

Conference Paper

Modern Methods and Devices for Obtaining Technological Smoke: Review

Grigoriy Shokin and Yulia Shokina

Murmansk State Technical University, Murmansk, Russian Federation

Abstract

The present article is based on the review of the current patent, scientific and technical sources. It summarizes the main types of smoke generators currently used in the meat and fish industry of the Russian Federation. The classification of smoke-generators on the basic attributes characterizing their technological and ecological efficiency is offered. Advantages and disadvantages of modern apparatuses for obtaining smoke are considered. The problem of contamination of food products with polyaromatic hydrocarbons (PAHs) during smoke smoking is reviewed. The main reason for the formation of this negative technological effect (pyrolysis of wood fuel in uncontrolled temperature conditions in the overwhelming majority of smoke generators and thermal chambers of different design) is pointed. The article substantiates the high urgency of improving the methods of obtaining carcinogenic free smoke compounds and devices on the basis of the analysis of constructions of domestic and foreign smoke generators and thermal chambers with the option of smoke generation, operated at food enterprises of the Russian Federation. Description of the method of smoke production with the use of infrared heating is given for the infrared smoke generator of Murmansk State Technical University as an example of successful solution of the problem mentioned in the article.

Keywords: smoked food, polyaromatic hydrocarbon contamination, smoke generators, thermal chambers, pyrolysis of wood fuel, IR smoke generator

Corresponding Author:
Grigoriy Shokin
doubledelay@yandex.ru

Received: 24 December 2019
Accepted: 9 January 2020
Published: 15 January 2020

Publishing services provided by
Knowledge E

© Grigoriy Shokin and Yulia Shokina. This article is distributed under the terms of the [Creative Commons Attribution License](#), which permits unrestricted use and redistribution provided that the original author and source are credited.

Selection and Peer-review under the responsibility of the BRDEM-2019 Conference Committee.

1. Introduction

In the last decade, the consumption of smoked foods and smoke-treated products, such as fish, various meat products and cheese, has been steadily increasing [1]. The use of traditional smoking is known to cause the inevitable contamination of products with polyaromatic hydrocarbons (PAHs) of type 3,4 - benzo(a)pyrene, which have a powerful carcinogenic effect on the human body [2]. These compounds are the products of decomposition of basic chemical components of wood from which smoke (cellulose, hemicellulose and lignin) is obtained by pyrolysis at temperatures above 380 °C [8–10] in devices and devices of various designs.

OPEN ACCESS

The PAH content in smoked food products is limited by the maximum allowable concentrations established by the legislation of individual countries and varies in the Russian Federation and EU countries in the range from 1 to 5 µg/kg of products, depending on the type.

However, in some products, depending on the method of obtaining smoke (method of smoke generation) and the type of wood used, the method and duration of smoke treatment [3], PAH content can significantly exceed the above normative values, reaching values of 250...1736 mg/kg in smoked fish (tuna, mackerel, sardine) [4] and 30,5...1779 mg/kg in smoked sausages [5--7]. Given the systematic consumption of such foodstuffs, the increase in the incidence of cancers affecting the digestive system of the population, e.g. stomach, pancreas and liver cancer, is expected [8].

Reduction of contamination of smoked food products with hazardous compounds can be achieved by drastically changing the approach to the design of equipment for smoke generation and overall smoking. It is highly expedient to exclude the possibility of carcinogenic compounds formation during wood pyrolysis already at the stage of equipment design, i.e. to provide constructively the possibility of wood pyrolysis temperature control during the whole process of smoke generation. Only reliable maintenance of wood fuel pyrolysis temperature at the level lower than the known carcinogenic peaks (lower than 380...450 °C) will allow practically excluding PAH formation and providing high carcinogenic safety of smoked food products.

2. Main Part

Smoke which is used for smoked food products is an aerosol that contains a large number of chemical compounds that can interact with each other and with the product, forming the necessary technological effects such as the formation of a characteristic "smoked" color of the surface, taste and aroma. Qualitative and quantitative composition of these compounds determines the quality, consumer properties and safety of smoked products [9].

