APPLICATION OF BIOMASS MOULDING FUEL TO AUTOMATIC FLUE-CURED TOBACCO FURNACES
Efficiency and Cost-Effectiveness

by

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Original scientific paper
https://doi.org/10.2298/TSCI181202156R

Biomass moulding fuel is an environmentally friendly and renewable energy source. We studied an independently-developed automatic flue-cured tobacco furnace, employing a biomass fuel source and studied the effect of biomass moulding fuel onbacco flue curing. We found that 1 kg of dried tobacco required 1.2 kg of biomass moulding fuel (heating value = 3550 kcal per kg). The energy input cost was 1.43 RMB[**] (fuel and electricity) and the labor cost was reduced by 75%, a reduction of 18.6% compared to the cost of burning coal. With respect to the environmental impact, the average emission concentration of smoke in the exhaust gas from the furnace was 16.2 mg/m³, SO_2 was 13.6 mg/m³, and NO_x was 2.3 mg/m³. Ringelmann blackness was less than 1. Compared to burning coal, all emissions were very low, demonstrating that the biomass moulding fuel furnace saved energy and reduced emissions compared to coal. In addition, the quality of cured tobacco and economic index were significantly improved.

Key words: *biomass, tobacco stem, flue-curing, tobacco leaf, clean energy*

Introduction

Tobacco flue curing is a process that consumes a large amount of heat [1, 2]. Drying one kilogram of tobacco usually burns 1.5-2.0 kg of coal. The heat utilization rate is approximately 30%, showing great inefficiency [3, 4]. In addition, during flue-curing season, the smoke, carbon oxides, oxides of sulfur and polycyclic aromatic hydrocarbons generated from coal-burning furnaces lead to pollution [5-7]. The curing process has become one of the main pollution sources in the manufacture of tobacco [8]. China has a current policy of *saving energy, reducing emissions and comprehensively utilizing resources, constructing an environmentally friendly and resource-saving society* [2]. Therefore, increasing heat utilization, lowering cost and reducing pollution while ensuring tobacco flue-curing quality and increasing economic benefits becomes an important research topic in tobacco flue-curing [9].

[*] Corresponding author, e-mail: biochar2018@henau.edu.cn; [**] RMB = 0.125 $

Biomass moulding fuel (BMF) is an environmentally friendly and RES [1]. The BMF is a hot topic in agricultural engineering the areas of clean renewable energy, efficient combustion, and automatic control technologies [10]. This study is based on an independently designed, automatic, flue-cured tobacco furnace. Utilizing technical and economic evaluation methods, we performed a thorough comparison study of the biomass heat utilization rate, energy efficiency, emission reduction, and cured tobacco quality. This work provides a theoretical foundation and technical support for the industrialization of BMF tobacco flue-curing technology. It is important to realize clean, low-carbonbacco flue-curing and promote sustainable development of modern tobacco circular agriculture [11-13].

Materials and methods

Experimental materials

Chinese tobacco 100 was employed for this flue-curing study in 3 biomass fuel bulk curing barns located at the Baofeng tobacco station, each with size of 2.7 m × 8.0 m.

Experimental

Blank test: The rate of temperature increase in the bulk curing barn heated by biomass was tested with no load in the barn [14].

Tobacco flue-curing experiments: the experimental tobacco leaves of the same species, nutritional conditions, and ripeness were collected form the same region. With the 10~11 leaf centrals as the testing objects, the average values of three flue-curing results were recorded [15, 16]. When the tobacco curing was complete the appearance of the leaves, chemical composition and economic characteristics were evaluated [17].

Table 1. Industrial analysis of biomass briquette fuels

Parameter	Symbol	Unit	Result
Total moisture	M_t	[%]	11.26
Air-dried moisture	M_{ad}	[%]	2.93
Ash [arb]	A_{ar}	[%]	11.21
Volatile [arb]	V_{ar}	[%]	64.02
Carbon [arb]	F_{Car}	[%]	17.46
Characteristic of char residue	CRC	–	1
Air dry s-based [%]	$S_{t,ad}$	[%]	0.03
Calorific value [arb kcalkg^{-1}]	$Q_{b,ad}$	[kcal/kg]	3926.5

Remark: test result from key Laboratory of Renewable Energy of Ministry of Agriculture of Henan Agriculturary University.

