Influencing Factors of Double Roll Coating Ratio of Reconstituted Tobacco by Papermaking

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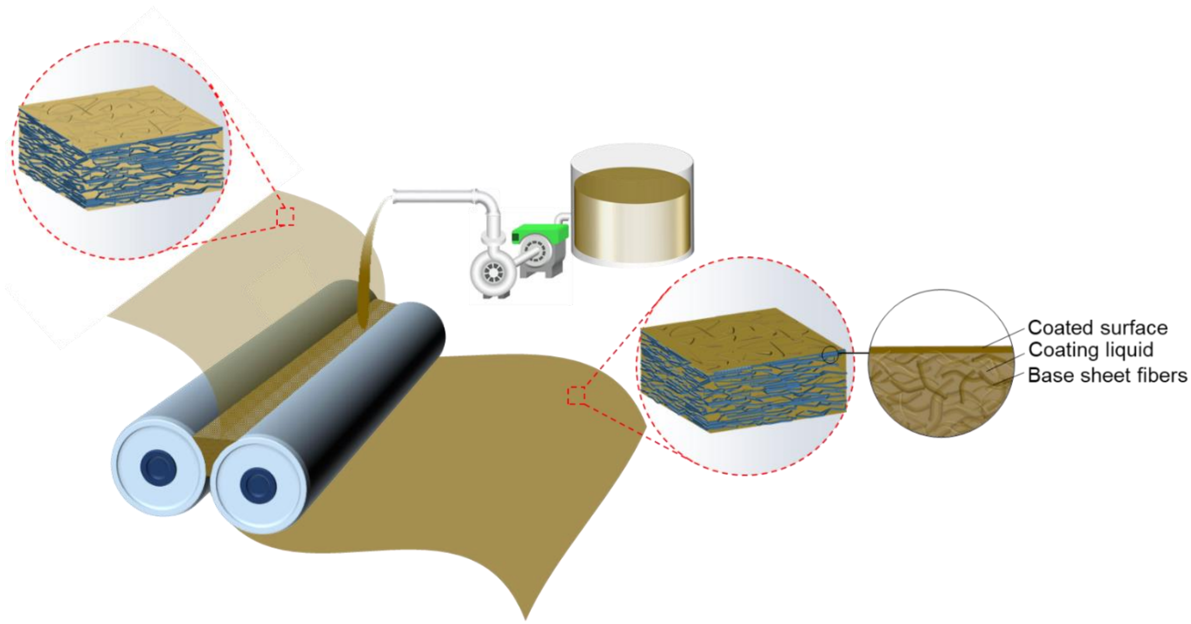
GRAPHICAL ABSTRACT



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To investigate and elucidate the influencing factors and laws of double-roll coating ratio (CR) for papermaking reconstituted tobacco and to assess the effectiveness of CR in characterizing the finished product's hot water soluble (HWS) content, base sheet (BS) specimens of reconstituted tobacco with varying bone-dry basis weights and moisture contents were prepared. These sheets were then coated with different physical indices of coating liquids using a small double-roll coater at different sheet speeds. Subsequently, the CR and HWS content of the finished product were analyzed. The results showed that when the viscosity of the coating liquid was > 280 mPa·s, the moisture content of the BS should be maintained between 18% and 22%, and the speed of the BS should be > 120 m/min; when the viscosity of the coating liquid is < 280 mPa·s, the moisture content of the BS should be maintained between 14% and 18%, and the speed of the BS should be > 120 m/min, so that higher HWS can be obtained in finished products. The bone-dry basis weight of the BS should be kept between 40 and 60 g/m^2. The suspension solid content of coating liquid should be < 9.5%.