The majority of scientists working in the field of smoking technologies consider phenolic and carbonyl compounds of smoke to be the most important for formation of almost all positive effects of smoking. The negative smoking effects include the contamination of PAH products, which are also contained in the smoke and are formed at temperatures of pyrolysis above 400 °C [10]. According to many researchers, to obtain smoke with good functional and technological properties, it is necessary to provide the temperature of pyrolysis of wood, close to the temperature of its ignition, from 220 to

350 °C [9, 11]. Exceeding 350 °C helps to reduce the proportion of active components of smoke and intensive decomposition of cellulose, hemicellulose and lignin with active formation of PAH.

Thus, the problem of sharp increase of carcinogenic safety of smoked foodstuffs is reduced to the solution of the problem of technical maintenance in the process of smoke generation of wood pyrolysis temperature at the level not exceeding 400 °C.

The urgency of this problem is extremely high today and undoubtable, because the share of smoke generators, which do not have the ability to automatically maintain the pyrolysis temperature at a given optimal level, is more than 90% [12].

The patent search and review of scientific and technical literature, as well as the review of official sites of smoker manufacturers, allowed analyzing a significant amount of equipment for smoke production. The review has shown that currently two methods are implemented in the smoke fields and smoke generating apparatuses: burning of wood in the form of sawdust, pallets, briquettes and bars directly in the thermal chamber and burning of fuel in special apparatuses, such as smoke generators, from where the smoke is delivered to the place of product processing by means of a chimney. For many decades in Russia smoked food products have been made with the use of smoke produced in centralized sources of smoke generation of various types, both domestic and foreign, mainly produced in Germany [12].

Nowadays such foreign brands as Autotherm (Germany), Vemag (Germany), Reich (Germany), Maurer (Germany), Bastra (Germany) and others are widely known in Russia. All operated smoke generators should be classified according to the following criteria, which characterize their technological and ecological efficiency:

1. type of energy source for fuel heating (with external and internal heat generation, endothermic and exothermic smoke generators, respectively);
2. design features of heating surface;
3. operation principle (open, with free air access to fuel space and closed, where air access is regulated);
4. level of automation and mechanization of the smoke generation process;
5. possibility of controlling the pyrolysis temperature;
6. level of smoke environment safety (PAH content).

Most often in the design of modern smoke generators there are technically implemented ways of obtaining smoke by smoldering, friction and by means of steam generation [12].

In the most widespread smoke (smoldering) generators, power supply to one smoke-forming part of fuel is carried out at the expense of the energy allocated at burning of its other part. Pyrolysis or incomplete combustion of wood is known to occur with the release of large amounts of heat from the exothermic decomposition of organic wood compounds to carbon and hydrogen. This heat is enough to warm a part of the wood to a temperature of about 300 °C, at which self-ignition occurs [12].

Pyrolysis of wood (sawdust, chips) in smoke-generators of smoldering occurs in a thick layer (from 15 to 20 cm) on a grate without mixing that promotes occurrence of open flame centers in which the temperature rises to values 800...1000 °C that leads to intensive formation of PAH. To extinguish the flames, various technical solutions for wood moistening are often used in the design of exothermic type smoke generators, but these measures lead to deterioration of the functional and technological properties of smoke (increased humidity of the smoke-air mixture, formed by "acidic" smoke with a large number of coarse soot particles). For minimizing the negative effects of wood moistening directly in the production of smoke in closed-type smoke generators, limited-volume fuel cells are used.

A common disadvantage of exothermic type smoke generators is the high consumption of wood per unit of smoke volume. Today in the Russian Federation the most common domestic exothermal smoke generators of the following brands are 9-FDG, H10-ID2G-1, IDA-2, L5-FDG, YA-5-FKE, also smoke generators designed by ZAO Klipmash, H29-IO2 smoke generators designed by SPC Sevrybtechtsentr, UDG-100 smoke generators, as well as their numerous modifications. The analysis of their designs allows allocating the general advantages and lacks for them.