Results and analysis

The BMF properties analysis

In the process of tobacco curing, the physical and chemical characteristics of biomass moulding fuels (the material of tobacco stalk)are the basis of technical and economic evaluation. The results are shown in tabs. 1 and 2.

Table 2. Main physical performance parameters of different fuels

Category	Diameter	Thickness	Density	Calorific value
Tobacco stalk-based briquette fuel	60	45	1.06	16257.5
Coal (loose)	–	–	–	16592.1

Analysis of flue-cured tobacco furnace gas emission

For exhaust gas monitoring, the exhaust gas monitor point was located at the vertical flue pipe of the biomass tobacco furnace outlet. Sampling and analysis followed established methods. The detection frequency was six times per tobacco curing cycle. We monitored the following parameters: the smoke, SO_2, NO_x, Ringelmann blackness at the exhaust gas outlet and the hot blast stove efficiency. The results are shown in tab. 3.

Table 3. Comparison of the gas emissions from BMF flue-cured and coal burning tobacco furnaces

No.	Parameter	Unit	Exhaust gas outlet		National standard limits of emission
			Coal	BMF	
1	Smoke temperature	°C	215	188	
2	Excess air factor	α	2.1	1.8	
3	Flue gas moisture content	[%]	4.2	5.0	
4	Flue gas-flow condition	[m^3h^{-1}]	2231	2050	
5	Flue gas-flow standard state	[m^3h^{-1}]	1512	1473	
6	Average emission concentration of smoke*	[mgm^{-3}]	138.4	16.2	200
8	Average emission concentration of SO_2*	[mgm^{-3}]	752.5	13.6	900
10	Average emission concentration of NO_x*	[mgm^{-3}]	137	2.3	
12	Ringelmann blackness	level	1	＜1	

Notes: the pollutant emission concentrations above are the value in the dry flue gas under standard states;
* means the measured values are converted to the concentration when the excess air coefficient = 1.80

The monitoring results showed that when BMF was used for tobacco curing, the average emission concentration of smoke was 16.2 mg/m^3, the average emission concentration of SO_2 was 13.6 mg/m^3, and the average emission concentration of NO_x was 2.3 mg/m^3 in the exhaust gas. The Ringelmann blackness was less than 1. Compared to burning coal, all the emission concentrations were significantly lower, indicating environmental advantages in multiple aspects. This was complied with GB/T3271-2001 *boiler air emission standards*, type two of Zone II time standard, tab. 4.

The results show the improvement of the newly designed biomass flue-curing furnace over a coal furnace. The BMF fueled furnace has significant technical advantages it saves energy, reduces emissions, can effectively reduce GHG and exhaust gases, tab. 5. This is significant in the environmental protection and reduction of pollution in tobacco curing regions.

Analysis of variation of temperature and humidity in the process of tobacco flue-curing

The temperature and humidity conditions were set up according to the three-stage curing model of flue-cured tobacco processing. The dry-bulb temperature of the automatic biomass tobacco furnace was controlled by adding fuel or closing the air inlet once, while the wet-bulb temperature was controlled by adjusting the air valve opening degree. The dry-bulb temperature of the coal burning curing furnace was controlled by adding coal and by adjusting the blower start/stop. The wet-bulb temperature was controlled by adjusting the air valve opening degree. Temperature and moisture sensors were placed in the middle of the upper and lower sheds and the entrances and exits of the blowers (JWSK-6 Wide temperature type temperature and humidity transmitter, ±0.5 °C, ±3% RH). A Shun Zhou ZigBee wireless communication acquisition module was used to collect temperature and humidity data, with a 4 seconds time interval. After it was loaded with tobacco, an anemometer (testo405-V1, 0~10 m/s，0～99 990 m³/h，± (0.3 m/s + 5% measured value)) was used to measure the blowing rate and volume when the blowers in the curing barns were turned on.

