Effect of Extrusion Parameters on the Production and Characteristics of Reconstituted Tobacco

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Abstract – **The task of the current study is to analyze reconstituted tobacco sheet (RTS), made by the extrusion-and-rolling method. An all-factor experiment has been conducted to estimate the effect of extruder's mouth shape, level of compression, percentage of carboxyl methylcellulose (CMC) and propylene glycol (PG) on the production process. Best technological properties of the RTS are estimated with the following conditions: square shaped mouth, 1:1 compression, 6% CMC.**

Keywords – **reconstituted tobacco, extrusion, specific mechanic energy (SME)**

I. Introduction

The goals achieved through the usage of reconstituted tobacco sheet (RTS) have long ago exceeded the mere economical range of utilization of waste tobacco materials. It is estimated that during cigarette production about 8-12% of the basic tobacco blend turns into wastes, consisting mainly of tobacco dust, lamina particles and stems [1]. The approximate quantities of unused tobacco wastes in Bulgaria are said to be around 5000-6000 tons per year and despite ongoing improvement of technology this trend is expected to continue in the next years [11]. This situation turns out to be a significant ecological problem as well, with respect to finding way to dispose of wastes and needs special attention, as there is no operative technological solution for the moment.

Although there are certain scientific achievements in the utilization of tobacco waste materials – through extraction with different solvents, or isolation of specific constituents, these achievements have no significant application yet and the most suitable way of dealing with the problem remains the transformation of waste (or parts if it) into reconstituted (homogenized) tobacco and its consequent incorporation in the blends for tobacco products. Besides, with the use of RTS in the blends for cigarettes a number of technological problems are affected - those connected to improving the physical characteristics of the blend, controlling smoke output (tar and nicotine content), and maintaining the desired smoking and flavour properties of the product [2, 4, 5, 10].

There are various processes for the production of RTS, but most of them are modifications of the two basic methods – the paper method and the slurry (cast sheet) method [1, 2, 4]. The reconstituted tobacco achieved by the different ways of production vary in a wide range, as every process forms a product with specific structure properties, texture, physical and chemical characteristics [1, 2, 4, 5]. The final properties of the RTS depend to a great extent on the quantity and nature of the additives incorporated and on the treatment of the raw materials. A good process is considered to be that leading to a final product, which would go through all the stages and operations of cigarette production in a way, analogical to that of the genuine tobacco strips.

As advantages of the currently studied method for production of RTS through extrusion and rolling (stretching) could be considered the relatively low presence of non-tobacco additives (carboxyl methylcellulose and propylene glycol), as well as the compactness of the equipment, the little investments needed, etc.

The task of the current study is to determine the effect of some construction features of the extruder (mouth shape, level of compression) on the energy consumption and productivity of the process, as well as on certain technological and chemical characteristics of the final product – reconstituted tobacco sheet.

II. Materials and Methods

The reconstituted tobacco sheet (RTS) studied in the current paper is made by the extrusion-and-rolling method, developed by a team of the University of Food Technologies – Plovdiv, Bulgaria [7]. The experimental equipment consists of a laboratory extruder Brabender 20 DN and a rolling (stretching) mechanism [7, 8]. As a raw material tobacco dust from the cigarette production of "Blagoevgrad BT" PLC is used, after sieving to obtain fraction with particle size below 400 μm. In the experimental blends are also included: carboxyl methylcellulose (CMC) as a binding agent, propylene glycol as a plasticizer and water [10]. The variants analyzed are designed up at the proportion tobacco dust: water ≈ 6, on the grounds that the above-mentioned proportion gives best hardiness and resistance of RTS [7].

The experiments are carried out under the following conditions: frequency of rotation of the active screw - 130min^{-1}; frequency of rotation of the feeding screw -80 min^{-1}; temperature throughout active screw's length – I zone – 30^0C, II zone – 50^0C, III zone –

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TABLE I
CHARACTERISTICS OF THE RECONSTITUTED TOBACCO SHEET

Sample variants				**M**$_c$, Nm	Q, kg/h	SME, Wh/kg	Nicotine, %	ρ_y, g/cm^3	Weight per area (air-dry matter), g/m^2	δ, mm
Mouth	Compression	CMC, %	PG, %							
Round	1:1	14	7	11,5	2,88	54,3	0.89	-	349	0.52
		14	3	13	2,52	77,6	0.86	-	353	0.53
		6	7	14	2,28	83,6	0.85	-	289	0.48
		6	3	16	2,4	90,7	1.08	-	392	0.50
	2:1	14	7	14,5	2,68	73,5	0.82	0.490	352	0.46
		14	3	15,3	1,95	107	0.79	0.490	346	0.44
		6	7	15,67	1,83	116	0.86	0.490	293	0.35
		6	3	16	1,44	151	1.09	0.498	382	0.45
Square	1:1	14	7	27,5	2,38	150,2	0.84	0.487	204	0.31
		14	3	30	2,4	162,5	0.89	0.462	233	0.33
		6	7	25	2,27	142,7	0.98	0.481	256	0.31
		6	3	27,5	2,25	158,6	1.05	0.475	198	0.32
	2:1	14	7	32,5	2,06	207,8	0.88	0.465	163	0.31
		14	3	38,5	2,3	221,2	0.86	0.451	236	0.34
		6	7	35	2,22	208,2	0.96	0.453	175	0.32
		6	3	33	2,55	171	1.06	0.484	212	0.37

