

PAPER • OPEN ACCESS

Study on combustion mechanism of biomass briquette and its application

To cite this article: Shuguang Liu *et al* 2019 *IOP Conf. Ser.: Earth Environ. Sci.* **227** 022008

View the [article online](#) for updates and enhancements.

Study on combustion mechanism of biomass briquette and its application

Shuguang Liu^{1,3}, Yage Gao², Liang Wang¹ and Xiaolong Chen¹

¹ School of Mechanical and Electrical Eng. Huangshan University, Huangshan, China;

² Department of Energy and Power Engineering, Tsinghua University, Beijing, China.

³ Email: Liushuguang@hus.edu.cn

Abstract. The biomass fuel is a kind of clean and renewable new energy. With the increasingly serious environmental pollution, it plays a more and more important role in the social activities of the short of fossil energy resources. However, compared with coal or wood, the combustion characteristics of biomass fuels are very different, so the study of its combustion mechanism is a very valuable job. The combustion mechanism of biomass fuel was introduced in detail with straw fuel as example; and the influencing factors of biomass fuel combustion were analyzed in many aspects such as furnace temperature, air quantity, biomass fuel particle size, reaction time, moisture content, ash content and gas solid mixing ratio. On above basis, a set of biomass briquetting combustion equipment for tea machinery is designed.

1. Introduction

With the rapid development of global economy, the energy consumption is also constantly growing, as the important resources of human survival and development, the non-renewable resources such as coal, natural gas and oil will be eventually exhausted, at the same time in the extensive use of these non-renewable energy will lead to a series of serious environmental pollution problems. So drastically improve existing the actual utilization of energy and low pollution and developing a kind of low polluted and renewable resource through the high and new science and technology to gradually replace the high pollution and non-renewable fossil energy, is the main way to solve the human energy and the environment pollution crises problems. At present, among many renewable energy sources, biomass energy has the most potential for development, because it has the characteristics of large resource reserves, no pollution and renewable [1,2].

Biomass fuel combustion mechanism is the basis of developing biomass fuel combustion equipment, because biomass fuel combustion mechanism is very different from that of coal or wood. In order to make the biomass fuel combustion equipment can have higher combustion efficiency and low environmental pollution, this article on biomass combustion mechanism is studied, and analysis of the factors to affect combustion of biomass fuel. On the basis of this, a kind of combustion equipment of biomass granule was designed for tea machinery field.

2. Biomass fuel combustion mechanism

2.1. Biomass fuel's characteristics

The elemental composition of biomass fuel is very different from that of coal, and Table 1 is the comparison table of elemental composition between biomass fuel and coal [3]. It can be seen from



Table 1 that there are the following differences between coal and biomass fuels: (1) high carbon content; (2) low oxygen content and low H₂O content; (3) low hydrogen content; Higher volatile content slightly lower; We're also going to have a high density.

Table 1. The comparison of elemental composition of biomass fuel and coal.

	C (%)	H (%)	O (%)	Volatile (%)	Ash (%)	Density (t/m ³)
Biomass burning (wood)	2	5~7	29-45	64~71	5~16	0.49~0.65
Coal (bituminous coal/anthracite)	23~91	4~5	4-19	6~39	6~24	0.7~1.0

Because of the difference of biomass fuel and coal on the components of above, so in order to make the biomass combustion equipment more economic, efficient and reliable when it works, so according to the different way of biomass fuel in the gas supply, combustion chamber structure and fuel supply properly adjusted to make the combustion more fully and more efficient is necessary.

2.2. Combustion stage of biomass fuel

2.2.1. Analysis of each combustion stage. The burning process of biomass fuel is a violent exothermic/endothermic physical and chemical reaction. In the process of combustion, due to the fuel and air mass/heat transfer process will happen, so the heat generated by the fuel combustion can make the environment temperature, elevated temperature can accelerate the mass transfer process. Therefore, the prerequisite for combustion is: not only adequate fuel, but also adequate air supply and adequate heat supply [4,5].

