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I Gaponenkov[1], O Fedorova[1], Zh Vasilyeva[1], and T Krepkaia[2]

[1] Murmansk State Technical University, Murmansk, Russia
[2] Peter the Great St. Petersburg Polytechnic University, Russia

gaponenkovmstu@mail.ru

Abstract. The article presents an analytical review of publications highlighting the possibilities of innovative application of technologies using the energy of the electromagnetic field of ultrahigh frequency (EMF microwave) in various industries. As the analysis of technologies based on the action of the electromagnetic field of the ultrahigh frequency range shows, they are already used to solve a variety of problems: from sterilizing compotes and drying lumber to producing thermally expanded graphite and the use of these technologies in medicine. This article highlights the main advantages of using the microwave electromagnetic field, regardless of the scope of its practical application. The implementation of innovations, based on the energy of the electromagnetic field of the microwave range in the technological schemes of various industries will reduce energy consumption and improve the efficiency of the technological processes themselves. This implementation will ultimately lead to increased productivity and lower capital and operating costs, it will allow to significantly modernize production in terms of reducing energy consumption per unit of the processed product, and in terms of improving the quality of raw material processing. Possible deficiencies and their solutions in production processes are described. A significant obstacle to the intensive implementation of these technologies is the fact that the nature of wave propagation in different materials, under different initial and final conditions, can differ significantly from each other. This, in turn, implies careful design of the hardware component (emitters and chambers) as well as finding the optimal process parameters (temperature and heating rate, installation power, intensity, frequency and electromagnetic field intensity).

1. Introduction

In the modern world, technological development inevitably entails an increase in global energy consumption. Thus, according to the International Energy Agency, the average energy consumption per capita increased over the period from 1990 to 2008 by 10% and continues to grow further [1]. Therefore, the development of energy saving technologies is increasingly developing. In the conditions of scientific and technical progress, as a result of the development of various types of energy and industry, electromagnetic radiation occupies one of the leading places in terms of its environmental and production importance among other environmental factors [2,3]. The spectrum of electromagnetic radiation is quite wide. In the last century, technologies using microwave radiation are being actively developed. In the 40s and 50s of the 20th century, microwave technologies (microwave) were mainly used in radar, but later the transfer of these technologies to various industries began. Food industry can be considered the first of such type of industry: microwave technology has taken a fairly strong place in various technological schemes of many industries for 30-40 years of its application.

The first decades of the 21st century in the development of microwave technologies can be characterized as a stage of "conquering" new areas of application.

2. Main part

At the beginning of the 21st century, many technological processes in various types of economic activity can be/or are carried out using the energy of the electromagnetic field of the ultrahigh frequency range. Food production, or more precisely its branches, continues to be one of them.

Thus, in the milling and baking industries, attempts are made to use the energy of the electromagnetic field to reduce and (or) eliminate contamination with various microorganisms of the products obtained during the processing of grain raw materials, as well as to increase the quantity and quality of the finished product [4-7].

In the course of a series of experiments, scientists found that after processing the flour obtained from dry grain, some changes can be observed: the quality of raw gluten of wheat flour and its extensibility increases, the acidity and humidity of flour decrease, and the percentage of protein and other nutrients increases. Microwave processing has minimal effect on other flour quality control parameters [5].

The use of electromagnetic field energy in the food industry is not limited to areas related to storage and grain processing only. A group of researchers from the Dagestan State Technical University dealt with the use of microwave energy in conservation and sterilization of various products. In the course of experiments, it was found that processing with the use of EMF improves the quality of the finished product and significantly speeds up the sterilization process itself [8]. The scientists from this university also found that using microwave energy improves the qualitative and quantitative yield of juice from apples [9].

In agriculture and agro-industry, the application of the electromagnetic field of ultra-high frequency as one of the pre-sowing treatment methods allows to increase grain yield, to increase resistance to adverse natural and anthropogenic factors; to increase seed germination, to activate growth processes in seeds [4]. In the Kazan National Research Technical University named after A.N. Tupolev, a series of experiments to study the effect of microwave radiation on conifer tree seeds was conducted. During the laboratory and field studies, it was found that treatment with EMF of various ranges leads to a significant increase in germination energy and seed germination [10].

Pre-sowing treatment of seeds of various food crops (buckwheat, malting barley) was carried out at the Krasnoyarsk State Agrarian University. In the course of theoretical and practical research, an increase in some important indicators was revealed. Thus, the indicators of "productive bushiness" and "biological efficiency" of barley increased, respectively, by 25% and 7.3% compared to untreated seeds [7]. The treatment of buckwheat seeds with electromagnetic fields increases seed energy, which, in its turn, leads to an increase in yield and its qualitative and quantitative characteristics [11]. But electromagnetic field energy can be used not only at the pre-sowing stage, but also immediately after harvesting.

After harvesting crops, grain drying should be carried out to ensure the required commercial quality of the finished product and its long-term storage [12]. This process is also quite successfully implemented in the microwave field.

