60

N = Revolution per minute of hammer shaft.

Power required to be delivered by the hammers

$P_{HAMMER} = F_H \omega r$ ----------- (7) **(NWAKAIRE et al 2011)**

Where

F_H = Force of hammers

ω = Angular velocity of hammer shaft = $\frac{2\pi N}{60}$ (N = Revolution per minute of Hammer)

r = radius of hammer shaft.

6.4: KEY SPCIFICATIONS OF PROTOTYPE

	ITEM	No.	DIMENSION	SHAFT	SPEED	FORCE	POWER
1	ROLLER	2	D = 100mm L = 203mm Feed length = πD = 479mm	Bearing = 40mm Pulley = 35mm Centre = 50mm	20rpm.	$F_R = mw^2r$ = 4.2N	P = F_R X V = 0.68W
2	CUTTER BLADE	6	Knife = L x W x T = 203mm x 75mm x 12mm.	Bearing = 40mm Pulley = 35mm Centre = 50mm	40rpm.	65.6N	27.7W
3	HAMMERS	24	Hammer = L x W X T = 152mm x 50mm x 12mm	Bearing = 40mm Pulley = 35mm Centre = 50mm	500rpm	$F_H = nmw^2r$ = 2096N	9756W

TOTAL 9.784W **10**Kw

Fig. 2 showing the front view of the fabricated machine.

Fig. 3 shows the fabricated machine in operation while the crushed residue is discharged.

6.5: CONCLUSION

The project was designed and fabricated. A 10kw popular IMEX diesel engine was installed to power the equipment. The prototype was tested and found satisfactory. However a cyclone which upper lighter discharge chute was covered with jute bag was added to improve the collection of the final product. Also a flywheel was attached to the hammer mill shaft to stop the lowering of the diesel engine speed noticed whenever much raw material was added to the chamber. It is decided that future commercialization shall incorporate a cyclone and a flywheel at the hammer mill shaft.

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