80^0C; level of compression – 1:1 и 2:1; extruder' mouth shape – square with dimensions 20/1mm and round with diameter 5 mm. The diameter of the round mouth is chosen in compliance with the condition of equal cross section areas. The characteristics of the rolling mechanism are as follows: rollers' diameter – 100 mm; frequency of rotation of the rollers - 22÷100 min^{-1}; daylight between the rollers – 0.04÷0.08 mm.

There has been determined the following characteristics of the reconstituted tobacco sheet: nicotine content (%) – after the spectrophotometric method [9]; thickness (mm) – using a thickness-meter with extended area of the measuring pawls; density (relative) of cut tobacco shreds (g/cm^3)– by the press method with Borgwaldt density meter [9], after cutting with a laboratory cutter to shreds with δ=0.8-1.0 mm; weight per area (air-dried matter) (g/m^2)– by weighing 10 squares 20/20 mm and drying at 103±2°C. The values shown in tables I and IV are mean arithmetic values of different number of repetitions, as demanded by the corresponding method.

The specific mechanical energy (SME) is calculated according to the equation [3, 7]:

$$SME = \frac{M_c.\omega}{Q}, \ Wh/kg \qquad (1)$$

where:

- M_c – resistance moment of the work screw in the process of extrusion, Nm;
- ω - frequency of rotation of the work screw rad/s. $\omega = (\pi.n_p)/30$, where n_p – frequency of rotation of the work screw, min^{-1}.
- Q – mass productivity, kg/h.

The productivity (Q) is determined through measuring the weight of samples taken from the working extruder at a defined period of time. The time periods are read with mechanical chronometer "Slava" with precision 0.1 s, and the weight of the samples is measured with an electronic balance with precision 0.01 g.

III. RESULTS AND DISCUSSION

To evaluate the influence of the composition of the initial blend and the construction characteristics of the extruder on the production process and the parameters of the final product, the following experimental factors have been studied: degree of compression of the active screw; percentage of carboxyl methylcellulose (CMC); percentage of propylene glycol (PG) and shape of the extruder's mouth. The results obtained both for the process characteristics and the reconstituted sheet produced are presented in Table I.

The index SME expresses the mechanical energy spent for producing one unit of weight extruded matter. The low consumption of mechanic energy, when combined with good physical and chemical properties of the final product, proves to be an index for the economic efficiency of the process [7].

The data obtained show that maximum productivity, and respectively - minimum energy consumption, are observed with the variants of a round extruder's mouth, with 14 % CMC and 7 % PG. When considering the characteristics of the sheet produced, however, it should certainly be emphasized that with respect to the analyzed technological characteristics these samples are considerably inferior to that coming out from the square mouth. Furthermore, the reconstituted tobacco sheet from the variants with level of compression 1:1 and a round mouth turned out to be with highly deteriorated outlook and texture, and

TABLE III

MATRIX OF EXPERIMENT

№	Encoded values								Natural values		
	x_0	x_1	x_2	x_3	$x_1.x_2$	$x_1.x_3$	$x_2.x_3$	$x_1x_2x_3$	x_1, mm	x_2,%	x_3,%
1	+	-	-	-	+	+	+	-	1:1	6	3
2	+	+	-	-	-	-	+	+	2:1	6	3
3	+	-	+	-	-	+	-	+	1:1	14	3
4	+	+	+	-	+	-	-	-	2:1	14	3
5	+	-	-	+	+	-	-	+	1:1	6	7
6	+	+	-	+	-	+	-	-	2:1	6	7
7	+	-	+	+	-	-	+	-	1:1	14	7
8	+	+	+	+	+	+	+	+	2:1	14	7

hence we have been unable to cut them and evaluate their relative density. Data in Table I show that there are observed generally higher values for the indices thickness, weight per area and relative density of the RTS with the round mouth. The density of the analyzed RTS is greater as a whole, compared to that of reconstituted tobacco produced by using other methods: American by the paper method – 0.325 g/cm^3 [5]; AZ 8 – France (by the Schwietzer technology) – 0.225 g/cm^3; MCF – France (by the thick pulps' method) – 0.300 g/cm^3 [6]. The measured values for the thickness of the sheet coming out from the square mouth are slightly higher than the real situation, because there is a specific wrinkling of the sheet. From a technological point of view, such wrinkling is desired and sought for, because it results in an increase of the filling properties of the material when incorporated in the tobacco blends for cigarettes. The samples produced with the square mouth under both levels of compression show considerably lower values for the weight per area index compared to those coming out from the round mouth. With respect to nicotine content no significant differences attributed to the factors studied can be observed.

