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EXPERIMENTAL EVALUATION OF A CONICAL-SCREW BRIQUETTING MACHINE FOR THE BRIQUETTING OF CARBONIZED COTTON STALKS IN SUDAN

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Abstract

Briquetting of the carbonized agricultural residues represents one of the possible solutions to the local energy shortages in many developing countries. It constitutes a positive solution to the problem of increasing rates of desertification in many areas worldwide. Agricultural residues are not attractive as a household fuel source for urban areas because they are very bulky and have low energy intensity. Also, to eliminate the smoke generation when burning agricultural residues requires processing it by carbonization before being used as a house-hold indoor fuel. Previously investigated, briquetting machines lacked high productivity and were of complicated designs. The present study puts forward a machine of simple design which could be manufactured locally in Sudan and of much higher productivity. The local Sudanese briquetting experience was overviewed, studying all the alternative available options and the market potential. The study presents a detailed design study of the new briquetting machine. The prototype was made and tested in the field at *Al-Gazeera* area in Sudan. The investigation results show that the new machine has a production rate better than all the previous alternatives. This low pressure screw briquetting machine was found to have a production rate equivalent to about eight times better than the production rate of the best local competitor. The production cost was found to be lower due to the lower binder requirement for the new machine, which is lower by about 65%. The initial moisture content of the feed stock required for this machine is lower by about 30 % compared to the best alternative, which results in shorter drying time for the fuel briquettes produced. The quality of the produced briquettes was found to be better and of lower smoke generation when burned due to the lower binder content.

Keywords: Biomass, Briquetting, Agro Waste, Rural Development, Molasses, Binders.

1. Introduction

Desertification is one of the biggest problems facing the world due to some environmental changes and human abuse of forest resources as fuel and building materials [1]. Desertification rate in Sudan is estimated to be 10-20 km/year towards the south. This is considered to be a very high rate. Based on that rate, Elmagzoup [2] predicted the complete disappearance of forests from most of central Sudan by the beginning of the 21^{st} century. Unfortunately this is exactly what happened in most of central and western Sudan. Forest is considered to be the main source of fuel for most of the urban and rural population of Sudan, a population which is increasing at a fast rate. Although there are a lot of changes in living styles and standards especially at urban areas, but the traditional cooking habits are still dominant, and most of the local dishes (e. g. *kisra* and *Asida*) still depend on using directly wood from forests as the preferred fuel, due to the availability and the cheapness of wood (in most cases people collect wood directly from the nearby forests at no cost) [3].

Charcoal is a traditional fuel widely used in many developing countries to meet basically household needs. It is considered as the best fuel for the most of the traditional cooking stoves in many areas in Sudan, and is preferred in the urban areas because of its smoke free burning [4].

Biomass resources, such as wood and charcoal, represent about 87.7% of fuel consumption for the household sector in rural areas and about 58.7% of house hold sector in urban areas in Sudan. Figure 1 shows the distribution of consumption for different types of fuels for the household sector in Sudan. Although the country is one of the biggest agricultural countries in Africa but agricultural residues do not contribute significantly as a fuel in this sector [7].

Recently dependence on fossil fuels started to hasten due new oil and gas discoveries and exploitations in Sudan. In the very near future charcoal is expected to be replaced by natural gas in most of the big cities, but in most of the rural areas and the small towns the situation of dependence on forests may remain unchanged for more few years.

One of the most viable alternatives to replace forests as the main energy resource is the abundant agricultural wastes produced in millions of tones from the wide agricultural areas in Sudan. Agricultural wastes are abundant throughout Sudan, but big mechanized agricultural schemes such as *Al-Gazeera* and *Al-Rahad* Schemes represent a special kind of consistency, concentration and availability of the agricultural wastes. Despite of the local use of some of the waste as fuel, fodder for cattle and for making shelters (i.e. building material), it is found that most of the agricultural waste does not play any significant economical role and is burnt directly in the fields to get rid of it and prevent the growth and spread of pests that might be living in them.