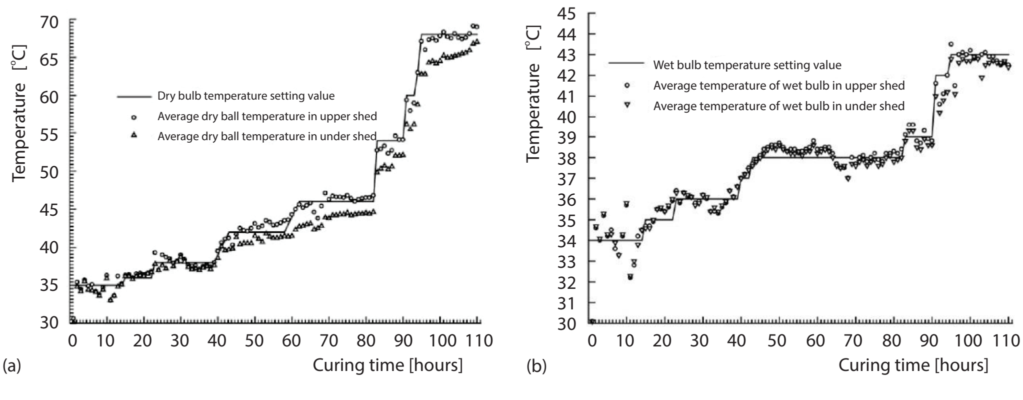
Table 4. Combustion characteristics of biomass briquette fuel flue-cured tobacco oven

No.	Parameter	Symbol	Unit	Result (exhaust gas outle)
1	Fuel receives base carbon	C_{ar}	[%]	30.51
2	Fuel receives base hydrogen	H_{ar}	[%]	3.8
3	Fuel receives base oxygen	O_{ar}	[%]	30.98
4	Fuel receives base sulfur	S_{ar}	[%]	0.01
5	Fuel receives base nitrogen	N_{ar}	[%]	0.76
6	Fuel receives base ash	A_{ar}	[%]	22.38
7	Fuel receives base moisture	M_{ar}	[%]	11.56
8	Ashless base volatiles from fuel drying	V_{def}	[%]	59.26
9	Fuel receives base calorific value	$Q_{net,v,ar}$	[kJkg^{-1}]	12645.3

Table 5. Measurement of positive equilibrium efficiency of fluecured tobacco furnace with biomass briquette fuel

No.	Parameter	Symbol	Unit	Result (Exhaust gas outle)
1	Air intake temperature	t_{js}	[°C]	26.0
2	Flue gas temperature at outlet	t_{cs}	[°C]	70.1
3	Inlet pressure	p_{js}	[MPa]	–
4	Flue gas outlet pressure	p_{cs}	[MPa]	–
5	Thermal power*	Q	[MW]	0.062
6	Fuel consumption	B	[KJh^{-1}]	21.0
7	Heat input	Q_r	[KJkg^{-1}]	12645.3
8	Positive Eequilibrium efficiency**	η	[%]	84.1

* Formula: $G(h_{cs}-h_{js})\cdot 10^{-5}/36$; ** Formula for Calculating Positive Equilibrium Efficiency: $G(h_{cs}-h_{js})\cdot 100/BQ_r$



Dry-bulb temperature reference value	Wet-bulb temperature reference value
Upper shed average dry-bulb temperature	Upper shed average wet-bulb temperature
Lower shed average dry-bulb temperature	Lower shed average wet-bulb temperature

Figure 1. Distribution curves of average dry-bulb temperature; (a) and wet-bulb temperature, (b) between the upper and lower sheds in the curing barns

The distribution curves of the average dry-bulb and wet-bulb temperatures between the upper and lower sheds in the curing barns are presented in figs. 1(a) and 1(b). The temperatures were recorded every hour from the beginning of curing. The maximum dry-bulb temperature difference between upper and lower sheds was 2.8 °C (96 hr) and the maximum wet-bulb temperature difference was 1.7 °C (95 hr). This indicated that the curing barn temperature distributions were relatively even. In addition, the maximum difference of the measured dry-bulb temperature and the reference value was 2.6 °C (97 hr) and the maximum wet-bulb temperature difference was 2.1 °C (98 hr), implying that the temperature and moisture controlling systems in the biomass-curing furnaces were very accurate.

Comparative analysis of economic benefits and social/environmental benefits

Economic benefits analysis

Economic benefit analysis is an important part of program feasibility research, as well as the foundation used to evaluate whether or not a program is ready for industrial development. Our research utilized the cost comparative analysis method. The curing costs of the BMF curing furnace and the coal burning curing furnace are shown in tab. 6.