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Keywords: Reconstituted tobacco; Moisture content of base sheet; Bone dry basis weight of base sheet; Viscosity of coating liquid; Brix of coating liquid; Machine speed; Coating ratio; Hot water soluble content

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INTRODUCTION

The papermaking process for reconstituted tobacco involves using tobacco waste as raw material, which undergoes extraction, pressing, concentration, pulping, base sheet forming, coating, drying, and cutting (Kuang *et al*. 2018; Zhang *et al*. 2023). The raw materials for reconstituted tobacco are diverse and sourced from various origins, leading to instability. Typically, tobacco waste, such as stems, scraps (primarily re-roasted tobacco leaf scraps), dusts, tobacco leaf veins, ash rods, and low-grade tobaccos, serve as the primary raw materials. Additionally, a certain proportion of softwood pulp fibers are incorporated using mechanical pulping processes to closely mimic the natural characteristics of tobacco leaves to enhance the utilization rate of tobacco raw materials and impart distinctive style features to cigarettes when blended into them (Liu *et al*. 2014; Jiang *et al*. 2015; Huang *et al*. 2019; Zhai *et al*. 2020; Zhao *et al*. 2020).

The level of hot water-soluble substances in reconstituted tobacco is one of the most crucial factors in determining its quality. It is widely acknowledged in the industry that a higher concentration of hot water-soluble substances in reconstituted tobacco products indicates a closer resemblance to natural ones, thus signifying superior quality. Currently, production processes typically indirectly evaluate this characteristic through CR, allowing for rapid testing and enabling online control over the content of hot water-soluble substances (Su *et al*. 2015; Wu *et al*. 2016; Zhang *et al*. 2016; Wu *et al*. 2020a,b).

However, the special properties of coating additives and the supply circulation process during the base sheet coating process result in viscosity and Brix value instability of the coated liquid supplied per unit time for reconstituted tobaccos. This instability is caused by fluctuations in the base sheet bone dry basis weight and moisture content, which further leads to fluctuations in both coating ratio and hot water soluble (HWS) content of the reconstituted finished good. Even in the presence of significant fluctuation, there is potential for degradation in the efficacy of the coating ratio indicator, which leads to concerns such as substandard quality of finished goods (Luo *et al*. 2022; Ye *et al*. 2022; Li *et al*. 2023; Zhang *et al*. 2023; Zhao *et al*. 2023).

This study utilized a 1200-mm width Fourdrinier machine to produce reconstituted tobacco base with varying basis weights and achieved different moisture content in the base by employing small cylinders in the drying section of the experimental trial line. Subsequently, the bases with different basis weights and moisture content were passed to have a double-sided impregnation and coating using various physical index coating solutions *via* a small coating machine. The influencing factors and the regularity of their interconnection of double-roll impregnation's CR for reconstituted tobacco by papermaking method were comprehensively investigated and elucidated through detection of the CR and HWS content of the finished product.

EXPERIMENTAL

Materials

The tobacco raw material recipe was as follows: 45% tobacco stems + 18% toasted tobacco scraps + 29% tobacco ash/powder + 8% softwood kraft.

The coating liquid recipe was as follows: 1000 kg concentrated liquid + 150 kg glycerin + 50 kg flavoring agents + washed tobacco powder. The proportion of the above materials added is based on the dry extract of tobacco.

Table 1. Information on Experimental Instruments

Num	Test Equipment and Material Names	Model/Specification	Manufacturers
1	Electronic analytical balance	MS304S	American Mettler Toledo company
2	Constant temperature and humidity chamber	KBF240	German binder company
3	Electro thermal blowing dry box	FED240	German binder company
4	Rotational viscometer	LVDV-S+	Brookfield
5	Brix refraction instrument	PAL-3	ATAGO
6	Scanning Electron Microscope (SEM)	EVO 18	German ZEISS
7	Small forming, coating, and drying line	1200 mm/ Customization	Chinese domestically/ combination equipment

Equations

The determination of the CR of reconstituted tobacco is typically represented by Eq. 1,

$$CR = (M_b - M_a) / M_b * 100 \quad (1)$$

where CR is the coating ratio (%), M_a is the bone-dry basis weight of base sheet (g/m^2), and M_b is the bone-dry basis weight of finish goods (g/m^2).