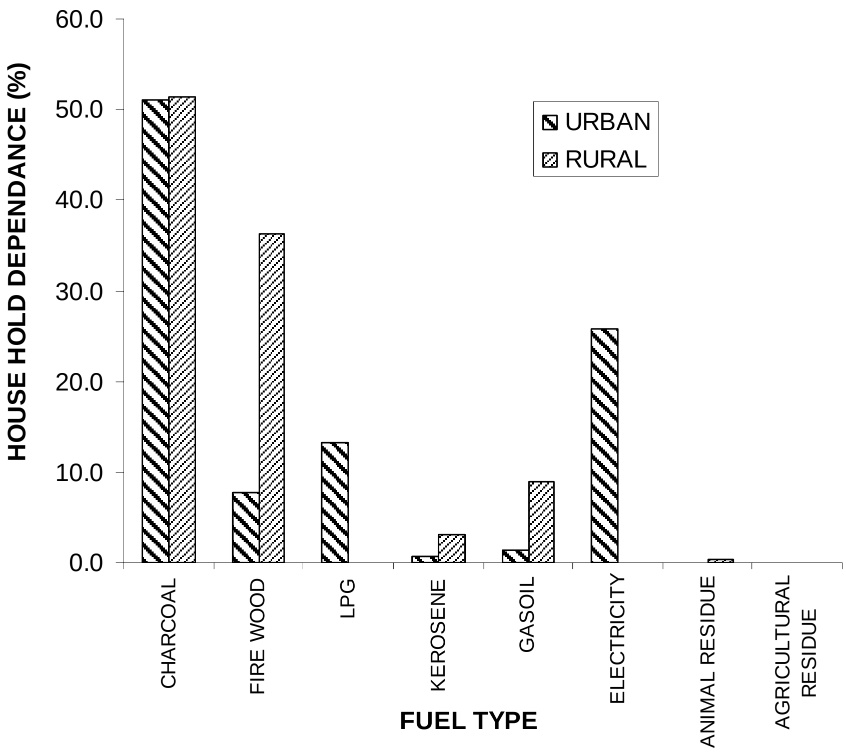

Fig.1. Distribution of fuel consumption by type for house sector in Sudan [7].

Cotton stalks remains to be the most available agricultural waste resource regardless of the recent declination of the amounts of cotton produced in Sudan, other agricultural waste available consist of sorghum, millet, wheat, rice, maize, ground nut, and sesame. Table 1 shows the size and distribution of each on of these residues in Sudan [8]. Biomass waste material is usually very bulky and has a very low density which makes it very difficult to be used in many types of burners and make its transportation also very uneconomical process. Densification of biomass is one of the solutions to this problem. For house hold use of briquettes carbonization is an important process to reduce the amount of smoke generated while cooking [5].

The process followed in this project to utilize cotton stalks as fuel in Sudan, starts with collection of the stalks in the field, and due to the fact that transport of cotton stalks out of the field is prohibited, stalks have to be carbonized in the field using metal kilns. The carbonized cotton stalks are then transported to the briquetting location to be pulverized into a fine powder form, and then mixed with the binder for briquetting [6].

2. The Local Previous Experience

Briquetting machines used in the briquetting of the agricultural residues are divided into three types depending on the die pressure range; the first type is the high pressure machines where the pressure reaches values more than 100 MPa. This type is suitable for the residues of good lignin content. At this high pressure the temperature rises to about 200- 250°C, which is sufficient to fuse the lignin content of the residue, which acts as a binder and so, no need of any additional binding material.

Table 1. Availability and distribution of agricultural waste in Sudan [8].

Crop	Area 1000ha	Yield Factor t/ha	Total 1000 tonnes	Availability Factor	Net Amount 1000 tonnes	Calorific Amount GJ/t	Energy Potential toe
Cotton	1000	1	1000	0.8	800	13.3	249000
Sorghum	7000	2.1	15000	0.3	4500	14.3	1500000
Millet	3000	1	3000	0.25	750	14.5	251000
Wheat	580	2	1160	0.3	350	17.5	143000
Rice	20	1.6	32	0.3	10	5.9	1400
Maize	140	1.8	350	0.6	150	11.6	40000
Groundnut	2300	1.2	2760	0.6	1660	23.3	906000
Sesame	2000	1.2	1400	0.6	840	14.3	281000
TOTAL	**16240**	**1.49**	**24700**		**9060**	**14.3**	**3380000**

The second type of machines is the medium pressure machines, with a pressure ranges between 5 MPa to 100 MPa, which results in lower heat generation [2]. This type of machines requires in most of the cases the use of an additional heat source to melt the internal lignin content of the feedstock and eliminate the use of an additional binder.

