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INVESTIGATION ON TRACTOR OPERATED PELLETING MACHINE FOR DENSIFIED FUEL PRODUCTION FROM ARGO RESIDUES

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ABSTRACT

Agricultural biomass waste converted to energy can substantially displace fossil fuel, which reduces emission of greenhouse gases and provide renewable energy. Pelletizing technology is one of best alternative to convert loose biomass into compacted material results reduces storage and transportation cost and also increases bulk density. In present experimental study, a more efficient and portable flat die type tractor operated pelleting machine was developed to produce cotton pellets and assess the performance of machines for small-scale farmers. In the present study for densification process of cotton stalk was used for evaluation of pellet production and characterization of pellets using PTO operated flat die type pelleting machine having capacity 50 kg/h. Box Behnken design by using Design Expert was used to optimize performance of flat die type pelleting machine. The calorific value of cotton pellets was found to be 4519.19 kcal/kg. During the experiment, the durability test was observed to be 93.75 per cent for cotton pellets. The volumetric energy density ratio was observed as 3.25 in cotton pellets. The thermal efficiency was found to be 16.21 per cent using cotton pellets. TG and DTG analysis cotton pellets justified that the obtained pellets samples were inclining towards the highest thermal stability. The performance tests showed that most of the requirements of small farmers including a minimum capacity 50 kg/h and pellet density 600 to 700 kg/m³ could be fulfilled by this machine.

Key words : Densification, Biomass, Pellets, Efficiency, Renewable energy, Cotton stalk.

Introduction

India is having a huge potential for a production of green energy. Biomass is one of the potential sources of renewable energy. As per MNRE report, India is having a potential to generate nearly 18,000 MW of energy from biomass. There are two routes for biomass conversion into useful fuel, namely the biochemical route and the thermo chemical route. Biomass can reduce CO_2 and acidic gas emissions and used as a continuous source for heat and power. Nowadays, use of densified biomass is gaining more popularity as it reduces handling, transportation and storage cost. Biomass can be densified in briquettes or pellets. Burning biomass material in pellets form for power generation overcomes the drawbacks of traditional use of biomass as low thermal efficiency. Biomass pellets could be used directly as fuel for residential heating stoves, heating boilers and large-scale power plants. Pelletization is the process of compressing or moulding the biomass into small lengthened particles such that the length is always greater than the width for general purpose usage. A wide array of biomass materials can be used to manufacture pellets, such as saw dust, corn stalk, rice husk, wheat bran, coconut skins and perennial grasses such as switch-grass (Kumar *et al.*, 2015). Most of the pelleting machines are operated using the electricity supply with an electric motor connection but the rural electricity supply in India is suffering both in terms of availability for a measured number of hours and penetration level. Most of the farmers utilized tractor as a power source at village level for performing field operation. Hence the tractor power source can be utilized for conversion of agro residue into pellets. A power transmission mechanism from tractor PTO to operate pelleting machine can overcome the problem of uneven availability of electricity. Considering the above facts, tractor operated pelleting machine was developed in order to utilize agro residue at the farm level and convert it into pellets.

Materials and Methods

The flat die and roller type pellet machine give better quality pellets. The design of flat die and roller is necessary for production of pellets from agro-waste material to convert it as a fuel for burning. Considering all the factors, a simple, convenient and efficient flat die and roller type pelletizing machine of approximately 50 kg/h capacity for agro residue material was developed. The components of pelletizing machine are feed hopper, flat die plate, roller press, pelleting chamber, main shaft, drive mechanism, gear box and frame (Aremu *et al*., 2014).

Selection of materials

Cotton stalk was selected as a feedstock for the production of pellets. The feedstock material was collected from the university farm. The material will be subjected to proximate analysis before and after the experiment.

Pellet Production Process

The shredded material was fed into the mixer and tap water was added to maintain moisture content of 20, 25 and 30 per cent (w.b.). The centrally rotating shaft in the mixer mix the feedstock with the help of blade and the material was discharged out from the mixer after thorough mixing. The grinded agro residue samples with different combinations of moisture content and particle size were discharged into the pelleting chamber by gravity flow. The temperature of the die plate and roller in pelleting chamber was increased during the pelletization process due to friction. The machine was operated by using power transmission tractor PTO mechanism and gear arrangement provided in the machine. At the same time temperature of agro residue pellets was also increased up to 70 to 72°C. Two rollers were provided in the pelleting chamber rotated in an anticlockwise direction over die plate and is used to press the feed material into the die holes to form uniform pellets. During the experiment, no external heating system was provided and no external binding agents were added during the formation of pellets. The pellets were collected and dried in open sun for one day to remove the moisture (Chou *et al*., 2009; Mushiri *et al*., 2017). The schematic view of proposed tractor operated pellet machine as depicted in Fig. 1.