The combustion process of biomass fuel is shown in Figure 1. The combustion process can be divided into four stages: fuel preheating, drying, volatile analysis combustion and coke combustion. The different stages of the biomass fuel combustion is serial in general, but there are also overlaps in the process, time needed for each stage is related to many factors such as type, composition and fuel combustion mode. In order to make the analysis more targeted, take straw as an example to illustrate the four stages of its combustion process.

(1) Preheating stage: after the straw is sent to the combustion equipment, the combustible material on the straw surface will be ignited by a specific ignition method, and the environmental temperature will gradually increase.

(2) Drying stage: water will evaporate in the gradually rising ambient temperature, making the straw dry. Meanwhile, the dry straw will continue to absorb heat and increase temperature.

(3) Volatile analysis combustion stage: when the temperature gets up to 106 ~ 106 °C, the straw on the surface of the volatile branch by precipitation in the form of gas, the structure of the fuel are becoming fluffy; Temperature rise further, when up to 260 ~ 370 °C, volatile burning in the first place. The volatile fraction can be burned only if temperature and concentration are prepared. With straw surface volatile combustion, the heat released by the gradual accumulation are accumulated, through the transfer and radiation spreading to straw lining, volatile separating out further and this part of volatile mixed with oxygen in burning, a lot of heat released at the same time, the volatile surrounded the coke in the rest of the straw, the oxygen chamber of a stove or furnace is difficult to directly contact to the surface of coke, so it is not easy for coke burning. The combustion of volatile components prepared thermal conditions for subsequent coke combustion [6].

(4) Coke combustion stage: with the decrease of volatile content, coke contacts with oxygen gradually, making coke start to burn. In the process of coke burning, the ash content will be produced continuously, and the coke in the inner layer of fuel will be wrapped by the ash content to prevent it from continuing to burn. At this point, if stirring or strengthening the air supply in the furnace from time to time, the remaining coke can continue to burn.

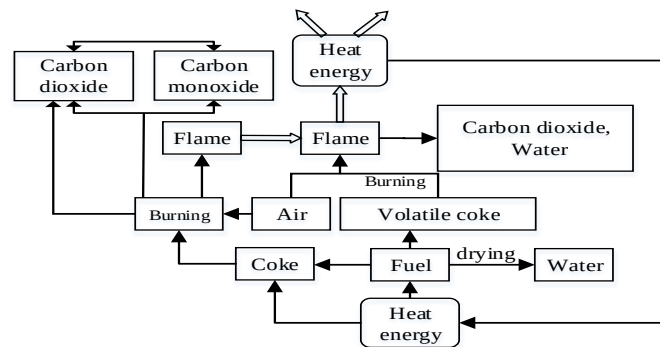


Figure 1. Biomass fuel combustion process.

In conclusion, the above combustion processes can be divided into two categories: endothermic reactions (preheating, drying and volatile analysis) and exothermic reactions. Volatile combustion and coke combustion, the former account for 15% of the combustion time, but provide 65% of the total heat, the latter account for 85% of the combustion time.

2.2.2. Temperature control. The combustion process of biomass fuel in the combustion equipment is [7]



When the supply of O_2 is insufficient, the CO_2 generated in equation (1) may conduct endothermic reaction with C in the air, leading to the decrease of environmental temperature. The equation is



At the same time, water vapor and C in the air may also conduct endothermic reaction



According to equation (2) and (3), both products CO and H can further exothermic reaction with O_2 , thus increasing the temperature in the hearth



From the above equation shows in the process of biomass fuel combustion, even if not complete combustion, but as long as there is enough air and after a certain time, the heat released by hearth can also meet the requirements. Therefore, a certain amount of flue gas is introduced in the combustion process, and the temperature of the hearth is decreased by the heat absorption reaction to prevent the coke slag in the hearth.

