Synergistic effect of the SHF electromagnetic field on the organometallic complex

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Abstract. The paper discusses a synergistic effect of the SHF electromagnetic field and high moisture content of the bran product with incorporated magnetic microparticles. The microparticles were standardized: the Fe size was 12.5–50 µm and the pycnometric density was 3.40 cm³. It was found that optimal processing conditions provide a significant increase in the temperature indicators of the experimental complex (EC) to 65 °C and 45% moisture content. It was shown that the SHF electromagnetic effect on the experimental complex allows production of a single complex of organic matter and magnetic agglomerates within a short period of time and energy range with the porosity of samples increased up to 74.14%. A microscope was used to examine the samples of the experimental complex and to analyze the microstructure of the resulting sample, where the structure was modified as a result of thermal exposure and it caused sintering of magnetic agglomerates and organic matter. The study results showed the necessity for further investigation of the synergistic effect of EC using the SHF electromagnetic method.

1. Introduction

To date, energy efficiency, sustainability and economic viability in the sector of mineral feed production are a promising area for agricultural industry and society [1]. Microwave methods can help achieve these criteria through uniform, rapid and environmentally friendly heating since no combustion products are formed, processing time is reduced and high bactericidal action and important nutrients of food products and compound feeds are preserved [2, 3].

Microwave heating is characterized by a number of properties that make the method different from conventional heating methods. This type of heating provides various modification paths and can cause structural changes in materials, sintering and formation of magnetic agglomerates [4, 5, 6, 7].

The effect of the SHF electromagnetic field on an organic object is mainly the effect of electromagnetic waves on the dipole water molecules. Therefore, it can be assumed that the bran product with different moisture content will not respond equally to electromagnetic treatment. The need for the SHF electromagnetic exposure of the components of animal feed is mainly due to the fact that most cereal feeds contain 50–70% of starch that is poorly absorbed by farm animals and poultry. This heat treatment allows the starch to modify into digestible dextrins and polysaccharides. Cereal feeds are distinguished by high energy nutritional value (from 1 to 1.3 feed units per 1 kg of feed) and good digestibility of organic matter (70–90%). They also contain a lot of vitamins, but the mineral content is minimal (1.5–4%). As it is known from the study of temperature parameters, the chemical composition of multicomponent cereal mixtures exposed to the SHF electromagnetic field was determined. It was
found that this exposure at 60–70°C insignificantly affected chemical composition, and the temperature increase up to 95 °C caused the greatest change, which decreased the nutritional value of the cereal product [10, 11]. The search for favorable treatment modes is still relevant [8, 9] despite a rather impressive history of studying the effects of electromagnetic fields on plant species.

In this regard, new approaches to the use of the SHF electromagnetic effects should be developed to produce feed with metal microparticle inclusions and to form their optimal set [23, 24]. Meanwhile, it is known that the reactivity of metal microparticles depends on their physicochemical characteristics: size, pycnometric density, shape, phase state, etc. In these terms, the biological properties of metal microparticles are poorly studied [12, 13]. The study of other types of effects, barothermal in particular, on the microstructure and properties of metals showed that processing results in a high degree of homogenization of the chemically and structurally inhomogeneous initial alloy [14].

In our study, we investigated the produced biologically active organometallic complexes by assessing the physicochemical characteristics of Me (Fe, Cu, Al, Cr, and Ni) microparticles, and the process of incorporating Fe magnetic microspheres into the organic product structure as a result of the SHF electromagnetic effect.

2. Materials and methods

Object of the study. The study used wheat bran with a crude fiber content of 8–10%, crude protein of 13–15%, and with a particle size of up to 1 cm. The microparticles of Fe microelement were purchased at NPP Highly Dispersed Metal Powders (frequency of 99.95%).

Experimental scheme. The study was conducted in the laboratories of the Department of Materials Science and Material Technology (Orenburg State University).

In the first series of studies, physicochemical properties of microparticles of Fe microelement were examined: size and pycnometric density. The particle size from 1 to 100 μm was determined by a microscopic method in accordance with GOST 23402-78. Micrographs of powder particles were taken with an ALTAMY MET 3 metallographic microscope with different magnification of particles under oblique illumination. To make a preparation, the studied powder was rubbed on a slide glass to an even layer using turpentine. The particle size was measured using an eyepiece micrometer with ×640 magnification. The calculation was performed using a standard technique. The measurements were made for about 100 particles for each type of powder. If necessary, the particle width and length were measured, and the size was taken as a mean value. The particle size of the powder was taken to be equal to the size of the particles contained in the fractions of about 10 percent or higher.

The pycnometric method was used to determine the powder density [18].

In the second series of studies, temperature and porosity were determined, and a visual study of EC under the SHF electromagnetic exposure was carried out.

The SHF electromagnetic treatment was performed using a LG MH-6347EV (PRC) installation with an operating frequency of 2450 MHz and an output power of 800 W. During the study, a mixture of bran and Fe microparticles was prepared in a ratio: wheat bran – 100 g and Fe microparticles – 7 mg/kg, which was exposed to the SHF electromagnetic field. The temperature of the test samples was measured immediately after exposure using the LT-300-F laboratory electronic thermometer.