The determination of the HWS content of reconstituted tobacco is typically represented by Eq. 2,

$$HWS = (M_1 - M_2 - M_0) / (M_1 - M_0) * 100 \quad (2)$$

where HWS is the hot water soluble content (%), M_0 is the bone-dry mass of the filter bowl (g), M_1 is the bone-dry mass of the reconstituted tobacco simple powder and filter bowl before blushing (g), and M_2 is the bone dry mass of the simple and filter bowl after flushing (g).

Test Standards

The CTCES YC/T 572 (2018) standard was used for the determination of coating ratio using the oven method. The CTCES YQ-GY/T 5 (2023) standard was used for the rapid determination of hot water soluble using the washing and filtering method. The CTCES YC/T 31 (1996) standard was used for the preparation of test sample and determination of water content using the oven method. The CTCES YQ-GYT 6 (2023) standard was used for the rapid determination of soluble solids content in tobacco water extracts and concentrated extracts from production process of reconstituted tobacco using the refractive method.

Methods

First, the tobacco raw materials were composed according to the recipe in the “Materials” section and then they underwent batch extraction of 1000 kg at a temperature of 65 ± 5 °C for 45 min. Subsequently, the extracted mixture was subjected to screw pressing for solid-liquid separation, with the solid phase (pulp) being mixed and beaten into low concentration pulp with two double disc refiners in series, and its target beating degree controlled at 45 ± 5 °SR. The liquid phase (extract) underwent purification before entering the evaporation tower for concentration. Additionally, after the pulp was beaten and formed into the base sheet and dried, glycerin, flavoring agents, and other conventional additives were added to the concentrated liquid as per the recipe in “Materials” to prepare the coating liquid. Finally, reconstituted tobacco finished goods were produced through tunnel drying after recombining sheets with coating solution on a double-roll dip coating machine.

As illustrated in Table 2, during the experiment, the flow of the pulp that pumps to the head box was adjusted to control the bone-dry basis weight of the base sheet. The steam pressure in the drying cylinder was adjusted to control the moisture content of the base sheet before coating. The steam pressure in the evaporator tower was adjusted to control the Brix value of concentrated liquid, and the amount of washed tobacco powder added to the coating liquid was adjusted to control its viscosity. Finally, samples of both base sheet and finished goods were taken, and after constant temperature and humidity treatment, the bone-dry basis weight and HWS content were tested.

Table 2. Table of Experimental Design Factors and Levels

No.	Machine Speed (m/min)	Moisture Content of Base Sheet (%)	Bone Dry Basis Weight of Base Sheet (g/m^2)	Viscosity of Coating Liquid (mpa·s)	Brix of Coating Liquid (%)
1	50	0	30.0	20	30
2	80	4	35.0	60	36
3	100	8	40.0	100	42
4	120	12	45.0	140	46
5	150	16	50.0	180	50
6	180	20	55.0	240	54
7	-	22	60.0	300	58
8	-	24	65.0	340	62
9	-	26	70.0	400	66
10	-	28	-	460	70
11	-	30	-	500	75
12	-	32	-	540	

Fig. 1. Reconstituted tobacco production process flowchart

RESULTS AND DISCUSSION

Pearson Correlation Analysis

Table 3 demonstrates a significant correlation with the CR of finished goods ($P < 0.05$). The influencing factors were ranked in the following order from strong to weak: viscosity of the coating liquid > Brix of the coating liquid > bone-dry basis weight of the base sheet > moisture content of the base sheet > paper machine speed. Additionally, there was a significant correlation with the HWS content of finished goods ($P < 0.05$), and the influencing factors were ranked as follows: Brix of the coating liquid > viscosity of the coating liquid > CR of the finished goods > bone-dry basis weight of the base sheet. It is worth noting that there was also a significant correlation between the viscosity and Brix of the coating liquid.