Table 6. Economic comparison of flue-cured tobacco with BMF and flue-cured tobacco with coal

Category	Unit	Flue-cured tobacco with coal	Flue-cured tobacco with BMF
Tobacco flue-curing	[hours]	121.0	118.5
Quality of fresh tobacco leaves	[kg]	3455.0	3467.3
Total quality of dry tobacco flue-curing	[kg]	412.5	414.2
Dewatering amount	[kg]	3042.7	3053.1
Coal consumption	[kg]	820.3	0
BMF consumption	[kg]	0	733.5
Coal price	Yuan	650	
BMF price	Yuan		580
Electricity consumption	[kWh]	265.4	228.6
Electricity price	Yuan	0.75	0.75
Electricity cost	Yuan	198.8	171.5
Tobacco flue-curing cost	Yuan per kg	1.77	1.43

Using BMF, the energy cost to cure 1 kg of tobacco is 1.43 RMB, tab. 6, which is lower than the cost of burning coal by 0.34 RMB per kg. Considering labor costs, the average cost of a coal burning bulk curing barn is 200 RMB per barn and the average cost of an automatic biomass bulk curing barn is 50 RMB per barn, which cuts the labor cost by 75%. Based on the results previous, with the current BMF production energy consumption of 20-22 kWh per tonne, if tobacco grower co-ops or tobacco growers produce BMF, the tobacco stem BMF total production cost would be 380-400 RMB per tonne. This projects that the tobacco curing energy cost is only 1.2-1.25 RMB per kg of cured tobacco. This demonstrates the significant economic advantage of the industrial development of the automatic biomass tobacco curing technology.

Social/environmental benefits analysis

Compared to burning coal, burning BMF saves energy and reduces emissions, tab. 7. It is well known that plants synthesize compounds through photosynthesis by using released CO_2, which makes this technology close to a zero-emission method. The emissions of SO_2, NO_x and smoke are also significantly reduced. Based on the physiochemical characteristics of biomass and coal fuels, a comprehensive comparative analysis of the emissions of air pollutants during the tobacco curing process with these two curing methods was conducted, tab. 7.

Table 7. Estimation of emissions of air pollutants from BMF tobacco curing and coal burning furnaces

Curing method	CO_2 per kg	SO_2 per kg	NO_X per kg	Emission of smoke per kg
Coal burning cured tobacco[a]	2522	23.28	5.82	230.8
Biomass cured tobacco	45.79[b]	0.25	0.76	16.17[c]

Notes: only compared the air pollutant emissions during the burning process; (a) data from *energy based data compilation 2009, the state committee of planning of energy*; (b) conversion of biomass power consumption during processing; (c) refer to *the first national census of pollution sources of industrial pollution sewage coefficient manual.*

As presented in tab. 7, the two fuels generated significantly different air pollutant emissions when burning in the curing barn following the same standard. With biomass fuel, the flue gas emission was reduced by 85-90%. This indicated that if BMF was used at the Kanglong ecological circular modern tobacco agriculture park (1000 acres tobacco planting scale), 560 tonnes of coal would be substituted and the emission of CO_2, SO_2 and soot would be reduced by around 1350 tonnes, 12.8 tonnes, and 110 tonnes, respectively. Thus, utilization of BMF has obvious ecological environmental advantages.

In addition, the BMF cured tobacco has significant social benefits. Assuming the straw ratio is 1, 0.25-0.3 tonnes of tobacco stems can be obtained per acre. Assuming the purchase price of tobacco stems per ton is 200 RMB, every acre of tobacco would bring additional 50-60 RMB income.

Cured tobacco quality comparison

With the acceleration of economic development and urbanization, the emission of air pollutants is increasing, and the scope of pollution is expanding. The problem of atmospheric environmental pollution with SO_2, particulate matter, and NO_x as the main pollutants is becoming more and more serious [18, 19]. Table 8 shows a chemical composition analysis of the upper two sheds' tobacco in coal burning and BMF burning barns. The results show that although the total sugar and reducing sugar percentages are lower in the biomass-curing barn compared to the coal-curing barn, the disaccharide ratio is higher in the biomass-curing barn. It indicates the transformation of sugars is more sufficient in the biomass-curing barn. The protein, nicotine and total nitrogen contents are slightly higher in the biomass-curing barn. From the Shmuck values, we find that the chemical composition of BMF flue cured tobacco has better coordination.

