

APPLICATION OF BIOMASS MOULDING FUEL TO AUTOMATIC FLUE-CURED TOBACCO FURNACES: EFFICIENCY AND COST-EFFECTIVENESS

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Abstract: Biomass moulding fuel (BMF) 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 BMF on tobacco flue curing. We found that 1 kg of dried tobacco required 1.2 kg of BMF (heating value = 3550 kcal/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, SO₂ 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 BMF 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 to 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 (PAHs) generated from coal-burning furnaces lead to pollution^[5,6,7]. 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].

BMF is an environmentally friendly and renewable energy source^[1]. 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-carbon tobacco flue-curing and promote sustainable development of modern tobacco circular agriculture^[11-13].

1 Materials and Methods

1.1 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.

1.2 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 from the same region. With the 10~11 leaf centrals as the testing objects, the average values of three flue-curing results were recorded^[15]. When the tobacco curing was complete the appearance of the leaves, chemical composition and economic characteristics were evaluated^[17].

2 Results and Analysis

2.1 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 Table 1.

Table 1 Industrial analysis of biomass briquette fuels

No.	Parameter	Symbol	Unit	Result
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1	Total moisture	Mt	%	11.26
2	Air-dried moisture	Mad	%	2.93
3	Ash (arb)	Aar	%	11.21
4	Volatile (arb)	Var	%	64.02
5	Carbon (arb)	FCar	%	17.46
6	characteristic of char residue	CRC	/	1
7	Air dry s-based (%)	St,ad	%	0.03
8	Calorific value (arb kCal/kg)	Qb,ad	kcal/kg	3926.5

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

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

2.2 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 6 times per tobacco curing cycle. We monitored the following parameters: the smoke, SO₂, NO_x, Ringelmann blackness at the exhaust gas outlet and the hot blast stove efficiency.

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 ³ /h	2231	2050	
5	Flue gas flow standard state	m ³ /h	1512	1473	
6	Average emission concentration of smoke*	mg/m ³	138.4	16.2	200
8	Average emission concentration of SO ₂ *	mg/m ³	752.5	13.6	900
10	Average emission concentration of NO _x *	mg/m 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/m³, the average emission concentration of SO₂ was 13.6 mg/m³, and the average emission concentration of NO_x was 2.3mg/m³ 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.

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

No.	Parameter	Symbol	Unit	Result(Exhaust gas outlet)
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}	kJ/kg	12645.3

Table 5 Measurement of positive equilibrium efficiency of flue-cured tobacco Furnace with biomass briquette Fuel

No.	Parameter	Symbol	Unit	Result(Exhaust gas outlet)
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 ¹	Q	MW	0.062
6	Fuel consumption	B	KJ/h	21.0
7	Heat input	Q _r	KJ/kg	12645.3
8	Positive Equilibrium Efficiency	η	%	84.1

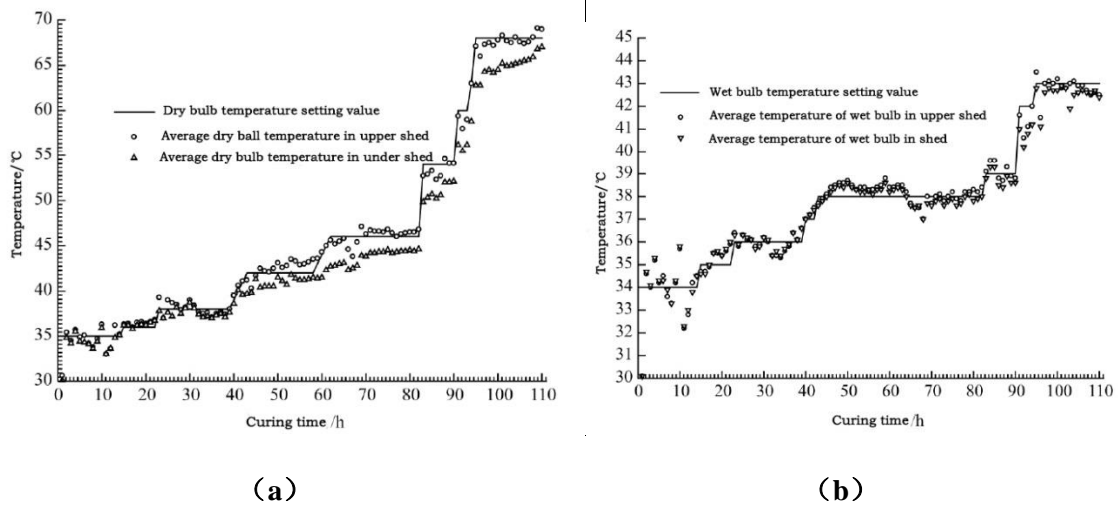
Remarks:1) Formula : $G(h_{cs}-h_{js}) \cdot 10^{-5} / 36$; 2) Formula for Calculating Positive Equilibrium Efficiency: $G(h_{cs}-h_{js}) \cdot 100 / BQ_r$

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 greenhouse gases and exhaust gases. This is significant in the environmental protection and reduction of pollution in tobacco curing regions.

2.3 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, $\pm 0.5^{\circ}\text{C}$, $\pm 3\%$ 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, $\pm(0.3 \text{ m/s}+5\%$ measured value)) was used to measure the blowing rate and volume when the blowers in the curing barns were turned on.



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

1. 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 Figure 1 (a) and (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.

2.4 Comparative analysis of economic benefits and social/environmental benefits

2.4.1 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 Table 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	h	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/kg	1.77	1.43

Using BMF, the energy cost to cure 1 kg of tobacco is 1.43 RMB (Table 6), which is lower than the cost of burning coal by 0.34 RMB/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 above, with the current BMF production energy consumption of 20-22 kwh/ton, if tobacco grower co-ops or tobacco growers produce BMF, the tobacco stem BMF total production cost would be 380-400 RMB/ton. This projects that the tobacco curing energy cost is only 1.2-1.25 RMB per kilogram of cured tobacco. This demonstrates the significant economic advantage of the industrial development of the automatic biomass tobacco curing technology.

2.4.2 Social/environmental benefits analysis

Compared to burning coal, burning BMF saves energy and reduces emissions (Table 7). It is well known that plants synthesize compounds through photosynthesis by using released CO₂, which makes this technology close to a zero-emission method. The emissions of SO₂, 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 (Table 7).

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

Curing method	CO ₂ /kg	SO ₂ /kg	NO _x /kg	Emission of smoke/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 Table 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 tons of coal would be substituted and the emission of carbon dioxide, sulfur dioxide and soot would be reduced by around 1350 ton, 12.8 ton and 110 ton, 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 ton 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.

2.5 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 sulfur dioxide, particulate matter and nitrogen oxides 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 Table 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

3 Conclusion

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, SO₂, and NO_x were 16.2 mg/m³, 13.6 mg/m³, and 2.3 mg/m³, 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 and applied^[23]. Therefore, development of biomass as a source of energy is significant to the construction of modern tobacco circular agriculture systems.

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