Cotton stalk   Shredded cotton stalk   Cotton stalk pellets

Fig. 1 : Pellet Production Process.

Performance Evaluation of Pelletizing Machine

Performance evaluation of proposed system was carried out at different operating conditions including various feedstock, different die diameter, different RPM of PTO shaft (Gao *et al*., 2014; Olusegun *et al*., 2017).

Determination of pelleting efficiency

It is ratio of the quantity of actual feed pelleted obtained at the main die orifice to the total feed input per unit time.

$$\eta_p = \frac{W_p}{W_t} \times 100 \quad (1)$$

Where,

η_P = Pelleting efficiency, %;

W_P = Total mass of pellets produced by the machine, kg;

W_T = Total mass of input, kg

Determination of Pelleting Capacity

This is the ratio of the quantity of actual feed pelleted to the time taken.

$$P.C. = \frac{W_p}{T} \quad (2)$$

Where,

P.C. = Pelleting capacity, kg/h;

W_P = Total mass of pellets produced by the machine, kg;

T = Time taken to pelletize the specified feed, h

Fuel consumption

In order to measure the fuel consumption during pellet production using tractor its fuel tank was filled with diesel up to the neck level during first test operation. One batch was processed through the normal running of the pelleting machine. Then tractor was stopped after completing the batch and fuel tank was refilled with diesel to maintain the original level of fuel. Total refilled diesel with the help of a measuring cylinder was the total fuel consumed for operating machine.

Data analysis

The experimental data was analyzed by using suitable tool. For analyzing the data following are the different independent and dependent variables.

Table 1 : Independent variables.

S. no.	Variables	Units	Levels (coded and decoded)		
			1	0	-1
1	Moisture content	%	20	25	35
2	Particle size	Mm	4	6	8
3	Speed of shaft	Rpm	150	200	250
Dependent variables					
S. no.	**Variables**	**Units**			
1	Pelleting efficiency	%			
2	Pelleting capacity	kg/h			
3	Pellet density	kg/m^3			
4	Fuel consumption	lit/h			

Properties of cotton pellets

The properties of cotton pellet were determined in terms of moisture content, volatile matter, ash content, fixed carbon, pellet durability, calorific value, volumetric energy density ratio, thermal efficiency, thermogravimetric analysis (Mostafa *et al*., 2019).

Moisture content

The moisture content in samples was determined by drying a weighed sample to constant weight in an oven at a temperature of 105°C for 24 hours.

Moisture Content (%) = ((B-C))/((B-A)) × 100 (3)

Where, A = Weight of the sample box, g;

B = Weight of the sample box + sample, g;

C = Weight of the sample box + sample after drying at 105°C at 24 h.

Volatile matter

The volatile solid content was determined by using muffle furnace maintained at 925 ± 20^{0}C for 7 minutes.

$$\text{Volatile solids (\%)} = \frac{(B-C)}{(B-A)} \times 100 \quad (4)$$

Where,

A = Weight of silica crucible, g;

B = Weight of crucible + dry matter before ignition, g;

C = Weight of crucible + sample after ignition (ash), g

Ash content

The residual sample in the crucible was heated without lid in a muffle furnace at 700 ± 50^{0}C for one half hour.

$$\text{Ash content (\%)} = \frac{(C-A)}{(B-A)} \times 100 \quad (5)$$

Fixed carbon

The fixed carbon content was the value obtained after subtracting the value of moisture content, volatile matter, and ash content from the hundred percent for balancing the value

Fixed carbon (%) =100 – (M.C.+ V.M.+ A.C.) (6)

Where,

M.C. = Moisture content, %;

V.M. = Volatile matter, %;

A.C. = Ash content, %

Pellet durability

The durability was calculated using the following relation

$$\text{PD} = \frac{W_a}{W_b} \times 100 \quad (7)$$

Where,

PD = Pellet durability, %;

W_a = Mass of the pellet after shaker treatment, g;