Table 3. Finished Good (FG) Coating Ratio Pearson Correlation Analysis Results Summary

	Machine Speed (m/min)	Moisture of BS (%)	Bone dry Basis Weight of BS (g/m²)	Viscosity of Coating Liquid (mPa·s)	Brix of Coating Liquid (%)	CR of FG (%)	HWS of FG (%)
Moisture of BS (%)	-0.002 0.980	-	-	-	-	-	-
Bone Dry Basis Weight of BS (g/m²)	-0.243 0.820	-0.172 0.638	-	-	-	-	-
Viscosity of Coating Liquid (mpa·s)	0.049 0.566	0.056 0.730	-0.203 0.880	-	-	-	-
Brix of Coating Liquid (%)	-0.196 0.592	-0.006 0.680	0.078 0.612	**0.746** **0.031**	-	-	-
CR of FG (%)	**0.323** **0.049**	**0.492** **0.044**	**0.558** **0.035**	**0.895** **0.001**	**0.806** **0.002**	-	-
HWS of FG (%)	0.023 0.085	0.142 0.112	**0.431** **0.047**	**0.611** **0.028**	**0.623** **0.014**	**0.679** **0.037**	-

Impact Analysis of the Base Sheet's Moisture Content and the Bone-Dry Basis Weight on the Finished Good's Coating Ratio

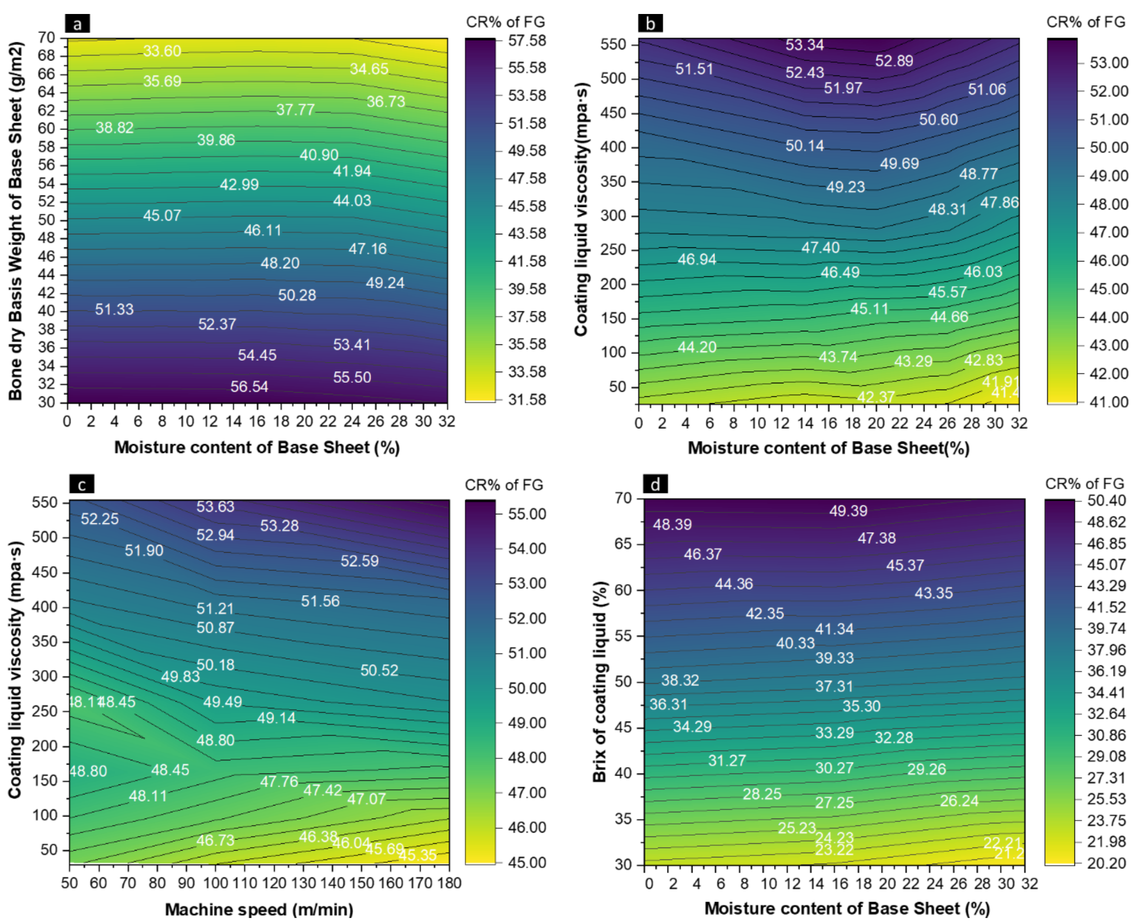

Fig. 2. The contour diagram of double-roll CR under different physical parameters of coating liquid and BS

