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Analysis of tobacco products by chromatography methods: review

Abstract: Currently, the number of consumers of tobacco products in the world is growing rapidly. In this regard, the number of tobacco companies and varieties of tobacco is growing. Many tobacco companies write a small amount of components presented in the cigarette on the product box. But in fact, this information does not fully reflect the contents of the cigarette. This article presents methods for determining organic compounds in tobacco products, using gas chromatography-mass spectrometry, liquid chromatography, and liquid chromatography-tandem-mass spectrometry. Also the determination of heavy metals in tobacco products by extraction-absorption spectroscopy, atomic absorption spectroscopy, inversion voltammetry, inductively coupled plasma optical emission spectroscopy.

Key words: tobacco products, gas chromatography – mass spectrometry, liquid chromatography, liquid chromatography – mass spectrometry, heavy metals.

Introduction

According to the World Health Organization (WHO) reports in May 2017, about 7 million people die of cigarettes every year. More than 6 million deaths were caused by direct consumption of tobacco and more than 890,000 by tobacco smoke(passive smoking). More than 1.1 billion smokers report that 80% of them live in countries with a low or medium standard of living [1]. In June 2017, 400 people were interviewed in Almaty, among which 77% of participants reported that they do not smoke, and the remaining 23% replied oppositely. People who smoke only one box or more per day are 13%, several cigarettes a day are 8% and several cigarettes in a month are 2%. The reason for smoking cessation is that 40% of the participants refused to smoke by voluntary will, and 32% reported that their health is deteriorating, 8% are unhappy with smoking, and 6% have changed the social environment and 5% are pregnant [2]. But, despite this, the number of consumers of tobacco products has not decreased. That's why the consumption of tobacco products by residents of the 21st century causes environmental pollution.

The period of tobacco production begins mainly with the cultivation of tobacco leaves. The tobacco leaf contains nicotine and other alkaloids, proteins, amino acids, carbohydrates and fatty acids, resins, essential oils and pectin compounds. When smoking there are distinguished various chemical compounds in the atmosphere of the Earth [3]. To this end, it is important to assess the quality of tobacco products, identify toxic compounds, and investigate environmental safety through gas and liquid chromatographic methods.

Gas chromatography mass – spectrometry (GC-MS)

With the help of gas chromatography, the tobacco industry determines the water content [4], nicotine [5] in the smoke condensate (cigarette smoking can be carried out by standard or non-standard methods) [6; 7]. Also, chromatography methods help to establish the quality of tobacco products in accordance with State Standard (GOST). The analysis of residual amounts of organochlorine pesticides in tobacco products (including leaf tobacco) is also carried out using chromatographs [8].

Gas chromatography methods are widely used in the study of tobacco products:

– identification and quantification of alkaloids in tobacco products;

– quantitative determination of moisturizers in tobacco products;

– identification and quantitative determination of flavors in electronic cigarette liquids;

– identification and quantification of aromatic, carcinogenic volatile compounds in tobacco products;

– identification and quantification of toxic compounds in the tobacco filter, etc.

By using the GC-MS method it is possible to determine the qualitative and quantitative composition of carcinogenic substances in tobacco smoke [9-11]. And as for the investigation of volatile organic substances, which are completely absorbed into the lungs of smokers, it was applied the GC-MS method [12]. British scientists have identified carbonyl compounds in tobacco smoke using GC-MS and HPLC. The GC-MS method proved to be more advantageous than HPLC [13]. Both GC-MS and HPLC methods were compared in the determination of phenolic compounds in tobacco smoke, after which the GC-MS method allowed to obtain a more precise and reliable result than HPLC. Using the GC-MS method, 24 types of phenolic derivatives in tobacco smoke were simultaneously identified, phenolic derivatives with a low concentration were also detected [14].