W_b = Mass of the pellet before shaker treatment, g

Calorific value

According to the ASTM D 3286 standard, the bomb calorimeter was used for the determination of the calorific value of the biomass. The mathematically, it is represented as

$$\text{CV} = \frac{T \times W - (CV_t + CV_w)}{x} \quad (8)$$

Where,

CV = Calorific value, kcal/kg;

T = Rise in temperature !;

W = Water equivalent, kcal/°C;

CV_t = Calorific value of nichrome wire × Weight of wire, kcal;

CV_w = Calorific value of thread× Weight of thread, kcal;

X = Weight of sample taken, kg

Volumetric energy density ratio

The energy density ratio of pellet fuel was calculated by using the equation as below

$$\text{ED}_{\text{ratio}} = \frac{\rho_p \times CV_{Pellet}}{\rho_A \times V_{Agro\ residue}} \quad (9)$$

Where,

ED_{ratio} = Energy density ratio;

ρ_p = Pellet density, kg/m^3;

ρ_A = Bulk density of agro residue, kg/m^3;

CV_{pellet} = Higher heating value of pellet, kcal/kg;

$CV_{Agro\ residue}$ = Higher heating value of agro residue, kcal/kg

Thermal efficiency

The water boiling test was conducted for the evaluation of the thermal efficiency of agro residue pellets using SPRERI tech cookstove. During the experiment, the materials used for the water boiling test were distilled water, pellets, vessel, lid, thermometer, etc. The following formula was used for the determination of thermal efficiency.

$$\eta = \frac{M_w \times C_p \times \Delta_t + M_{we} \times \lambda}{F \times CV} \quad (10)$$

Where,

η = Thermal efficiency, %;

M_w = Initial volume of water taken, kg;

C_p = Specific heat of water, kcal/kg°C;

ΔT = Mass of water evaporated, kg;

M_{We} = Latent heat of water, kcal/kg;

F = Quantity of fuel used, kg; CV= Calorific value, kcal/kg

Thermogravimetric analysis

Thermogravimetric analysis of agro residue pellets was done to understand the internal physio-chemical transformations affecting the thermal stability of the different bio components, that occurred during the process. A thermogravimetric analyzer (Model: STA 7300, Make: Hitachi) was used. The thermogravimetry provided information about the weight loss (per cent) of agro residues pellets with respect to the temperature or time (thermogram) during the thermal degradation process. TGA analysis was performed at the Department of Renewable Energy Engineering, CTAE, Udaipur.

Results and Discussion

Performance Evaluation of Tractor Operated Pelleting Machine using Cotton Stalk

Effect of moisture content and speed of shaft on pelleting efficiency for cotton stalk

With increasing moisture content from 20 to 30 per cent at 150 to 250 rpm speed of shaft, the pelleting efficiency also increased from 81.88 to 92.48 per cent in the cotton stalk as shown in Fig. 3. The maximum pelleting efficiency 92.48 per cent was observed at moisture content 30 per cent and speed of shaft 250 rpm whereas the minimum pelleting efficiency 81.88 per cent was observed at moisture content 20 per cent and speed of shaft 150 rpm.

Effect of moisture content and speed of shaft on pelleting capacity for cotton stalk

The moisture content increases from 20 to 30 per cent at 150 to 200 rpm speed of shaft, the pelleting capacity increased from 41.48 to 44.75 kg/h then slightly decreased from 44.75 to 40.56 kg/h and speed of shaft at 250 rpm, the pelleting capacity increased from 44.48 to 46.12 kg/h due to higher speed of shaft as depicted in Fig. 3. The maximum pelleting capacity of 46.12 kg/h was observed at moisture content 30 per cent, particle size 6 mm and speed of shaft 250 rpm, whereas the minimum pelleting capacity of 40.46 kg/h was observed at moisture content 25 per cent, particle size 6 mm and speed of shaft 150 rpm (Table 2).