The possibility of treating compound feeds and individual ingredients with the ultrahigh-frequency electromagnetic field has been considered at the All-Russian Research Institute for the Mechanization of Animal Husbandry (VNIIMZH). The possibility of using microwave heating is being discussed as an alternative to traditional methods of heat treatment, which is associated with the need to convert starch into digestible dextrins and polysaccharides; neutralizing anti-nutritional inhibitors in soy and erucic acid in rapeseed; decontamination of bacteria, fungi and other microorganisms that are toxic to humans and animals in the grain components of compound feeds; heat treatment of fish, meat and bone meal, molasses, fats and other non-grain components. The use of microwave processing allows us to simplify the technology of animal feed production, to reduce specific energy and material consumption [3].

Heating with the use of electromagnetic energy has recently been applied in the woodworking industry. As in many other industries, the main frequency ranges used in the woodworking industry are 435, 915, 2450 MHz. For drying large volumes of wood, it is common to use the frequencies of 435 and 915 MHz. Sources of high frequency waves with an operating frequency of 2450 MHz are mainly used to remove moisture from thin lumber due to shallow depth of wave penetration into the material being dried[13].

The presence of free and bound moisture in the material being processed allows with the use of the microwave field to produce rapid volume heating, which, in its turn, allows to significantly speed up the drying process. And some part of the water in the form of steam is removed through the wood's capillary system free from moisture, ensuring its internal steaming, i.e. moisture-and-heat treatment, in the course of the removal of residual stresses occurs, and, consequently, the manifestation of internal and external damage in lumber decreases [14].

The use of microwave heating in the woodworking industry can significantly increase the speed and quality of some technological processes. Thermal inertia-free process allows you to accurately set the required thermal and temporal processing parameters. Also, wood-drying chambers are characterized by low energy consumption, high reliability, short payback periods, mobility, wood hardening during the drying process up to 60%.

In the course of experimental studies at the Voronezh State Forest Engineering Academy they proved the possibility and feasibility of using wastewater generated during microwave drying of oak wood in forestry, winemaking, food industry and perfumery production [15].

At the Irkutsk State Technical University they proposed to use the drying of lignite concentrate with the help of microwave radiation. In the course of theoretical and practical research, a number of significant advantages were revealed compared to the traditional convection method of processing coal samples from various fields, such as reduction of processing time and explosion-proof processing, reduction of nitrogen and sulfur content in coal, reduction of energy consumption and metal equipment [16, 17].

Technologies with microwave heating are actively used in medicine. Studies show that radiating systems are suitable for heating thin films or microwave hyperthermia of malignant tumors. The method is to heat a tumor with the help of electromagnetic radiation to a temperature level of 42–44 ° C [18]. The advantages of microwave hyperthermia are those that the exposure zone is heated from the inside, with uniform warming of tissues, without damaging the skin. Modern installation for local microwave hyperthermia "Yacht-3" (FSUE "NPP" Istok ", Fryazino) allows you to create and maintain a long-term zone of hyperthermia in the tumor of almost any configuration with minimal impact on the surrounding organs and tissues [18-20].

The activities of medical institutions generate waste is classified as hazardous and extremely hazardous. This waste needs to be disinfected and recycled. Currently, all medical institutions mainly use the method of chemical disinfection of waste, which is then sent to rubbish dumps, landfills or buried in graves. The method of chemical disinfection itself does not have 100% disinfection efficiency and is dangerous for medical personnel, harmful to the environment and is quite expensive.

A microwave installation has been designed in the city of Obninsk, which is intended to disinfect medical waste directly at the places where it is initially generated. This installation is patented, certified, has the permission of the Ministry of Health of Russia to be use and it is still the only Russian development in this area [21]. The principle of disinfection in a microwave installation, in contrast to traditional methods, is based on the microwave effect of radiation on infected materials, resulting in the death of all microorganisms. Infected materials are collected in disposable bags and loaded into reusable containers. The containers are placed in the microwave installation and processed to complete disinfection in several stages. Then the decontaminated waste, which is already safe for both the environment and humans, is removed from the containers and sent in disposable bags to landfills for domestic waste [22].

Various devices, based on the principle of using the energy of the electromagnetic field, allow us to process not only waste from medical institutions, but also waste generated in various industries. For example, in the course of the joint work of OJSC "Research Institute-Tantalum" and the Institute of Crystallography named after A. V. Shubnikov of the Russian Academy of Sciences data were obtained that confirm the possibility of using the energy of the microwave EMF energy for firing a ceramic matrix with immobilized active industrial waste from radiochemical and chemical-metallurgical industries [23].

In the Research Center for Applied Electrodynamics of the Kazan State Technical Research University named after A. N. Tupolev they have conducted research and design development for processing petroleum products and oil sludge [24].