The third type is the low pressure machines that work at pressure less than 5 MPa and room temperature. This third type of machines requires the addition of binding materials, and is considered to be the most suitable type for the carbonized materials due to the lack of the lignin material due to the carbonization process and due to the low energy requirement for this type of machines [5].

Briquetting of the agricultural waste materials was investigated in Sudan for long time. There were many studies conducted by the Energy Research Centre (ERC) to develop a briquetting machine in Sudan. Most of the studies targeted the carbonized agricultural residues such as the ground nut shells, sugar cane baggasses and cotton stalks. The first local machine was a manual press designed by Mr. Grant B. Curtuis in 1985 for experimental purposes and preliminary product evaluation. In 1986 another manual machine was designed by Prof. William I. Asaad, this machine was based on a power screw concept and operated manually with a very low production rate [6]. Later this machine was replaced by a pneumatic press, which improved the productivity slightly but it is still fall beyond the ERC expectations for a commercially acceptable briquetting machine [5].

Better results were achieved by the double piston hydraulic press produced by the ERC in 1987, which produced about 25 kg/h of briquettes of a density of about 500kg/m^3. The hydraulic double piston press is shown in Fig. 2. The present work is showing the result of the ERC efforts to replace the hydraulic system with a more productive and reliable briquetting system, and to improve the quality of the product to be more suitable for the household needs in Sudan [6].

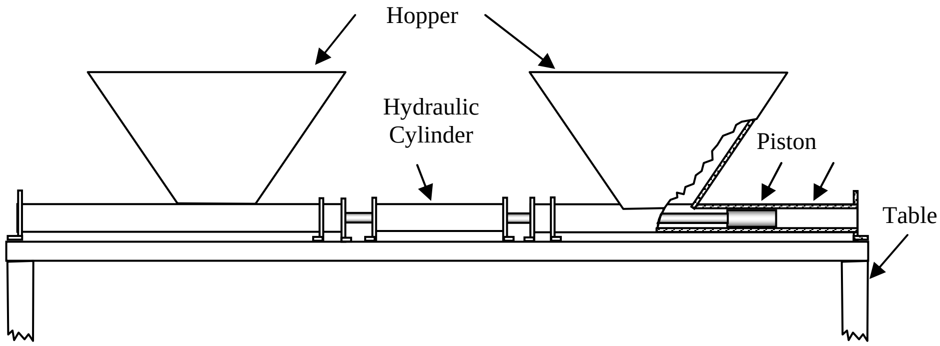

Fig. 2. The double acting hydraulic briquetting machine.

3. Description of the System

Cotton stalks are carbonized in the field then transported to the briquetting plant which is located in a location easily accessible from all the surrounding fields. The briquetting production plant consists of a briquetting machine, a hammer mill for grinding of the carbonized cotton stalks, a binder storage tank, a mixing drum to prepare the slurry and a drying space. Figure 3 shows a schematic view of the briquetting production plant.

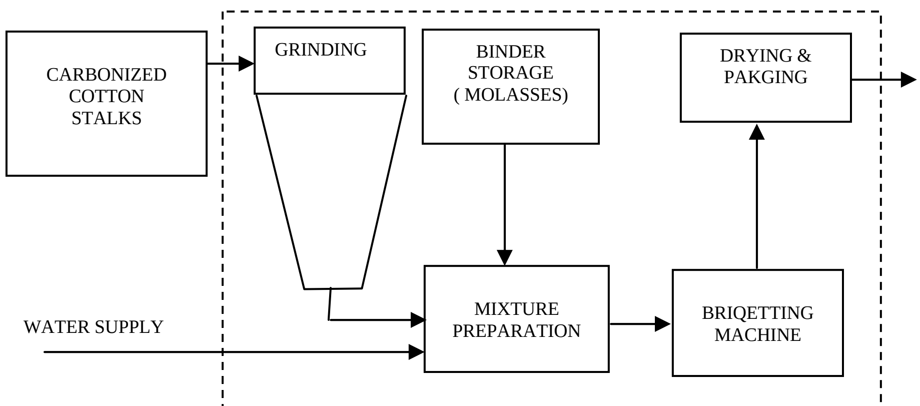

Fig. 3. A schematic view of the briquetting production plant.