The gas chromatography-mass spectrometry method has a greater influence on the determination of chemical compounds in the smoke of electronic cigarettes than liquid chromatography. Scientists Goniewicz M.L, Knysak J, Gawron M having studied the smoke of 12 types of electronic cigarettes and ordinary cigarettes came to the conclusion that in tobacco smoke, 9.44 times less toxic substances [15]. Scientists Schober W, Szendrei K, Matzen W identified 7 polyaromatic hydrocarbons, propane-1-2-diol, a high amount of nicotine, carcinogenic glycerin and aluminum in the smoke of electronic cigarettes [16]. According to the authors of Schripp T, Markewitz D, Uhde E, the smoke of electronic cigarettes contains formaldehyde, acetaldehyde, isoprene, acetic acid, diacetyl, acetone, propanol, propylene glycol, diacetin (separated from flavorings), aromatic oils, nicotine [17]. By the studies of American scientists in the smoke of electronic cigarettes there are formaldehyde, acetaldehyde, propionaldehyde, acrolein, crotonaldehyde, methyl ethyl ketone, butyraldehyde, hydroquinone, resorcinol, catechol, phenol, m-cresol, p-cresol, o-cresol, 1,3-butadiene, isoprene, acrylonitrile, benzene, toluene, styrene, beryllium, cadmium, chromium, cobalt, lead, manganese, mercury, nickel, selenium, tin, N-nitrosonoricotine, N-nitrosoanatabine, N-nitrozoanabazine, 4- (methylnitrosamino) -1- (3-pyridyl) -1-butanone), 1-aminonaphthalene, 2-aminonaphthalene, 3-aminobiphenyl, 4-aminob phenyl, naphthalene, acenaphthylene, acenaphthene, ftorin, phenanthrene, anthracene, flyuranten, pyrene, benzanthracene, hrizon, benzo (b) fluoranthene, benzo (k) fluoranthene, benzo (g, h, i) perylene [18].

According to the above-mentioned study, GC and MS were able to replenish each other and demonstrated a number of advantages:

– increased separation efficiency (per connection);

– high efficiency and identification of separation;

– simultaneous identification of different samples by their nature;

– qualitative and rapid detection of various compounds (alkaloids, aromatic compounds, nitrogen compounds, etc.)

High performance liquid chromatography (HPLC)

HPLC along with GC-MS is also important in the investigation of tobacco products. The HPLC method has the following advantages:

– efficiency of separation

– high analysis speed

– highly accurate quantitative method

– high sensitivity

– lowest quantity of the sample to be penetrated.

Today, the “Cooperation Centre for Scientific Research Relative to Tobacco” has announced a residual amount and a list of 118 pesticides found in tobacco. In this connection, HPLC and LC-MS methods have a greater influence on the determination of pesticides in tobacco than GC-MS [19].

In 2016, Brazilian scientists Gabrieli Bernardi, Magali Kemmerich, Lucila C. Ribeiro, Martha B. Adaime, Renato Zanella, Osmar D. Prestes examined tobacco by HPLC and GC-MS. As a result, the HPLC method determined 55 pesticides, GC-MS method could not identify that amount of pesticides in tobacco [20].

The HPLC method and LC-MS make it possible to qualitatively and accurately determine the pesticides in tobacco products, as well as to isolate the analytes from the column well [21-25].

In 2017, scientists from the US Liqun Wang, Roberto Bravo Cardenas, Clifford Watson examined sucrose, aldose and humectants in cigarettes using HPLC. To determine the 11 types of sucrose, they used a HILIC column with a film thickness of 1.7 µm, and spent 15 minutes for sample preparation. The scientists came to the conclusion that the method is the most optimal, and by using the HILIC column all the peaks were accurately displayed, and it has a high sensitivity (1.2 ng/ml) [26].