As depicted in Fig. 2-a, under constant physical indicators of coating liquid (Brix value of 45%, viscosity of 240 mPa·s, washed tobacco powder content of 1.5%) and the machine speed of 120 m/min, the CR from the base sheet that had a bone dry basis weight at 50 g/m^2 tended to gradually increase followed by a decrease with rising moisture content of base sheet during coating. A moisture content of base sheet within the range of 14% to 18% was conducive to achieving an improved CR on the finished good, and there was also an increasing trend in the favorable range of moisture content with the increase in bone dry basis weight of base sheet. When maintaining constant physical indicators of coating liquid and the machine speed, the CR from different moisture contents in the base sheet gradually decreased as the bone-dry basis weight of base sheet increased.

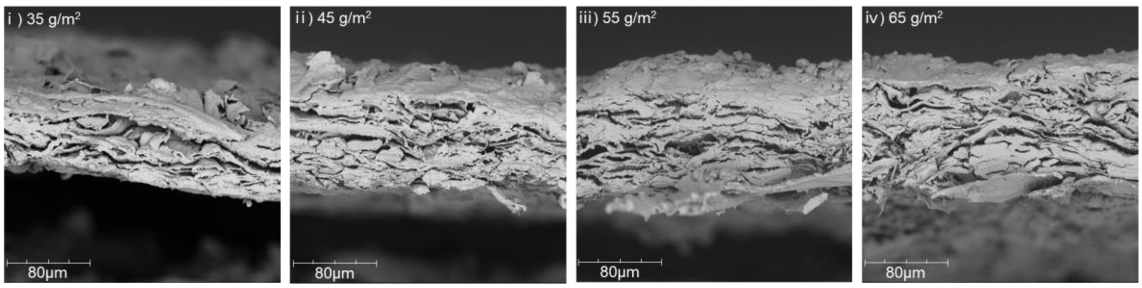

Fig. 3. Cross-sectional images of the base sheet at different bone dry basis weight

As depicted in Fig. 3, the cross-sectional SEM scanning image of the substrate revealed that, with constant base sheet's density, an increase in bone dry basis weight of base sheet resulted in a proportional increase in base sheet's thickness. Consequently, this led to a longer path for the coating liquid to penetrate. It can be inferred that under identical coating conditions, a higher bone-dry basis weight of the base sheet will result in a reduced CR and a lower HWS. These conclusions are also supported by calculation formulas Eqs. 1 and 2, as mentioned in Equations.

Impact Analysis of the Coating Liquid's Viscosity and the Base Sheet's Moisture Content on the Finished Good's Coating Ratio

As depicted in Fig. 2-b, when both the speed of the paper machine (120 m/min) and bone-dry basis weight (50 g/m^2) were held constant, and under the same moisture content of the base sheet, it was observed that a higher viscosity of the coating liquid leads to an increased CR of the finished good. However, the variation in the CR of finished good when exposed to different coating liquid viscosities was related to the moisture content of the base sheet. Specifically, when the viscosity of the coating liquid was low (≤ 280 mpa·s), a lower moisture content between 14% to 18% of the base sheet was found to be advantageous for achieving a higher CR. The predominant physical adsorption between the coating liquid and base sheet was mainly attributed to the capillary effect. When the moisture content of the base sheet was low, its surface capillaries were abundant with higher fiber dryness and with stronger water absorption performance. Therefore, to achieve a better capillary effect, the liquid needs to have a larger surface tension and less viscous action between molecules. However, high liquid viscosity will hinder molecular movement and weaken capillary effect. As the viscosity of the coating liquid gradually increased (> 280 mPa·s), an increase of the moisture content of the base sheet between 18% to 22% was conducive to obtaining a higher CR. This is primarily because as the coating liquid becomes more viscous, there is greater viscous action between molecules making it difficult for it to penetrate into base sheets. Meanwhile, a higher moisture content on the base sheet's surface leads to an increase in polar molecule quantity with specific physical adsorption force, as well as benefiting from osmotic pressure for penetration and substance adsorption between paper sheets and coatings. Similarly, if the viscosity of the coating liquid continues to increase while maintaining a low moisture content in the base sheet, there is an elevated probability of uncoated plaque or uncoated sandwich layers emerging, which leads to a decrease in the CR of the base sheet.