The advantages include the simplicity of design and operation, the disadvantages are a primitive system of water quenching of open flames, the lack of any mechanization of the technological process of smoke generation, as well as automatic control and management of the process. On aggregate of advantages and disadvantages, domestic smoke-generators of exothermic type, which are mass operated at the small enterprises, can be classified as out-of-date devices.

The review of designs of the import smoke-generators presented at the Russian food enterprises allows characterizing them as the smoke-generators with internal heat formation. However, their comparison with domestic apparatuses reveals many competitive advantages:

1. possibility to prevent local wood overheating in the process of smoke generation in automatic mode without human involvement;

2. technical possibility and means of control and management in automatic mode of important technological parameters of smoke such as relative humidity and temperature;
3. low energy and wood consumption per unit of smoke volume;
4. efficient systems for purification of emissions into the atmosphere.

Smoke generators by VERINOX, AUTOTERM chip smoke generators, REICH and VEMAG smoke generators are the most widely used in the domestic market and food industry. Often foreign manufacturers of smoke generators offer a number of devices with a different set of functional options and post-sale service. Such tactics allows foreign companies to attract the largest number of customers, which are most often the food enterprises of different producing orientation and production capacity. So, for example, in the Russian market of smoke-generators, sets of devices of German and Polish companies "FESSMAN", "Schröter", "FEMAG" (in which consumers are given a choice between the smoldering smoke-generator, RATIO-TOP, the frictional smoke-generator, RATIO-FRICTION, and the liquid smoke-generator, RATIO-LIQUID) [12] are presented.

The analysis of the collected information allows us to identify the main advantages and disadvantages of domestic and imported smoke generators with internal heat generation. The best models have the ability to prevent the formation of open flames in the process of fuel pyrolysis, equipped with systems for cleaning smoke emissions of varying degrees of complexity and efficiency or characterized by minimal emissions. However, an absolute disadvantage of all devices of this type is the lack of possibility to reliably control the temperature of wood pyrolysis, which contributes to the formation of PAH and further contamination of food products.

The principal difference between smoke generators with external heat generation (endothermic) and apparatuses with internal heat generation (exothermic) is the way of heat supply to wood from an external source. Structurally, most often it is realized by means of constant supply of heat energy to wood from heaters of different types with some coolant, or due to friction. This principle allows maintaining the temperature of pyrolysis of wood at the time of smoke formation at the temperature of the coolant or slightly higher, which creates a fundamental opportunity to monitor and control the temperature regime of pyrolysis, which is responsible for the carcinogenic safety of smoke. Now at the Russian food enterprises, endothermic smoke generators both domestic and imported are in charge, such as PSM-2, which is a modernization of smoke generator PSM-VNIRO, smoke generator "Kasakrus" of French manufacture, as well as smoke generators H10-IDG-2, SG-2. In all these models, the heating of sawdust

is carried out on metal plates of different design, which in their turn are heated with the help of electric heating devices [12].

Steam smoke-generators by the "AUTOTERM" corp., model AD 54/AD 56, smoke-generator VEMAG H507/C represent devices for reception of "smoky steam" which receive dry distillation of wood sawdust. The main advantage of steam smoke generators is high carcinogenic smoke safety and full absence of PAH. The disadvantage of devices is the raised moisture content and temperature of smoky steam which do not allow one to use it for cold smoking without additional preparation [12].