Liquid chromatography mass – spectrometry (LC-MS)

The US “Food and Drug Administration” in 2012 introduced six primary amines to the list of especially dangerous carcinogens. This is o-toluidine, 2,6-dimethylaniline, o-anisidine, 1-naphthylamine, 2-naphthylamine and 4-aminobiphenyl. Also, the International Agency for Research on

Cancer reported that -toluidine, 2-naphthylamine, 4-aminobiphenyl lead to the development of cancer. These amines are in tobacco and while smoking they pass into tobacco smoke [27-28]. Chinese scientists using LC-MS method to determine six primary amines, concluded that this method is automated, fast, and very accurate (the sensitivity of the method is 0.04-0.58 ng / cigarette). The whole experiment was spent only 30 minutes and all 6 primary amines were determined simultaneously in the tobacco smoke [29].

The LC-MS method is most significant in the determination of amines and the mercapturic coupling of acrolein in the urine of smokers and non-smokers [30-33].

When using GC-MS and LC-MS methods, phthalates and tereflates were determined in liquids of electronic cigarettes. As a result, the LC-MS method showed a good separation for analytes such as diethyl, dibutyl, benzylbutyl, diphenyl, bis (2-ethylhexyl), di-n-octyl, diisoninyl and diisodecyl, dimethyl, bis-2-ethylhexyl. Has shown high sensitivity (100ng/ml) for the analytes. Since diphenyl, diisinyl and diisodecyl were non-volatile, they were not determined by GC-MS [34].

The LC-MS method proved to be the most suitable and allowed to obtain a more accurate and reliable result for the qualitative and quantitative determination of pyridine, 2-picoline, 4-picoline and quinoline in tobacco smoke [35].

Atomic absorption spectroscopy (AAS)

Tobacco smoke is toxic, and contains a large amount of carcinogenic substances. In the smoke there are both organic carcinogens and inorganic substances. This is cadmium, lead and other heavy metals [36]. In both tobacco and tobacco smoke, heavy metals such as Cd, Cr, Pb, Ni are found that penetrate the body through tobacco smoke [37-42]. Also tobacco smoke contains Cd and Hg, which are absorbed into the body, and lead to the development of cancer. Cd refers to the first group of carcinogenic substances, and Hg to the second [43; 44].

Table 1 – Methods for determining components in tobacco products

№	Method	Detectable component	Sample preparation	Methodological conditions	Reference
1	2	3	4	5	6
1	Extraction absorption spectroscopy	Cadmium	Tobacco was calcined in a corundum dish in a muffle furnace at a temperature of 600-700° C. Then, 5-7 ml of HNO_3 ($\rho = 1.4$) was added, again calcined for 10-15 minutes.	Spectrophotometer SF-16 $\lambda = 585$ nm ditch = 0.1 cm.	[50]
2	Atomic absorption spectroscopy	Heavy metal (Cu, Zn, Pb, Ag, Fe)	Samples were dried in an oven for 1 hour at a temperature of 105° C. Then 10 cm^3 of concentrated hydrochloric acid was added and the heating was continued for another 30 minutes.	Spectrometer Quantum-2A	[51]
3	Inversion voltammetry	Heavy metal (Cu, Zn, Pb, Cd, Hg)	Samples of tobacco weighing 0.2 g were collected, ashes were taken as a whole. The samples were treated with concentrated nitric acid.	Voltammeter TA-4 background electrolyte – 10 ml 0.45 M solution of formic acid	[52]
4	Inversion voltammetry	Heavy metal (Cu, Zn, Pb, Cd, Hg)	The tobacco smoke was extracted with an aqueous solution of 0.1 M formic acid	Voltammeter TA-4 background electrolyte – 10 ml 0.45 M solution of formic acid	[53]
5	Inversion voltammetry	Mercury (Hg)	The tobacco smoke was extracted with an aqueous solution of 0.1 M formic acid	Voltammeter AVA-3 background electrolyte – H_2SO_4 – 0.4 mol/l , KNO_3 – 0.1 mol/l , trilon B. – 0.001 mol/l	[53]