The above-stated considerations served as a basis to exclude the factor "mouth shape" from our further investigation and to carry out an all-factor experiment 2^3. The input factors: X_1 – level of compression at the active screw; X_2 – percentage of carboxyl methylcellulose; and X_3 – percentage of propylene glycol; as well as their maximum and minimum levels, and variation intervals, are presented in Table II.

TABLE II

INPUT FACTORS RANGE

Factor Level	Symbol	X_1	X_2	X_3
Basic level	x_{i0}	-	10	5
Interval of variation	Δx_i	-	4	2
Minimum level	$x_{i\,min}$	1:1	6	3
Maximum level	$x_{i\,max}$	2:1	14	7

Table III shows the experimental matrix of the input factors with their encoded and natural values.

The model of regression equation sought for the target function – the specific mechanic energy SME (Y) is of an incomplete quadratic type:

$$Y = B_0 + B_1.X_1 + B_2.X_2 + B_3.X_3 + B_{12}.X_1.X_2 + + B_{13}.X_1.X_3 + B_{23}.X_2.X_3 + B_{123}.X_1.X_2.X_3 \qquad (2)$$

In Table IV the results for the estimated SME of the analyzed sample variants are given (in three fold repetition).

TABLE IV

SPECIFIC MECHANIC ENERGY

№	X_1	X_2	X_3	SME, Wh/kg			SME_{cp}, Wh/kg
				1	2	3	
1	-	-	-	156.94	159.12	159.74	158.60
2	+	-	-	170.83	171.88	170.27	171.00
3	-	+	-	161.97	163.32	163.21	162.50
4	+	+	-	220.14	223.12	220.34	221.20
5	-	-	+	141.30	143.52	143.28	142.70
6	+	-	+	206.96	209.30	208.34	208.20
7	-	+	+	148.85	151.20	150.55	150.20
8	+	+	+	206.72	208.80	207.88	207.80

These results prove to be the basis for deriving the following adequate regression equation, depicting the dependence of the specific mechanic energy on the input variables: level of compression of the active screw of the extruder, percentage of carboxyl methylcellulose and propylene glycol:

$$Y = 177.8160+24.2325X_1+7.6925X_2+4.7572X_1X_2+ 6.5425X_1X_3 - 5.9175X_2X_3 \qquad (3)$$

It could be seen that the variable X_3 – the percentage of propylene glycol, drop out of the equation as a separate factor. It affects the SME only in combination with the two other factors – X_1 and X_2.

Fig. 1 shows the response surface and Fig. 2 – the contours of equal response for the target function SME.

Fig. 1. Estimated response surface

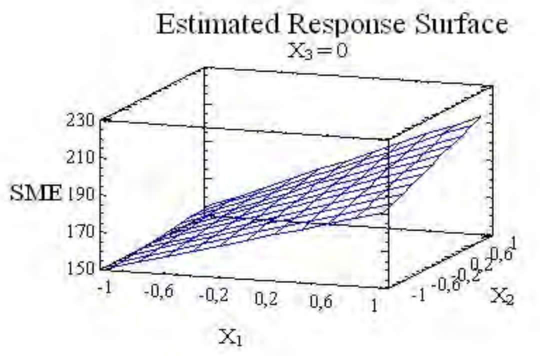
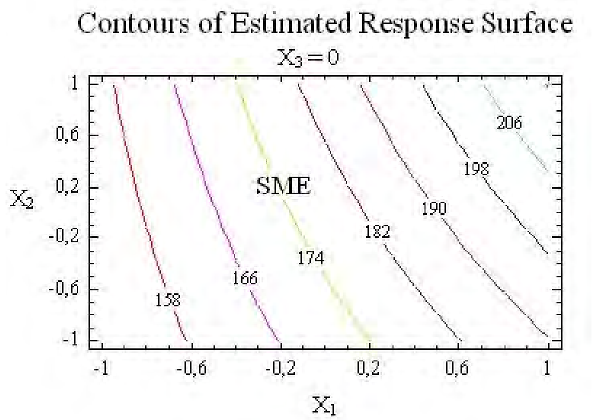


Fig. 2. Contours of estimated response surface



The estimated response area (Fig. 1) is approximated to a plain with a positive slope at higher level of compression and higher percentage of CMC. Similar information can be derived from Fig. 2.

IV. CONCLUSIONS

1. The reconstituted tobacco sheet made by applying the square-shaped mouth surpasses that made with the round mouth in basic technological indices (thickness and weight per area), despite the worse energetic parameters.

2. From the energetic point of view, with approximately equal physical and chemical properties, it is more favourable to extrude the tobacco sheet with
no compression at the active screw (volume ratio at the beginning and at the end of the screw 1 : 1) and percentage of CMC approx. 6 %.

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