Among smoke generators with external heat formation, the second place on quantity of models after smoke generators of smoldering occupied by frictional smoke generators of disk type. The greatest distribution in Russia friction smoke generators have received in the 90's, more often at the enterprises it is possible to meet devices such as VEMAG H501/D, Friction Smoker FR-702/FR-1002, Maurer, DF-300, DGF-50, etc. as a part of universal smoke chambers of manufacture of Germany. Structurally, friction smoke generator is a body with a friction inside, with an entrance hole and a branch pipe for smoke extraction. The clamping device which fixes a wooden block, is established in the case and provides reciprocating movement. The device includes a drive, which is equipped with a cassette for the placement of wooden blocks in it, and is placed in the lower part between the clamping device and the body inlet. The energy used for pyrolysis of wood is the friction energy of the wood against the cylinder. Structurally friction smoke generators can slightly differ, so there are models of cylinder type with pneumatic compression of a wooden blocks which are easily placed in the doors of thermal chambers [12--14].

The advantage of all friction smoke generators is the ability to obtain smoke with a minimum content of PAH (pyrolysis occurs at a temperature not exceeding 400 °C), as well as a small amount of electricity. The disadvantages of these devices are an increased noise level, the need to prepare the wood before use (usually using blocks of certain sizes), expensive maintenance (change of milling cutter or cylinder), as well as a specific aroma of smoke and high content of soot particles in it. In addition, wood is often ignited as a result of local overheating of the working surfaces, which requires pulse operation.

An example of a successful solution to the problem mentioned in the article is the development of the Department of Food Production Technologies of Murmansk State Technical University: infrared smoke generator (IRSG) [15]. In this device the smoke is obtained by infrared heating of pre-moistened sawdust with the bulk weight from 84 to 116 kg/m³ and humidity from 50 to 70 %. Matching the parameters of the emitter with

the optical properties of the layer of sawdust allows controlling the amount of energy supplied to the wood, and thus allows maintaining the temperature of pyrolysis not higher than 450°C. At this pyrolysis temperature, there are practically no carcinogenic and pro-carcinogenic substances in the smoke and the products. Studies of smoked products made with the use of smoke from IRSG showed that the content of 3,4-benz(a)pyrene in it was less than 0.0002 µg/kg of products [15]. The disadvantage of the mentioned device is the periodic principle of operation and low smoke efficiency.

3. Conclusions

The review of 114 models of smoke generators sold and commonly used in Russia has shown that there is no ideal equipment for obtaining carcinogen-free smoke at present.

No exothermic smoke generators can be considered as smoke generators producing safe smoking environment (pyrolysis temperature does not exceed 450 °C). Lack of manufacturer's data on pyrolysis temperature serves as an indirect confirmation of this conclusion.

Automated exothermic smoke generators include about 50 % of the units of the considered equipment. As a rule, the drive of the fuel slider or the process of controlling the smoke flow is automated. Some models of modern smoke generators are equipped with a fire extinguishing system (no more than 20% of exothermic models). In these models, a temperature sensor installed in the pyrolysis zone registers the excess temperature and transmits a signal to switch on the water supply to the working zone.

According to the design of the heating surface, smoke generators can be divided into models with underfloor heating (28% of the total number of exothermic apparatuses considered), with underfloor heating via electric fuel ignition from the electric heater, with underfloor heating via flame ignition from the torch, and with underfloor heating via ignition from the electric heating element. The most promising models are smoke generators with electric ignition of fuel, which allow saving its consumption per unit of finished product.

The review of patents has shown that in the last ten years more and more attention is paid to the development and improvement of the technological process of smoke formation in order to improve the safety of smoke and smoked products by manufacturers of smoke-generators and other equipment for smoking food products, both in Russia and abroad.

Among all variety of equipment for reception of the safe smoky environment, smoke generators with external heat formation are the most promising. Depending on the

peculiarities of heat supply, endothermal smoke generators can be divided into gas-fired and electrically heated smoke generators, as well as friction and steam generators. Smoke formation occurs in a thin layer on the energy supply side, which makes it possible to regulate the pyrolysis temperature by changing the temperature of steam or heater capacity and, as a consequence, the impact on the qualitative composition of smoke. The disadvantage of such smoke generators is high-energy consumption, as well as a high smoke temperature at the exit of the device. This requires additional conditioning of the smoke or diluting it with fresh air, which reduces the quality.