Table 8. Comparison of the tobacco chemical composition from the two different fuel barns

Curing barn type	Protein [%]	Reducing sugar [%]	Potassium [%]	Nicotine [%]	Total nitrogen [%]	Total sugar [%]	Disaccharide ratio	Shmuck value
Coal-curing barn	8.77	23.90	1.56	2.98	1.86	30.12	0.8	3.41
Biomass-curing barn	9.62	21.87	1.62	2.86	1.92	28.65	0.87	2.65

The comparison of tobacco appearances from the two different curing barns is shown in tab. 9. The superior tobacco and secondary tobacco ratios as well as the average tobacco prices from the biomass-curing barn are slightly higher than coal-curing barn. We can attribute this to the accurate and efficient temperature control in the biomass-curing barn, which leads to even temperature distribution. Also, application of waste heat sharing technology reduces the loss of chemicals in the tobacco allowing the tobacco to be cured in a suitable environment, resulting in better quality.

Table 9. Comparison of the tobacco appearance from the two curing barns

Curing barn	Superior tobacco ratio [%]	Secondary tobacco ratio [%]	Other tobaccos ratio [%]
Coal burning curing barn	25.3	64.5	10.2
Biomass-curing barn	28.6	65.4	6.0
Difference	3.3	0.9	4.2

Conclusions

We saw significant advantages of the BMF curing technology in several areas. From an economic perspective, curing 1 kg of tobacco required 1.2 kg of BMF (heating value no less than 3550 kcal/kg). The curing energy cost was 1.43 RMB (fuel and electricity), which was lower than burning coal by 18.6%. From an environmental perspective, the average emission concentrations of soot, SO_2, and NO_x were 16.2 mg/m^3, 13.6 mg/m^3, and 2.3 mg/m^3, respectively, in the exhaust gas outside of the biomass-curing barn. The Ringelmann blackness was less than 1. Compared to burning coal, all emission concentrations were lower. These results showed the significant economic and environmental advantages of the BMF technology in saving energy and reducing emissions.

The quality of cured tobacco was also improved over coal-curing technologies [20]. The superior tobacco and secondary tobacco ratios and average price of tobacco were slightly higher in the tobacco obtained from the biomass-curing barn compared to that from the coal-curing barn [21]. The disaccharide ratio was higher in the tobacco from the biomass-curing barn, which indicated more sufficient sugar transformation. The chemical composition of the tobacco had better coordination.

Using the BMF to bake tobacco can reduce the labor of adding fuel, cleaning ash and other links in the process of baking, reduce the cost of baking tobacco, increase the average price of flue-cured tobacco and the proportion of superior tobacco, and increase the economic benefits of tobacco, and improve the chemical quality and smoking quality of Flue-cured tobacco [22]. In summary, using BMF as clean renewable energy for tobacco curing not only reduced tobacco waste and improved the local environment in the tobacco agricultural region, it also reduced pollution. With the support of relevant policies, the technology of Flue-cured Tobacco with biomass pellet fuel can be further promoted an applied [23]. Therefore, development of biomass as a source of energy is significant to the construction of modern tobacco circular agriculture systems.

Acknowledgment

We are grateful to the anon-ymous referees for their many valuable and helpful comments. This work was supported by Study on Distribution Characteristics of Soil Carbon and Nitrogen and Key Technologies of Tobacco Quality Improvement in Nanping [2017] 21; Research and Application of Key Technologies for Developing High-quality Tobacco Leaves with Ecological Characteristics in Dandong (20183100001-40802). National Natural Science Foundation of China (U1504509), National Science and Technology Ministry（2015BAD21B03）, Natural Science Foundation of Henan Province (162300410155), Project of science and technology tackling key project in 2017, Henan provincial science and Technology Department (172102310355), science and technology research program of Henan Province (162102210271, 172102310737, 182102110010), Key scientific research projects of colleges and universities in Henan Province (17B416001), and Science and Technology Innovation Fund of Henan Agricultural University (KJCX2018C03)

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Paper submitted: December 2, 2018
Paper revised: January 25, 2019
Paper accepted: February 5, 2019