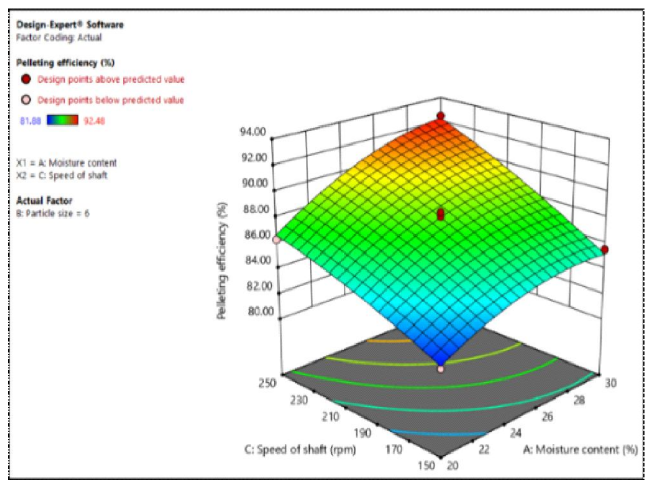

Fig. 2 : Effect of moisture content and speed of shaft on pelleting efficiency for cotton stalk.

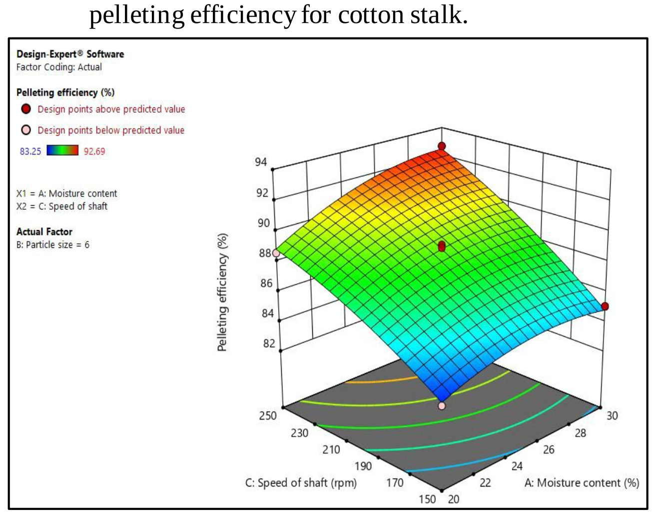

Fig. 3 : Effect of moisture content and speed of shaft on pelleting capacity for cotton stalk.

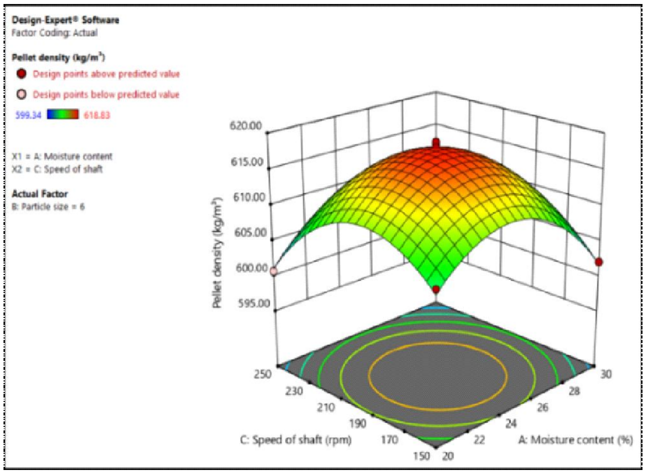

Fig. 4 : Effect of moisture content and speed of shaft on pellet density for cotton stalk.

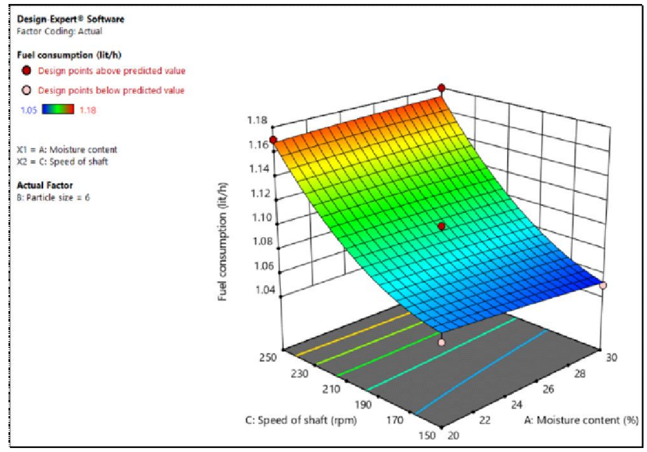

Fig. 5 : Effect of moisture content and speed of shaft on fuel consumption for cotton stalk.

Table 2 : Analysis of variance (ANOVA) data showing the effect of independent variables on the pelleting efficiency of cotton stalk.