Impact Analysis of the Coating Liquid's Brix and the Base Sheet's Moisture Content on the Finished Good's Coating Ratio

As depicted in Fig. 2-d, both the speed of the paper machine (120 m/min) and bone-dry basis weight (50 g/m^2) were held constant, and under the same moisture content of base sheet, it was observed that a higher Brix of the coating liquid led to an increased CR of the finished good. The variation in CR at different Brix levels was influenced by the moisture level of the base sheet. A lower moisture content of the base sheet was advantageous for achieving a larger CR when the Brix of the coating liquid was low (≤ 60%). However, as the Brix gradually increased (≥ 60%), an increase in the moisture content of base sheet was more favorable to achieve a larger CR. Similarly, if the Brix of the coating liquid continues to increase while maintaining a low moisture content in the base sheet, there is an elevated probability of white spots emerging, which leads to a decrease in the CR of the base sheet.

Impact Analysis of the Coating Liquid's Viscosity and the Machine Speed on the Finished Good's Coating Ratio

As depicted in Fig. 2-c, when the moisture content of the base sheet was at 18% and the bone-dry basis weight at 50 g/m^2 were held constant, a higher viscosity of the coating liquid resulted in a higher CR of the finished good at the same machine speed. The variation in CR under different viscosities was significantly influenced by the machine speed. For coating liquid with low viscosity (≤ 280 mPa·s), a lower machine speed (≤ 120 m/min) was more advantageous for achieving a higher CR. This is primarily because in a lower viscosity coating solution, the acquisition of CR relies mainly on capillary effect-dominated permeation absorption, and a lower speed promotes longer residence time of base sheet in the coating liquid, thereby enhancing the permeation absorption effect of base sheet and coatings. When the viscosity was high (> 280 mpa·s), a higher machine speed (> 120 m/min) was more advantageous for achieving a higher CR. This is primarily because faster machine speeds can generate higher sheet speed when it gets through the coating liquid and increased longitudinal shear force on base sheet in maceration tank, facilitating relative displacement of liquid molecules and thereby facilitating the formation of more pronounced shear deformation in high-viscosity liquids. This shear deformation aids in separating liquid molecules from the bulk, which allows the base sheet to carry away a greater amount of the coating. As depicted in Fig. 4-e, when both bone-dry basis weight of base sheet (50 g/m^2) and speed of paper machine (120 m/min) were held constant, an increase in washed tobacco powder addition led to a gradual rise in viscosity of the coating liquid. The fitted curve for y (viscosity of coated liquid) and x (washed tobacco powder add proportion) can be represented by equation y = 9.0804e^0.3554x (R^2 = 0 .9737). Simultaneously, the finished good's CR also increased. When moisture content of the base sheet ranged between 0 ± 0.5%, 10 ± 0.5%, 20 ± 0.5%, and 30 ± 0.5%, the fitted curve for y (CR of finished good) and x (viscosity of coating liquid) can be represented by the equation as follows: y = 8E-07x^2 - 4E-05x + 0.3753 (R^2 = 0.9922), y = 9E-07x^2 - 3E-05x +

0.3643 (R^2 = 0.9887), y = 1E-06x^2 - 0.0001x + 0.3572 (R^2 = 0.9914), and y = 1E-06x^2 - 0.0002x + 0.3489 (R^2 = 0.9960).