2.2.3. Amount of air required for combustion. The combustible elements of biomass fuels are generally C and H. The exothermic reaction between C and H and O_2 occurred during combustion. Most combustion equipment gets O_2 from the air. Therefore, in general, the amount of air required for combustion should be calculated as the basis for the design of combustion equipment. The combustible components in biomass fuel, which react with O_2 in the reaction equation



The volume percentage of biomass fuel and the amount (volume) of oxygen required for each combustible component can be directly calculated from equations (6), (7) and (8). The theoretical air quantity required for fuel can be obtained from the following equation

$$V^0 = (1/2CO + 2CH_4 + 1/2H_2) / 21 \quad (9)$$

The amount of air required during combustion is

$$L_\alpha = \alpha V^0 L_g \quad (10)$$

Where, α is the air excess coefficient, and in order to make the fuel can be completely burned without premixed condition, its value is 1.5-2.8, and the optimal value is 2.0; L_g is gas consumption.

2.2.4. Quantity of smoke emission. The amount of smoke emission has an important influence on the structure and size design of biomass fuel combustion device, so the calculation of smoke emission is also very important. The amount of smoke emitted by biomass fuel is related to its element composition, water content and air excess coefficient. The calculation formula for the amount of smoke discharged during the combustion of 1Kg biomass fuel is

$$\begin{aligned} V_{py} &= 0.1868(0.376S^y + C^y) \\ &= 0.11H^y + 0.0134W^y + 0.006N^y + (1.02\alpha_{py} - 0.32)V^0 \end{aligned} \quad (11)$$

Where, V_{py} is the actual smoke emission of 1Kg biomass fuel, unit is m^3/kg ; S^y , C^y , H^y , W^y and N^y are respectively the application base contents of S element, C element, H element, water element and N element for fuel materials (%); α_{py} is the Q value at the smoke exhaust.

There is a positive correlation between the heat loss of smoke emission and the temperature of smoke emission in the furnace, so the heat loss of smoke emission increases with the increase of smoke emission.

2.2.5. Combustion temperature. The burning temperature of biomass fuel is directly related to fuel type, composition, environmental conditions and combustion equipment. Combustion temperature is also one of the key parameters of biomass fuel combustion equipment design. In general, the equilibrium relationship between heat intake and heat discharge in biomass fuel combustion determines the actual combustion temperature [8].

The heat inhalation of biomass fuel mainly includes the chemical heat of fuel and the heat generated by fuel Q_{DW} , the physical heat Q_f of fuel and the physical heat Q_a of air.

The heat emission from biomass fuel combustion mainly includes that the combustion product contains physical heat Q_p ($Q_p = V_p \times C_{pp} \times T_p$, where, V_p is the burning amount of fuel, C_{pp} is the average specific heat of combustion products, T_p is the temperature of combustion products), Heat transfer Q_t to the environment when the combustion product burns, Heat loss Q_{loss} due to incomplete combustion of fuel.

It can be seen from the heat balance principle that when the heat input is equal to the heat output, the combustion product reaches a relatively stable combustion temperature, that is, the heat balance equation is

$$Q_{DW} + Q_a + Q_f = V_p \times C_{pp} \times T_p + Q_t + Q_{loss} \quad (12)$$

According to equation (12), the temperature of the combustion product is

$$T_p = \frac{Q_{DW} + Q_a + Q_f - Q_{loss} - Q_t}{V_p \times C_{pp}} \quad (13)$$

3. Factors of influencing biomass fuel combustion [9]

3.1. Furnace temperature

Furnace temperature is the most direct factors affecting biomass fuel combustion, on the premise of fully considering the coke slagging problems, must increase the temperature of the furnace in the greatest extent, to promote the biomass fuel combustion reaction rate.

3.2. Air volume

The process of combustion depends on the supply of fuel and air. The combustion reaction will lead to fuel waste due to insufficient air supply and incomplete combustion. But if too much air is supplied,

the extra air will take away the heat it absorbs, lowering the temperature of combustion and making it unstable. Therefore, the air volume needs to have an optimal range, so the stability of the air excess coefficient is the prerequisite to ensure the stability of the combustion process.