Despite the disadvantages of smoke generators with energy supply from external coolants (superheated steam, gas, mechanical friction energy, infrared radiation) are the most environmentally friendly devices. Smoke produced in these devices can be easily condensed and neutralized in liquid form, which allows attributing this type of generators to the number of very promising in non-waste technologies, which have a minimum emission.

The most advanced methods of heating wood are the ones that consider heating with mechanical energy, electricity, electromagnetic fields of ultra-high frequencies, infrared radiation.

References

- [1] Russian market magazine: food and drinks, Retrived from: <http://foodmarket.spb.ru/current.php?article=2295>.
- [2] Kim, Ig. N., Kim, Georg. N., Krivosheeva, L.V., Hitrovo L.A. (2012). Study of the content of carcinogenic compounds in smoked fish of industrial production. *Hygiene and sanitation*, vol.9(2), pp. 41-47.
- [3] Hitzel, A., Pöhlman, M., Schwägele, F., Speer, K., Jira, W. (2013). Polycyclic aromatic hydrocarbons (PAH) and phenolic substances in meat products smoked with different types of wood and smoking spices. *Food Chemistry*. vol. 139, pp. 955-962.
- [4] Essumang, D.K., Dodoo, D.K., Adjei, J.K. (2013). Effect of smoke generation sources and smoke curing duration on the levels of polycyclic aromatic hydrocarbon (PAH) in different suites of fish *Food and Chemical Toxicology*. vol. 58, pp. 86-94.
- [5] Fasano, Ev., Martinez-Carballo, El., Simal-Gandaraa, Jes., Yebra-Pimenteln (2016). Food Control Profiling, distribution and levels of carcinogenic polycyclic aromatic hydrocarbons in traditional smoked plant and animal foods. *Food Control*, vol. 59, pp. 581-590.

- [6] Snezana Skaljac Marija Jokanovica Vladimir Tomovica Maja Ivica Tatjana Tasicb Predrag Ikonicb Branislav Sojica Natalija Dzinica Ljiljana Petrovica (2018). Influence of smoking in traditional and industrial conditions on colour and content of polycyclic aromatic hydrocarbons in dry fermented sausage «Petrovska klobasa». *LWT*, vol. 87, pp. 158-162.
- [7] Kresimir Mastanjevic Brankica Kartalovic Jelena Petrovic Nikolina Novakovic Leona Puljic Dragan Kovacevic Marko Jukic Jasmina Lukinac Kristina Mastanjevic (2019). Polycyclic aromatic hydrocarbons in the traditional smoked sausage «Slavonska kobasica». *Journal of Food Composition and Analysis*, vol. 83.
- [8] Lochan Singh, Tripti Agarwal (2018). Polycyclic aromatic hydrocarbons in diet: Concern for public health. *Trends in Food Science & Technology*, vol. 79, pp. 160-170.
- [9] Kurko, V.I. (1960). Physico-chemical and chemical bases of Smoking. Moscow: Pishchepromizdat.
- [10] Kim, Georg. N. (2007). Ecological safety of production of smoked fish products. Moscow: Koloss.
- [11] Sink, I.D. (1977). Chemical effects of smoke processing on frankfurter, manufacture and storage characteristics. *J. food science*, vol. 2(6), pp. 1489-1503.
- [12] Shokina, Yul.V., Obukhov, A.Yu., Korobitsyn, A.A. (2019) The technique for food production. Smoke-Generating equipment and technologies, Retrieved from: <https://lanbook.com/catalog/>
- [13] Ershov, M.A., Shokina, Yul.V. (2001) A method for producing smoky smoke using the energy of IR-radiation and a device for its implementation. Pat. 2171033 Russian Federation
- [14] Zonin, V.G. (2006) Modern production of sausage and salted-smoked products. SPb: Profession
- [15] Shokina, Yu.V., Korobitsyn, A. A., Obukhov, A. Yu. (2009) Development and improvement of methods for obtaining safe smoke. *Fish industry*, vol. 5, pp. 80-83.