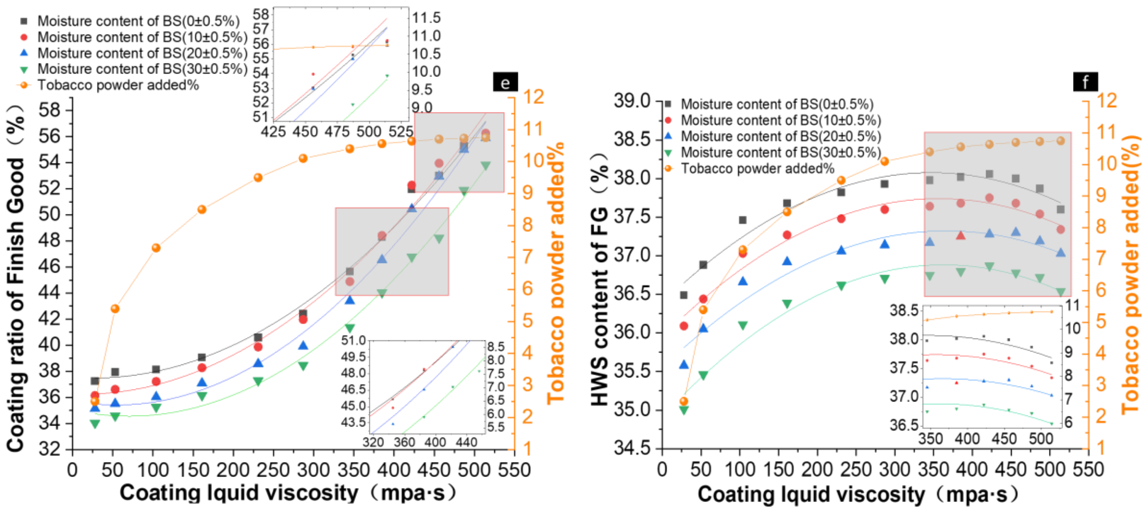

Fig. 4. The relationship between tobacco powder added percent and viscosity of coating liquid and the corresponding CR and HWS content of FG under different moisture content of BS

However, as depicted in Fig. 4-f, as the proportion of washed tobacco powder addition increased, the viscosity of the coating liquid also rose, the HWS content in the finished good exhibited a pattern of initial increase followed by decrease. This is primarily attributed to higher levels of tobacco powder present in the coating liquid as its quantity increases. Further, under a fixed finished good's CR, elevated levels of tobacco powder resulted in decreased HWS content due to its classification as insoluble suspended solids with minimal solubility in hot water. When moisture content of the base sheet ranged between 0 ± 0.5%, 10 ± 0.5%, 20 ± 0.5%, and 30 ± 0.5%, the fitted curve for y (HWS content of finished good) and x (viscosity of coating liquid) can be represented by equation as follows: y = -3E-07x^2 + 0.0001x + 0.3626 (R^2 = 0.9893), y = -3E-07x^2 + 0.0001x + 0.3578 (R^2 = 0.9950), y = -2E-07x^2 + 0.0001x + 0.3539 (R^2 = 0.9697) and y = -2E-07x^2 + 0.0001x + 0.3494 (R^2 = 0.9488).