This briquetting process consists of extrusion of the material by a screw extruder which acts as a continuous feeder. The volume of the material is decreased as it is transferred from the hopper to the die exit. This is achieved by increasing the root diameter of the threaded shaft gradually starting with a small diameter at the feeding position and increase gradually to a maximum value at the die position. Figure 4 shows the design of the screw. Due to the limited manufacturing facilities at the location of the plant the screw manufacturing was the biggest challenge faced during the process. Making the extruder screw was really a big challenge when dealing with such a task in an environment of limited manufacturing facilities.

The easiest method was found is to taper the shaft diameter from one side into a conical shape and then grooving the thread base on the shaft tapered surface, then welding a heavy steel plate to form the thread. The thread height was made constant and of a value smaller by only a little clearance than the inner diameter of the barrel, this was conducted using a normal lathe turning operation.

The feed stock consists of the slurry mixture of the carbonized powdered cotton stalks and the binder. The briquettes were relatively moist when produced and required to be placed under the sun for drying before packing them for distribution.

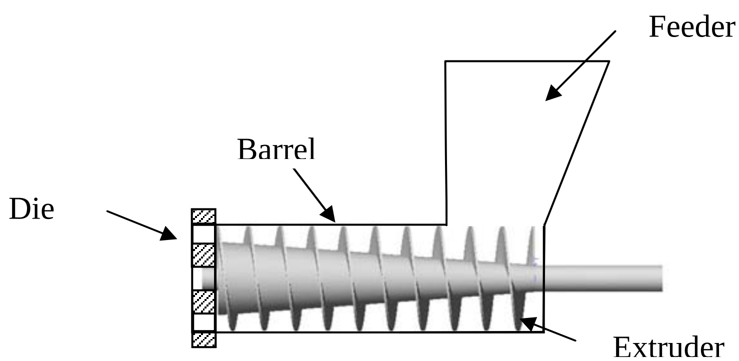

Fig. 4. The screw briquetting machine design.

4. Materials and Methods

The main objective of this project was to develop a briquetting plant for the utilization of the cotton stalks at the *AL-Gazeera* Scheme in Sudan using the available local technical resources. This part of the work is investigating the mechanical performance of the briquetting machine as well as measuring the production rate and the quality of the product.

There are many variables that affect the briquetting machine performance, the production rate and the briquettes quality. These variables may be divided into two main groups: the first group includes variables which are related directly to the machine design and the production process, while the second group consists of the variables related to the properties of the feed stock and its constituents. The first group of variables consists of the machine's compression ratio; the die shape and dimensions and the ratio of the screw volume utilization at the feeder area. These parameters were found to be difficult to be changed during the experimentation process; for this reason they were taken as constants related to this specific machine. The other group which were taken into consideration as optimization variables for are the moisture content of the feedstock mixture and the binder content. For this experimental setup the binder used was the Molasses, which available in big amount, and is not utilized economically by most of the sugar factories in Sudan. Molasses generate some when burning; this is why reducing the amount of the binder used results in better quality. Preparation of the samples for experimental measurements requires measuring the moisture contents of the binder and the carbonized cotton stalks before mixing.

5. Results and Discussion

The machine prototype was manufactured locally by a standard workshop in Khartoum industrial area, and transported to *Al-Gazeera* area in central Sudan for actual field testing. All the testing measurements were conducted at the field and at the Energy Research Centre (ERC) main laboratories at *Suba*, south of Khartoum. The machine general performance was found to be very good when working at the right slurry composition. The slurry moisture content was reduced gradually to find the minimum possible moisture content for continuous operation of the briquetting machine. The lowest value was found to be 30% moisture content, above which the machine started to stop frequently due to the die blockage by the relatively dry slurry.