3.3. Biomass fuel particle size

As the reaction of solid particles is generally carried out on its surface, the larger the surface area of biomass fuel particles is, the more favorable the combustion reaction is. The particle size is inversely proportional to its surface area. Therefore, the size of biomass fuel particles should be minimized in order to improve its combustion reaction efficiency.

3.4. Reaction time

The burning of biomass fuel also belongs to the category of chemical reaction, so the burning of biomass fuel can only be finished after a certain period of time. Sufficient reaction time is also one of the important factors for biomass fuel to complete combustion reaction.

3.5. Water and ash content

Combustion reaction is exothermic reaction, and the evaporation can strongly absorb heat, the process of the burning of biomass fuel belongs to self-sustaining type, so its moisture content should not exceed 79%, if more than, need to use the auxiliary fuel combustion.

Because ash content in fuel is not combustible, the higher the ash content of biomass fuel, the lower its heat value and burning temperature. In the process of combustion lining in the unburned fuel may be packaged by ash content, and then make the fuel combustion rate reduced, at the same time when the temperature reaches a certain height, the high ash content will increase the amount of melting, so reasonable measures should be taken to make the fuel combustion completely, and at the same time reduce the corrosion on burning stoves.

3.6. Gas-solid mixing ratio

In combustion, need a certain amount of oxygen diffusion to the fuel particle surface, in the process of fuel combustion reaction, the inner lining of the ash content will gradually exposed, then wrap up the not complete combusted of carbon. Therefore, in the process of combustion, it should be agitated from time to time to ensure a reasonable gas-solid mixing ratio, so that ash can be peeled off and the incomplete combustion of carbon can be exposed, and finally fuel can be fully burned.

The above analysis shows that temperature, air quantity and gas-solid mixing and reaction time and space is the three elements of biomass fuel burn adequately, the design of combustion equipment should according to the combustion characteristic of different biomass fuels take those factors into consideration, in order to improve the combustion of biomass fuel efficiency

4. Design of combustion equipment for forming fuel

4.1. Design ideas

Molding fuel preparation mainly adopts curing technology, by adding bonding agent and acceleration, low-grade biomass can be converted to the high grade biomass fuels which are convenient for storage, transportation and using. Biomass granule combustion machine is a kind of forming fuel combustion equipment, which is used more and more in agricultural machinery, biomass power generation, industrial boiler, food drying equipment and other industries. In the field of tea machinery, biomass burning machine filming for the tea machine and dry tea frying machine are used, in general combustion machine can consume an energy between 150000 calories and 700000 calories, the combustion value limits its application scope that it is only suitable for small dryer.

4.2. Overall design

(1) Temperature design: according to the combustion characteristic of straw fuels, fuel burning have a total of four stages, the sequence of the combustion is hair of decomposition, precipitation and diffusion, phase and stratified combustion; Because biomass has a characters of high ash content, low ash melting temperature and easy slagging, such as excessive internal heat is easy to cause ash melting bond, when design temperature control system by controlling the operation to achieve the role of regulation. Chamber of a stove or furnace in high temperature flue gas temperature and precipitation of volatile are needed, in this process we set the temperature in the temperature of 1200 °C, due to the coke in the process of burning the required temperature is not high, it cannot exceed the softening temperature of the biomass granule molding fuel, we will set it under 900 °C for avoiding over softening temperature of the coke and realizing the full combustion of fuel and ash slagging rate control.

(2) Theoretical air volume calculation: the biomass particulate fuel is mainly the combustion of C, H and other elements, and the theoretical air volume required for the combustion of 1 kg fuel is determined according to equations (9) and (10).

(3) Volume calculation of combustion equipment: the volume of combustion equipment is directly proportional to the fuel inlet ratio and heat generation, and inversely proportional to the volume heat load

$$V = \frac{BQ}{3600q_v} \quad (14)$$

Where, V is the volume size (m^3) in the combustion furnace; B is the fuel consumption (kg/h); Q is the low heating rate of fuel (kJ/kg); q_v is the thermal load (kW/ m^3) in the furnace.