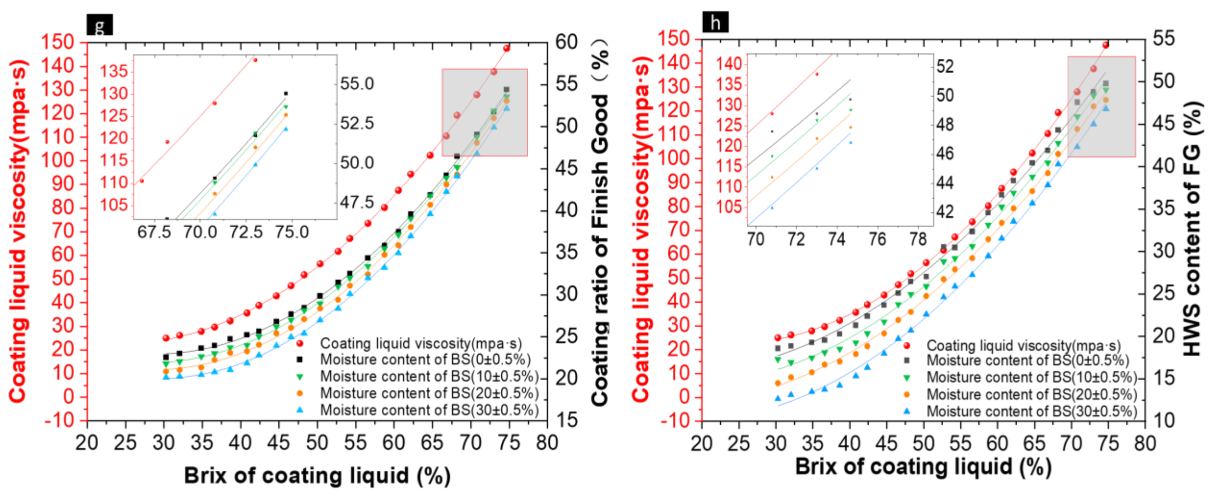

Fig. 5. The relationship between Brix and viscosity of coating liquid and the corresponding CR and HWS content of FG

As depicted in Fig. 5-g, when both bone-dry basis weight of base sheet (50 ± 1 g/m^2) and the speed of paper machine (120 m/min) were held constant, an increase in Brix of coating liquid led to a gradual rise in viscosity of the coating liquid. The fitted curve for y (Viscosity of coated liquids) and x (Brix of coating liquid) can be represented by equation $y = 0.0488x^2 - 2.3547x + 51.035$ ($R^2 = 0.9996$). Simultaneously, the finished good's CR also increased. When moisture content of the base sheet ranged in the following four different gradients, which are 0 ± 0.5%, 10 ± 0.5%, 20 ± 0.5%, and 30 ± 0.5%, the fitted curve for y (CR of finished good) and x (Brix of coating liquid) can be represented by equations as follows: $y = 0.0149x^2 - 0.8581x + 35.334$ ($R^2 = 0.9995$), $y = 0.0147x^2 - 0.8245x + 33.5$ ($R^2 = 0.9995$), $y = 0.015x^2 - 0.86x + 33.383$ ($R^2 = 0.9992$), and $y = 0.0157x^2 - 0.922x + 33.587$ ($R^2 = 0.9995$). However, as depicted in Fig. 5-h, as the Brix of coating liquid increased, the viscosity of the coating liquid also rose, and the HWS content in the finished good exhibited a gradual increasing trend. However, the rate of increase of HWS was slower than that of CR. When moisture content of the base sheet ranged in the following four different gradients of 0 ± 0.5%, 10 ± 0.5%, 20 ± 0.5%, and 30 ± 0.5%, the fitted curve for y (HWS content of finished good) and x (Brix of coating liquid) can be represented by equations as follows: $y = 0.0104x^2 - 0.3388x + 18.465$ ($R^2 = 0.9964$), $y = 0.0111x^2 - 0.4011x + 18.074$ ($R^2 = 0.9968$), $y = 0.011x^2 - 0.3697x + 15.366$ ($R^2 = 0.9987$), and $y = 0.0115x^2 - 0.4057x + 13.542$ ($R^2 = 0.9978$).

CONCLUSIONS

1. The bone-dry basis weight of the reconstituted tobacco base sheet should be carefully controlled within a specific range, as excessively low levels can lead to reduced production efficiency, while excessively high levels may result in its incompatibility with the drying equipment, as well as inadequate coating. The optimal range for recon tobacco was found to be 40 to 60 g/m^2.
2. An elevation in the Brix refractive index value or the content of suspended solids in the coating liquid will result in an escalation of viscosity, and upon reaching a specific threshold, it will induce an inverse proportional relationship between coating ratio (CR) and hot water soluble (HWS) in reconstituted tobacco.
3. When the viscosity or Brix value of the coating liquid increases, it is typically essential to proportionally increase the moisture content of the base sheet to attain a higher HWS.
4. The content of suspended solids in the coating liquid should be carefully regulated to remain below 9.5%, as exceeding this threshold may compromise the functionality of the CR on HWS and result in a significant deviation from their relevance.

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