Source	Sum of squares	df	Mean square	F-value	p-value
Model	118.60	9	13.18	66.15	< 0.0001*
Residual	1.39	7	0.1992		
Cor total	119.99	16			
Std. dev.= 0.4463			R^2= 0.9884		
Mean= 87.07			Adjusted R^2 = 0.9734		
C.V.%= 0.5126			Predicted R^2 = 0.9008		

* = significant at 1% Adeq precision = 29.8053

The linear terms moisture content, particle size, speed of shaft, quadratic term moisture content, particle size, interaction term moisture content × speed of shaft was found significant at 5% significance level. F-values indicated that speed of shaft was the most influencing parameter in a linear way whereas the effect of particle size was the least.

The linear terms moisture content, speed of shaft, quadratic term moisture content, speed of shaft interaction term moisture content × speed of shaft was found significant at 5% significance level. F-values indicated that speed of shaft was the most influencing parameter in a linear way whereas the effect of particle size was the least.

Effect of moisture content and speed of shaft on pellet density for cotton stalk

The increase in moisture content from 20 to 25 per cent at 150 to 200 rpm speed of shaft, the pellet density increased from 600.56 to 618.03 kg/m³ then for moisture content from 25 to 30 per cent at 200 to 250 rpm speed of shaft, the pellet density decreased from 618.03 to 601.09 kg/m³ as shown in Fig. 4. The maximum pellet density was observed at 618.83 kg/m³ at moisture content of 25 per cent, particle size 6 mm and speed of shaft 200 rpm whereas minimum pellet density was observed at 599.34 kg/m³ at moisture content 30 per cent, particle size 6 mm and speed of shaft 250 rpm (Table 3).

Effect of various process parameters on fuel consumption of tractor for cotton stalk

With increasing the speed of shaft from 150 to 250 rpm at 20 to 30 per cent moisture content, fuel consumption of tractor increased from 1.062 lit/h to 1.184 lit/h. With increase in the speed of shaft from 150 to 250 rpm at 20 to 30 % moisture content, the fuel consumption increased from 1.052 to 1.176 lit/h as depicted in Fig. 5. The maximum fuel consumption of tractor was found at 1.176 lit/h with moisture content 30 per cent, particle size of 6 mm and speed of shaft 250 rpm whereas minimum fuel consumption of tractor of 1.052 lit/h was found at moisture content 25 per cent, particle size 4 mm and speed of shaft 150 rpm (Table 4).

The linear terms moisture content, particle size, speed of shaft, quadratic term moisture content, particle size, speed of shaft interaction term moisture content × particle

Table 3 : Analysis of variance (ANOVA) data showing the effect of independent variables on the pelleting capacity of cotton stalk.

Source	Sum of squares	df	Mean square	F-value	p-value
Model	49.04	9	5.45	44.35	< 0.0001*
Residual	0.8601	7	0.1229		
Cor total	49.90	16			
Std. dev.= 0.3505			R^2= 0.9828		
Mean = 43.69			Adjusted R^2 = 0.9606		
C.V.% = 0.8023			Predicted R^2 = 0.8590		

* = significant at 1% Adeq precision = 21.6388

Table 4 : Analysis of variance (ANOVA) data showing the effect of independent variables on the pellet density of cotton stalk.

Source	Sum of squares	df	Mean square	F-value	p-value
Model	862.13	9	95.79	158.79	< 0.0001*
Residual	4.22	7	0.6033		
Cor total	866.35	16			
Std. dev.= 0.7767			R^2= 0.9951		
Mean= 607.71			Adjusted R^2= 0.9889		
C.V.% = 0.1278			Predicted R^2= 0.9517		

* = significant at 1% Adeq precision = 30.1655

Table 5 : Analysis of variance (ANOVA) data showing the effect of independent variables on the fuel consumption of cotton stalk.

Source	Sum of squares	df	Mean square	F-value	p-value
Model	0.0261	9	0.0029	48.96	< 0.0001*
Residual	0.0004	7	0.0001		
Std. dev. = 0.0077			R^2= 0.9844		
Mean = 1.10			Adjusted R^2 = 0.9643		
C.V.% = 0.6972			Predicted R^2 = 0.8150		

* = significant at 1% Adeq precision = 20.4623

size and moisture content × speed of shaft was significant at 5% level. F-values indicated that speed of shaft was the most influencing parameter in a linear way whereas the effect of moisture content was the least.