(4) Furnace row area calculation: Furnace row is a support bar in grate plate burning machine under the high temperature combustion zone, fuel stays on the grate plate it needs oxygen to burning, as a result of the fire grate plate side set a ventilation pipe, so to improve the fuel combustion, need to vent is set in grate plate. Grate plate area computation is as follows

$$R = \frac{BQ}{360q_R} \quad (15)$$

Where, R is the area size of furnace platen (m^2); q_R is the thermal strength (kW/ m^2) within the unit area of furnace platen.

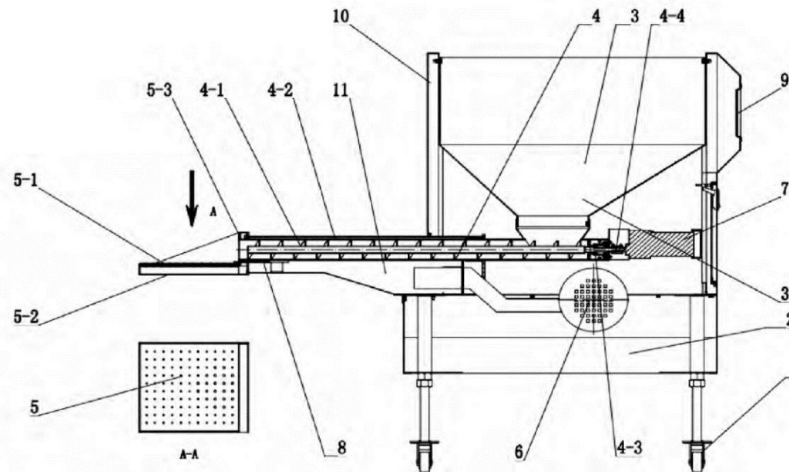
4.3. Structure design

A kind of the 3D design software called Solid works is used for 3d modeling in product design, and virtual assembly technology is adopted to verify the rationality of the design. Biomass particle combustion machine structure designed as shown in Figure 2, mainly including frame, a regulating wheel, outer garment, hopper, feeding parts, drive motor, blower, burning plate components, ignition device, ventilation duct (distribution), control system and other components, including frame, hopper and feeding component form, detachable whole, feeding parts core element is installed in the cylinder wall can rotate freely feeding feeding screw, burning plate component fixed on the feeding parts discharging bottom, it is characterized by platform structure, including the underframe, burning platform, such as vertical end plate structure, Replace the traditional particle combustion chamber combustion platform or platforms for granular materials burning chamber of a stove or furnace, guarantees the vertical combustion flame, burning completely fully, and avoid the phenomenon of tempering traditional particle combustion machine easily.

4.4. Electrical design

Combustion machine transmission part is composed of feeding motor and ventilation, biological particles forming fuel are transport to hearth for burning from transport pipeline drove by hopper feeding motor, at the same time the ventilation motor distribution air output, so that the heat pipe can reach to the required heat. Electrical control adopts PLC, real-time control of motor speed to achieve control of feed speed and the size of the air flow, to ensure that the temperature of the heating body

internal constant, so that it can realize the temperature's accurate control. The schematic diagram of electric combustor is shown in Figure 3.



1. Wheel assembly; 2. Rack; 3. Feeding hopper; 4. Feeding components; 4-1. Feeding screw; 4-2. Feeding cylinder; 4-3. Bearing; 4-4. Coupling; 5. Combustion components; 5-1. Combustion panel; 5-2. Combustion bottom plate; 5-3. Combustion riser; 6. Blower; 7. Driver; 8. Ignition system; 9. Control system; 10. Outer cover; 11. Ventilation pipe

Figure 2. Structure of biomass pellet combustion machine.