At the end of the 20th and the beginning of the 21st century, considerable attention abroad in the field of wastewater is paid to non-reagent methods of conditioning sewage sludge. The thermal method of treating precipitation, which is implemented by means of convection heating, is quite widespread. However, operating experience shows that during the operation of the installations the annular space is clogged with solid particles, which are contained in the draft. It takes considerable time to heat industrial volumes of sludge. The hardware of this method of conditioning is metal-intensive [25]. The use of EMF microwave energy in treating precipitation can eliminate the existing disadvantages of thermal conditioning.

The Kaluga branch of the Moscow State Technical University named after N.E. Bauman developed a reagent-free technology for purifying drinking water and treating sewage sludge using microwave radiation [26]. They used a module was (a generator unit with power supply) as a source of microwave radiation, which provided the generation of microwave radiation at a frequency of 2450 MHz in pulsed and continuous modes, the power being regulated in the interval from 0.3 to 5 kW. The research results showed that such a method of heat treatment of sewage sludge has a high efficiency even at low microwave power values [26].

Researchers from the Volgograd State Technical University conducted a series of studies on the reduction of the number of microorganisms in wastewater during treatment with an electromagnetic field. The data obtained from the experiments show that there is a significant decrease in the number of microorganisms, which, in turn, allows the use of treated water in the irrigation systems of agricultural fields [27].

The energy of the electromagnetic field of ultrahigh frequency with different design can be implemented in water treatment and wastewater disposal. Particularly noteworthy are the achievements of researchers in the field of water disposal, summarizing which, it can be concluded that by introducing the EMF treatment section into a comprehensive wastewater treatment scheme, high cleaning results can be achieved. With the use of ultrahigh frequency wave energy, decontamination processes accelerate. Especially noticeable is reduction in microbiological contamination. The use of volumetric, rather than convection, heating eliminates the disadvantages of the thermal gradient method of conditioning sewage sludge [28].

Technologies using microwave energy are being used more and more in various industries. This processing method, in addition to those described above, can also be used in cable rubberizing, vulcanization, evaporation of petroleum products, the production of thermally expanded graphite, to increase the efficiency of cotton wool purification, to accelerate the process of curing catalysts and resins, polyethylene terephthalate depolymerization, and many others [29-36].

The analysis of scientific papers on the development of microwave technologies, allows you to identify their main advantages (regardless of the scope of practical application of these technologies):

1) high concentration of energy per unit of volume, which allows processing the largest amount of material in a relatively short period of time with less energy;

2) thermal inertia free, i.e. the ability to instantly enable thermal effects on the material being processed, which in turn improves the accuracy of maintaining the specified processing parameters;

3) the current level of electromagnetic field perturbation allows you to control the parameters of this field: the direction of propagation, intensity, frequency, and others, which makes it possible to introduce more stringent processing boundary conditions;

4) partial ecological purity of the process due to the absence of combustion products and the release of harmful substances into the atmosphere;

5) high bactericidal effect of EMF microwave.

But in addition to significant advantages, there is a disadvantage of this method associated with the effect of electromagnetic fields on human health, although thanks to the rationing of working time and microwave radiation, it is possible to provide a technological process which is safe for workers. In production, staff safety can be provided in the following ways.

1. Identifying the boundaries around industrial equipment, beyond which microwave radiation will comply with current regulations, and accordingly, will not harm human health. The fenced area will be insignificant, because the flux of radiated energy rapidly weakens with distance from microwave radiation sources (inversely proportional to the square of the distance) [37, 38].

2. Building various absorbing and reflecting screens [39]. At present, a significant amount of shielding materials and coatings is already known. The most optimal material must be selected in accordance with specific sources of electromagnetic radiation, as well as the technological scheme in which these sources are present.

The analysis of foreign and domestic scientific literature on similar problems shows [40, 41] that in any industry, finding the optimal process parameters: temperature and speed heating, installation power, intensity, frequency and intensity of the electromagnetic field and many others is always a priority for scientists and practitioners in the implementation of technologies using microwave energy.

To solve the problem of optimization, considerable scientific and material costs are required. In addition, a significant obstacle to the intensive comprehensive dissemination of these technologies is the fact that the nature of wave propagation in different materials, under different initial and final conditions, can differ significantly from one another. In turn, this implies careful design of the emitters and cameras in which microwave processing takes place.

3. Conclusion

An analysis of publications available to authors on the industrial use of EMF microwave allows us to state the fact that there is a significant amount of research in the area of expanding the use of microwave energy in various fields of anthropogenic activity that are both at the stage of theoretical understanding and at the stage of operating industrial equipment. Virtually all authors, including the authors of this article, agree that the use of microwave radiation in technological schemes of various industries will reduce energy consumption and increase the efficiency of technological processes, which will ultimately lead to increased productivity and lower operating costs. It will allow to significantly modernize production both in terms of reducing energy consumption per unit of processed product and in terms of improving the quality of source material processing. In compliance with the rules of operating microwave power equipment, safety and labor protection standards, the process will be safe for the health of workers.

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