The EC porosity was determined using acetone in accordance with GOST 6217-58.

A visual study of the experimental complexes was performed to assess modification of the bran product and Fe microparticles. The test samples were experimental complexes EC1 – native bran + EMF SHF, EC2 – bran + water 45% + EMF SHF, and EC3 – bran + Fe (7 mg/kg) water (45%) + EMF SHF. EC samples were visualized using a MBS-10 optical microscope. For reflected light microscopy, 20 μl samples were placed on a glass slide, and then the glass slide was installed on a microscope stage to obtain an image using an objective lens with ×32 magnification and microscope field of 5.6 mm. The samples were fixed using a Leica DFC 290 digital camera.

Statistical processing. Data are expressed as mean values ± standard error of the mean. Statistical analysis was performed using Statistica 10.0 (StatSoft Inc., USA) and Microsoft Excel (Microsoft, USA). Significance of the group differences was estimated using Student’s t-test with p≤0.05 considered
as significant.

3. Results

Most of the metal microparticles presented below are irregular in shape: rounded and spongy.

![Micrographs of Fe powder particles](a) x80 magnification; (b) x160 magnification; (c) x640 magnification.

**Figure 1.** Micrographs of Fe powder particles: (a) x80 magnification; (b) x160 magnification; (c) x640 magnification.

Fig. 1 shows that Fe microparticles exhibit a spongy shape and the size of 12.5 to 50 μm, which is confirmed by the minimum pycnometric density.

The study of the effect of temperature and moisture content on the experimental complex exposed to the SHF electromagnetic field showed that the incorporation of Fe microparticles into EC3 and EC4 leads to the increased exposure temperature in EC1 and EC2 (Fig. 2).

![Graph showing temperature and moisture content](a) Samples: OK1, OK2, OK3, OK4; (b) Temperature, °C; (c) Moisture content, %

**Figure 2.** Effect of temperature and moisture content on the experimental complex exposed to the SHF electromagnetic field.

We assessed physicochemical properties of the experimental complexes produced by mixing bran with Fe microparticles subjected to the SHF electromagnetic exposure. The study showed that the porosity in EC3 (74.14%) increased at 45% moisture content as compared to that in EC1.

A visual study revealed thermal modification of bran with 45% moisture content after the SHF electromagnetic exposure and modification features. In particular, the formation of a porous structure can be observed at 54 °C, and additional moistening by 45% reveals highly porous structure of bran at 56 °C. Double modification of bran and Fe microparticles subjected to the SHF electromagnetic exposure at 65 °C and an output power of 800 W will lead to insignificant sintering, formation of magnetic agglomerates and modification of structural changes in in the bran product.
4. Discussion
The chosen microparticles of metals are essential components vital for farm animals. The mechanism of particle penetration into the animal’s body through various biological barriers and the gastrointestinal tract depends on its physical and chemical properties [19].

Our study aimed to investigate physicochemical characteristics of Fe microparticles and to combine Fe magnetic microspheres with organic bran particles using the electromagnetic method (SHF) to produce biologically active organometallic complexes.

We established the size and pycnometric density of metal microparticles since these indicators are crucial for interaction with biological systems. The less the pycnometric density of metal microparticles, the greater the surface area. The pycnometric density was determined according to the previously described method, and further studies employed powders with minimum density. However, the experimental studies showed an ambiguous effect of the pycnometric density of metal microparticles, which is confirmed in [20, 21].

The studied barohydrothermal effects on the feed mixture of bran and highly dispersed metal particles showed an increase in the specific surface of the samples with 65–70% moisture content and a processing temperature of 120 °C [22]. Moisture content is the most significant factor for SHF exposure as well.

Additional moistening of EC affects the output temperature of the product, while the optimal moisture content is 45% (EC2, EC1). Our experiments showed that the temperature of exposure was 65°C (EC4), which is close to the bran protein denaturation temperature and optimal for conversion of starch into digestible dextrins and polysaccharides. An exposure temperature of 65 °C, operating frequency of 2450 MHz and output power of 800 W initiate diffusion processes and thus enable the formation of the chemically initial and structurally heterogeneous complex. The applied power of the SHF electromagnetic exposure significantly exceeds the sintering limit temperature with exposure time of 90 seconds and determines the course of deformation processes of metal particles. Sticking of particles and further sintering of surfaces results in the formation of agglomerated metal particles in EC. The electromagnetic effect of EC is efficient for the creation of highly porous microstructure, which exceeds the results obtained in conventional heat treatment. Double modification of bran and Fe microparticles subjected to the SHF electromagnetic exposure revealed a synergistic effect on the bran structure due to the increased porosity and appearance of magnetic properties in EC. It can be assumed that the incorporation of Fe microparticles into the lignocellulosic complex will intensify agglomeration during sintering and thus will lead to new structural variants of the formation and modification of experimental complexes.

5. Conclusion
The use of the SHF electromagnetic energy in combination with microdispersed Fe particles is efficient to increase the microporosity of experimental complexes and to form an optimal microstructure with a temperature of 65° and moisture content of 45%, which exceeds the results obtained in conventional heat treatment.

In addition, the improvement of the developed experimental complexes in order to implement them in feeding of farm animals and poultry is still relevant.

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