The linear terms speed of shaft and quadratic term speed of shaft were found significant at 5% significance level. F-values indicated that speed of shaft was the most influencing parameter in a linear way and moisture content was least one.

Optimization of Process Parameter for Cotton stalk

The optimum operating conditions for moisture content, particle size and speed of shaft were 26.11 per cent, 5.65 mm and 204 rpm respectively corresponding to these values of process variables, the values of pelleting efficiency, pelleting capacity, pellet density and fuel consumption were 87.06 per cent, 41.65 kg/h, 613.05 kg/m^3 and 1.13 lit/h, respectively.

Properties of Agro Residue Pellets

Proximate analysis

The results of proximate analysis of cotton pellets are given in Table 6 (Nguyen *et al*., 2015).

The durability is highly important for handling, storage and transportation. During the experiment, durability was observed to be 93.75 per cent for cotton pellets. The calculated calorific value for the cotton pellets were 4519.19 kcal/kg, respectively. The energy density ratio was observed 3.25 in cotton pellets. The thermal efficiency of the SPRERI tech stove using pellets fuel were found to be 16.21 per cent using cotton pellets.

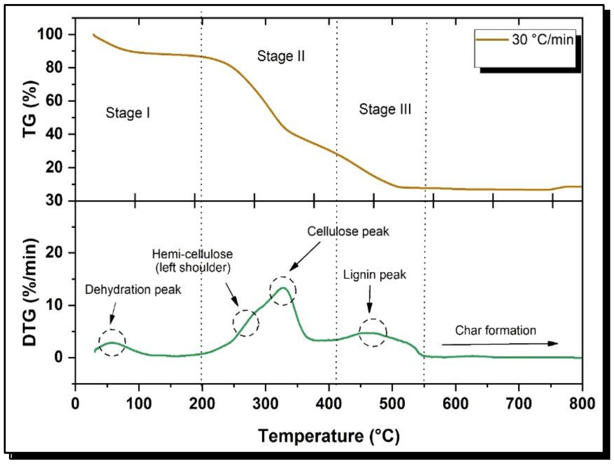

Fig. 6 : TG and DTG behavior of cotton pellets at 30°C/min.

Table 6 : Proximate analysis of cotton pellets.

Agro residues	Moisture content (%)	Volatile matter (%)	Ash content (%)	Fixed carbon (%)
Cotton pellets	4.13	73.47	5.73	16.67

Thermogravimetric analysis

The thermogravimetric and differential thermal behavior of cotton pellets were performed in a TG-DTG unit for obtaining the thermal degradation curves or patterns. The obtained TG and DTG curves for pyrolysis of cotton pellets are shown in Fig. 6. According to above results, the weight loss during the first stage (water and light volatiles) was higher in the case of agro residues due to higher moisture content. The low moisture content of pellets may be due to the densification process during which pellets were dried. The thermogravimetric and differential thermal analysis of agro residues pellets justified that the obtained pellets sample were inclining towards the highest thermal stability.

Conclusion

In present work, the pelleting machine was able to operate effectively at a power level that can be obtained from the power take-off output of a small tractor (18 hp) has been designed and evaluated for the production of pellets at the pilot scale. The performance tests showed that most of the requirements of small farmers including a minimum capacity 50 kg/h and pellet density 600 to 700 kg/m³ could be fulfilled by this machine. Box Behnken design by using Design Expert was used to optimize performance of flat die type pelleting machine. The flat die type machine was able to operate effectively at a power level that can be obtained from the power take-off output of a small tractor has been designed and evaluated for the production of pellets at the pilot scale. The optimum operating conditions for moisture content, particle size and speed of shaft were 26.11 per cent, 5.65 mm and 204 rpm, respectively corresponding to these values of process variables the values of pelleting efficiency, pelleting capacity, pellet density and fuel consumption were 87.06 per cent, 41.65 kg/h, 613.05 kg/m^3 and 1.13 lit/h, respectively for the cotton stalk. The calorific value of cotton pellets was found to be 4519.19 kcal/kg. After the pelletization of cotton pellets had moisture content 4.17 per cent, volatile matter 73.47 per cent, ash content 5.73 per cent and fixed carbon 16.67 per cent, respectively. The thermal efficiency of pellets fuel was found to be 6.21 per cent using cotton pellets. TG and DTG analysis of cotton pellets justified that the obtained pellets samples were inclining towards the highest thermal stability. One good feature of the machine was that no waste was recorded as the residue ingredients could be recycled.

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