Continuation of table 1

№	Method	Detectable component	Sample preparation	Methodological conditions	Reference
1	2	3	4	5	6
6	Atomic absorption spectroscopy	Cadmium	The samples were dried in an oven at 80 ° C for 12 hours and allowed to cool in a desiccator. After that, it was treated, concentrated with HNO_3	Spectrophotometer UNICAM 969 $\lambda = 228$ nm	[54]
7	Atomic absorption spectroscopy	Heavy metal (Cu, Zn, Pb, Cd, Cr)	Cigarette smoke was collected in a conical flask which was filled with 50 ml of methanol and 2 drops of 1M nitric acid	Spectrometer Shimadzu 6200 graphite furnace	[55]
8	Inductively Coupled Plasma Optical Emission Spectrometry	Heavy metal (Al, Cd, Co, Cr, Mn, Ni, Pb, Sr)	1.5 g of tobacco was placed on a porcelain plate and 10 drops of 65% HNO_3 were added. The solution was then treated with 1.5% HNO_3.	Spectrometer iCAP 6300 Duo	[56]
9	Gas chromatography–mass spectrometry	Nicotine	0.1 g of the tobacco leaf powder was extracted 3 times with 5 ml of methanol and sonicated for 30 minutes.	Column: VF-5 (30 m × 0,25 mm × 0,25 μm); t_{oven}= 50 – 200°C (τ_{held}= 20 min); υ = 4°C/min; t_{oven}= 200 – 300°C; υ=10°C/min;	[57]

10	Liquid chromatography–tandem mass spectrometry	52 pesticides	2 g of ground tobacco were soaked with 6.25mL of 1% aqueous acetic acid for 5min	Column: Hydro RP-80 A (150 mm × 2,0 mm × 4μm); $t_{therm.}$=35°C;
				mobile phase A = methanol: water (10:90);
				mobile phase B = water: methanol (90:10);
					[58]

11	Liquid chromatography–tandem mass spectrometry	Nitrosamines	0.5 mm of a e-cigarette liquid and 50 mL of phosphate buffer (pH 7.2) containing 0.2 g of ascorbic acid were placed in a 100-mL flask.	Column: Eclipse Plus C18 (50 mm × 2,1 mm × 1,8 μm); $t_{therm.}$=30°C;
				mobile phase A = 0.002% formic acid;
				mobile phase B = methanol;
					[59]

12	Liquid chromatography-tandem mass spectrometry	Flavouring additives and nicotine	e-liquid samples were weighed in a 50 mL volumetric flask and diluted with a mixture of ACN:H_2O (1:9,v/v).	Column: Ace Ultracore Super C18 (100 mm × 2,1 mm × 0,25 μm); $t_{therm.}$=30°C; mobile phase A = water 0.05% v/v of formic acid; mobile phase B = acetonitrile 0.05% v/v of formic acid;	[60]
13	Gas chromatography–mass spectrometry	Caffeine	Tobacco from one cigarette was spiked with 10 ml of caffeine solution (100 mg/ml) and was shaken at 130 rpm by an orbital shaker in 25 ml of citrate buffer (5 mM ascorbic acid in 100 mM citrate–phosphate buffer, pH 4.5) at room temperature for 24 h.	Column: DB-5ms (30 m × 0,25 μm); $t_{oven.}$= 40°C ($\tau_{held.}$= 1 min) – 160°C ($\tau_{held.}$= 1 min); υ = 20°C/min; $t_{oven.}$= 160°C ($\tau_{held.}$= 1 min) – 200°C ($\tau_{held.}$= 1 min); υ = 4°C/min; $t_{oven.}$= 200 – 260°C ($\tau_{held.}$= 1 min); υ=15°C/min;	[61]
14	Gas chromatography–mass spectrometry	Diacetyl and acetylpropionyl	1g of each e-liquid sample was weighted into a 10ml brown flask and 500μl of internal standard was added. After that 300μl was transferred into a 10ml headspace vial to which 0.05g of sodium chloride was added.	Column: VF-5ms (60 m × 0,25 mm × 0,25 μm); $t_{oven.}$= 55°C ($\tau_{held.}$= 13 min) – 250°C; υ = 50°C/min;	[62]