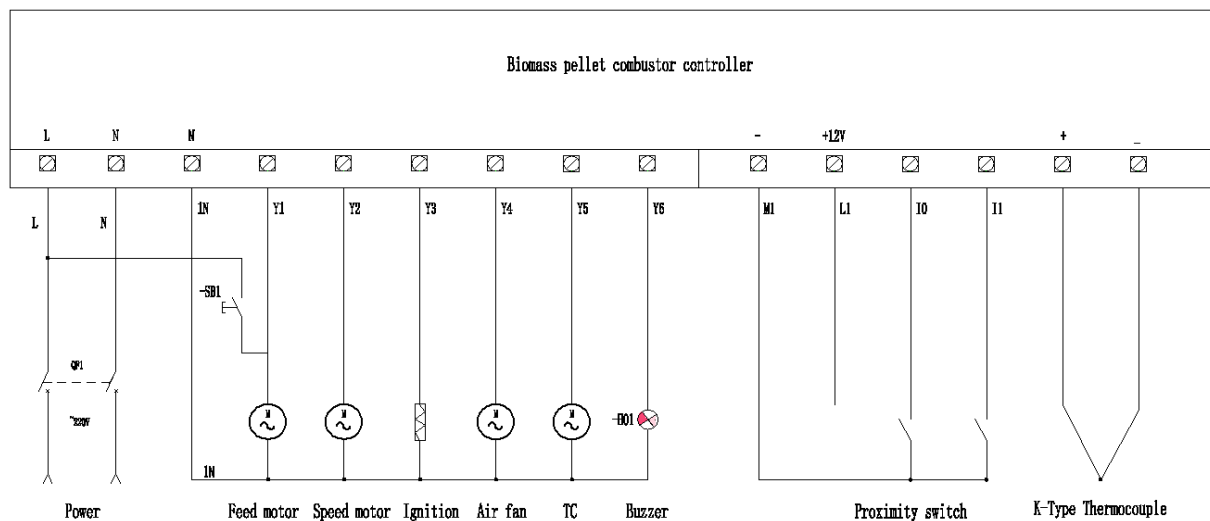


Figure 3. Control circuit of biomass particle burner.

5. Conclusions

Biomass fuel is a clean and renewable new energy source. With the increasingly severe environmental pollution, it plays an increasingly important role in the link of fossil energy shortage. However, compared with coal or wood, biomass fuel has a great difference in combustion characteristics. It is of great value to study its combustion mechanism. This paper detailed the combustion mechanism of the biomass fuel analysis, then respectively from the furnace temperature, air quantity, biomass, particle size, reaction time, moisture content, ash content and gas-solid mixing ratio on the influencing factors of biomass fuel combustion to discuss, the research results can provide reference for designing combustion equipment of biomass. Finally, a kind of biomass fuel combustion equipment is designed

for the drying process in the field of tea machinery. The successful development of the device, can realize the tea clean production and reduce the labor intensity, reduce the cost of tea production enterprises, for energy-saving combustion in the field of tea production and has an important significance in the promotion of countryside.

Acknowledgment

This work is supported by the key project of natural science research in Anhui (KJ2018A0408) and the emergent engineering research and practice project in Anhui (2017xgkxm47).

References

- [1] Guo Haokun 2017 *Journal of Chinese Agriculture Mechanization* **38(3)** 77-79
- [2] Du Haifeng, Yan Chao 2016 *Energy Chemical Industry* **37(2)** 41-46
- [3] Gilbe C, Ohman M, Lindstrom E, et al 2008 *Energy & Fuels* **22(5)** 3536-3543
- [4] Luo Juan, Huo Shulin, Zhao Lixin 2009 *Renewable Energy Resource* **6** 90-95
- [5] Baerenthaler G, Zischka M, Haraldsson C, et al 2006 *Biomass and Bioenergy* **30(11)** 983-997
- [6] Wang Xin, Li Dingkai, Ni Guangdou 2007 *Journal of combustion science and technology* **13(1)** 86-90
- [7] Dias J, Costa M, Azevedo J L T 2004 *Biomass and Bioenergy* **27(6)** 531-539
- [8] Huo Zhonglan, Jia Mengli, Guo Qianhui 2007 *Renewable Energy Resource* **25(1)** 71-72
- [9] Tian Zhongfu, Wang Shuxiang, Cao Youwei 2014 *Anhui Agriculture Science* **42(2)** 541-543