Samples were taken for different slurry moisture content values, and the mass of each patch produced within a certain interval of time was measured on dry bases, measurements were usually taken after two days of sun drying of the specimens on open drying trays. The best production rate was found is 198 kg/h when the initial feed stock moisture content was adjusted to 35 %, lower moisture contents resulted in lower production rates due to the machine's frequent blockages, while higher moisture contents resulted in lower production rate after drying due to the initial higher water content. This production rate is about eight times the production rate of the double acting hydraulic press described earlier. This production rate could have been improved slightly if the slurry handling system was mechanized, but this was thought to complicate the system and increase the manufacturing cost.

Samples were taken from all the production patches at the different moisture and binder compositions and subjected to the drop test suggested by Pryor [4], in which a certain number of specimens were dropped from a height of two meters on a hard concrete floor. The results of the test showed that all the specimens of binder content higher than 3 % passed the test, however specimens of binder content lower than 2.5% were found to be very brittle and were very difficult to handle and transport.

The best machine performance were reported at a moisture content of 35% and a binder content of 7%, at these conditions the machine didn't show any blockage signs. The briquettes received a very good acceptance by the locals at the *Al-Gazeera* area when distributed to check the acceptance, they were found to be very good when used with *El-Suroor* stove which was developed by ERC earlier. Figure 5 shows the production rate as a function of the moisture content for samples of different binder content. The Figure illustrates that the higher binder content results in better production rate.

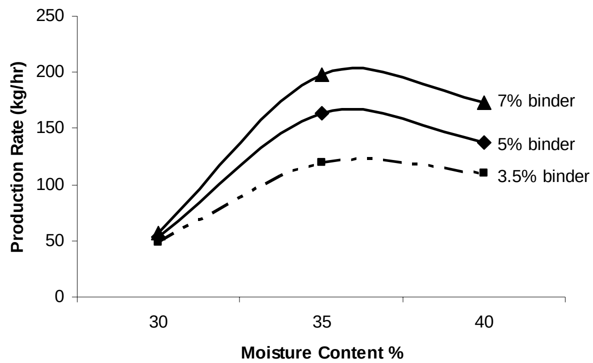

Fig. 5. Variation of the production rate with the change of the moisture content.

The comparison between the present system and the previous local system shows a lot of improvement in the production rate, which is 8 times better than the previous system; the binder content is lower in the present system by 65% when compared to the previous system; and the moisture content is lower by 30% when compared to the previous system. Figure 6 shows these comparisons.

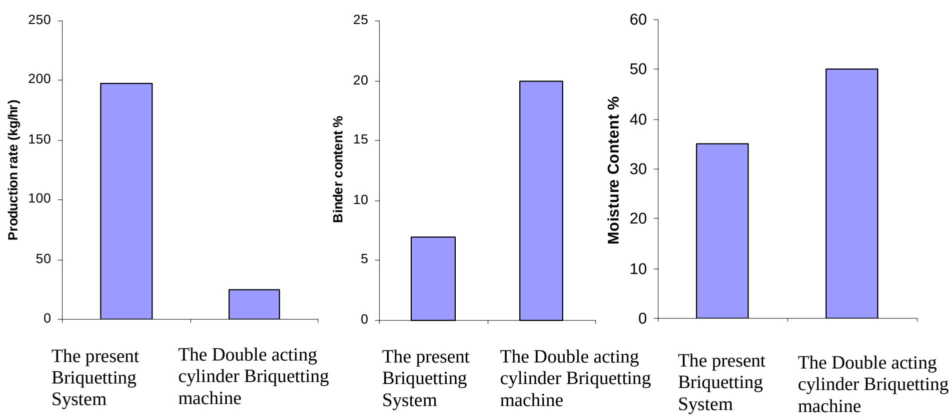

Fig. 6. Comparison between the present briquetting machine and the previous system.

6. Conclusions

A low pressure briquetting machine was designed and the prototype was manufactured locally in Sudan. The briquetting system used is based on a power screw concept, and is suitable for the briquetting of the carbonized agricultural waste for household fuel production. The system showed a very good production rate when compared with the previous local systems. The production rate of the new system was found to be 198 kg/hr, which is eight times the production rate of the previous local machine. The binder content required by the new system was lower than the previous system by 65% which means a big reduction in the total production cost, and better quality due to the lower smoke generation. The initial moisture content of the slurry required for the new system was reduced to 35% instead of 50% required by the previous system, this resulted in lower drying time of the produced briquettes.

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