Continuation of table 1

№	Method	Detectable component	Sample preparation	Methodological conditions	Reference
1	2	3	4	5	6
15	Gas chromatography–mass spectrometry	Free and bound aromatic compounds	10.0-g tobacco sample was extracted with 250 ml of dichloromethane.	Column: HP-5 (30 m × 0,25 m × 0,25 µm); $t_{oven.}$= 40°C ($\tau_{held.}$= 2 min) – 270°C ($\tau_{held.}$= 10 min); υ = 2,5°C/min;	[63]
16	Gas chromatography–mass spectrometry	Glycosidically bound aroma compounds	2.0 g of dried tobacco was placed in a 100 mL cappedflask and 10µL of internal standard was added. The sample wasextracted by ultrasonic washer in twice with methanol (20 mL and 20 mL) for 30 min each..	Column: HP-5ms (60 m × 0,25 mm × 0,25 µm); $t_{oven.}$= 60°C ($\tau_{held.}$= 1 min) – 280°C ($\tau_{held.}$= 5 min); υ = 2°C/min;	[64]

17	Liquid chromatography-tandem mass spectrometry	Trace amounts of nicotine	10 mg of an electronic cigarette liquid was transferred to a 10 ml flask and extracted with 50 µl of pyridoxine hydrochloride.	Column: Zorbax Eclipse XDB-C8;
				(150 mm × 4,6 mm × 5 µm);
				$t_{therm.}$=35°C;
				mobile phase A = acetonitrile with 0.01% of formic acid;
				mobile phase B= water with 10 mM of ammonium formate;
					[65]

18	Gas chromatography–mass spectrometry	Humectants	4g of each tobacco product were extracted with 50 mL of methanol containing 2.0 mg/mL 1,3-butanediol and shaken for 1 hour After that extracts were filtered through Whatman 30 µm filter paper.	Column: DB-Wax (15 m × 0,53 mm × 1 µm); $t_{oven.}$= 120°C ($\tau_{held.}$= 2 min) – 180°C ($\tau_{held.}$= 4 min); υ = 15°C/min;	[66]
19	Liquid chromatography	Eight polyphenols	0.25 g of tobacco powder was extracted with ultrasonic extraction for 30 min in 40 mL of methanol-water (70:30, v/v) solution and centrifuged at 10,000 rpm for 10 min.	Column: Zorbax Eclipse XDB-C18; (50 mm × 4,6 mm × 1,8 µm); $t_{therm.}$=30°C; mobile phase A = 0.01% formic acid mobile phase B= acetonitrile;	[67]
20	Gas chromatography–mass spectrometry	Benzene, toluene, ethylbenzene, and xylene	3.0 g of a 1 cm long tobacco filter was transferred to a 60 ml flask. After that, 50 ml of a 2-hexanone solution was added.	Column: TG-WaxMS (30 m × 0,25 mm × 0,25 µm); $t_{oven.}$= 35°C ($\tau_{held.}$= 2 min) – 100°C; υ = 15°C/min; $t_{oven.}$= 100°C – 220°C ($\tau_{held.}$= 3 min); υ = 20°C/min;	[68]

The atomic absorption spectroscopy method is usedto determine heavy metals in tobacco. During the research, a flame and electrothermal atomization is used. In general, a flame AAS [45; 46] and AAS with a graphite furnace [47-49] are used. After studying different literature, they came to the conclusion that AAS with a graphite furnace was the most widely applied.

In most cases, the GC-MS methodwas used for definition of organic components in tobacco products, such as nicotine, caffeine, aromatics, humectants, benzene derivatives. The GC-MS method gave a good possibility of isolating the components, as well as made it possible to determine unknown substances by their mass spectra. During the analysis, various columns were used, and all samples were dissolved in methanol. The techniques often used a gas chromatograph aglient from the United States. The method of atomic absorption spectroscopy was often used to determine heavy metals in tobacco products.

Conclusion

Chromatographic techniques for the determination of components in tobacco products were presented in this paper. The material can be used to control the quality of tobacco products in the market of Kazakhstan, as well as in the field of health and ecology.

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