ISSN 2409-9066. Sci. innov. 2016, 12(4): 11—15 doi: http://dx.doi.org/10.15407/scine12.04.011

Avdieieva, L.I.

Institute of Engineering Thermophysics, the NAS of Ukraine,
2a, Zhelyabova Str., Kyiv 03680, Ukraine, Tel. +38 (044) 453-28-44

IMPLEMENTATION OF THE PRINCIPLE OF DISCRETE-PULSE ENERGY INPUT TO THE CREATION OF NANOTECHNOLOGIES FOR FOOD INDUSTRY

The expediency of using the principle of discrete-pulse energy input in directional control of lipid nanostructures formation and industrial production of functional materials with them in order to reduce energy consumption and increase process productivity has been substantiated. The example of using lipid nanostructures for improving a new type of food for special dietary purpose has been given.

Keywords: lipid nanostructures, discrete-pulse energy input, disperse systems, and products of special dietary purpose.

All advanced economies pay great attention towards R&Ds in the field of nanotechnology and their commercialization. In Ukraine, the fundamental and applied research concerning the design, testing and application of nanotechnologies and nanostructural materials has been carried out during the recent 15—20 years upon request of the National Academy of Sciences of Ukraine, funded by grants of the Ministry for Science and Education, international research foundations, and directly by industrial corporations. The majority of R&D works have been appreciated in the world and recognized as advanced technologies. This research has been made within the framework of the government target R&D program *Nanotechnologies and Nanomaterials* for 2010—2014.

The design and application of nanomaterials is one of the most relevant directions of nanotechnology development. Much attention is paid to nanopreparations as carriers of biologically active and pharmaceutical substances that due to target delivery enable to improve the effectiveness of new drugs. Among these drugs, there are vesicles of phospholipids widely used in pharmacology, medical sphere, and cosmetics [1, 4]. There are significant prospects for the use of nanomaterials in other areas, such as in the food industry. In the foodstuffs the lipid nanostructures act as the nano-containers to transport biologically active substances (proteins, amino acids, vitamins, minerals, etc.) directly inside the cells and release them gradually thereby increasing the duration of their effects and enhancing the effectiveness. After utilization, the phospholipids are used by the organism to build new cells [1, 2, 3]. Despite a large output in the food industry and good prospects for using the nanomaterials, Ukraine lacks advanced energy-efficient industrial technologies for obtaining the nanomaterials.

The priority of present-day R&D activities and application of nanomaterials is the design of high-performance energy-saving technologies that enables obtaining high-quality and competitive products. The aim of this work was to conduct comprehensive analytical and experimental studies to intensify the formation of lipid nanostructures and to create energy efficient industrial technologies for the production of functional materials for food industry.

Reducing energy consumption and increasing productivity of the formation of lipid nanostructures can be achieved through the use of advantages of the method of discrete pulse energy input (DPEI) implemented in various types of equipment, for example, in rotary-pulsation apparatus (RPA). The DPEI conception defines the ways of direct conversion of energy to be used for performing useful work to accelerate the interfacial heat and mass transfer when processing the heterogeneous environments. When using the DPEI method, the energy continuously supplied to the machine in the form of short high-power pulses is discretely distributed in the working volume and concentrated directly on the surface of individual dispersed particles where it is necessary to perform useful work [5—7]. Thus, the DPEI method enables to perform targeted management of dispersion and homogenization, to receive high-quality materials, to reduce the specific power consumption per unit of production, and to produce drugs in industrial quantities.

To determine the characteristics of dispersion and homogenization of complex heterogeneous systems with phospholipids, a set of experimental studies has been carried out for establishing the impact of phospholipids content, their concentration, process temperature and repeating pattern and other factors on the properties of lipid vesicles formed under conditions of multifactor impact by DPEI. The main characteristics of vesicular phospholipid particles are their size and inner volume. The size of particles formed depends on changing conditions of the process and is measured by *ZetaSizer-3-Malvern Instrument* laser photon-correlation spectrometer (UK) equipped with a He-Ne-laser LGN-111 (P = 25 mW, λ = 633 nm). This method enables determining the diffusion coefficient of particles dispersed in liquid by analysis of characteristic time of fluctuations of scattered light intensity. Laser light scattered from aqueous suspension of nanoparticles (refractive index of water is equal to 1.33) is recorded and statistically processed for 90 sec, at 22 °C, at a scattering angle 90°. The measurement range of the device is from 1 nm to 50 μm. The results of measurements are processed using *PCS-Size mode v1.61* software [8, 9].

The experimental studies were conducted on a cylindrical type rotary-pulsating flow apparatus (RPA) consisting of two stators and a rotor with an inner radius R_{rot1} = 35 mm and an outer radius R_{rot2} = 38 mm. The width of annular gap between the rotor and the stators δ = 0.2 mm. On the surfaces of the rotor and the stators there are n = 24 slots having the following dimensions: width a = = 3 mm, a height h = 25 mm and depth l = 3 mm, overlapping with the revolution of the rotor. The rotor nominal angular velocity is 314 rad/s. The SOLEC dried soy lecithin (EU) was used for preparation of phospholipid suspension.

The results of studying the dependence of mean particle diameter on lipid concentration at different temperature of dispersion are showed in Fig. 1.

The data presented in Fig. 1 feature a significant effect of temperature regimes of DPEI-treatment of phospholipid aqueous dispersion on the size of the particles. At a temperature of 20 °C, the size of dispersed particles was the highest for all samples studied, due to the specific feature of lipid behavior below the phase transition temperature. An increase in homogenization temperature up to 42 °C results in the transfer of phospholipid dispersion from solid into liquid crystalline state and in weakening of intermolecular bonds, which leads to a decrease in the average diameter of the particles formed.

Further increase in temperature up to 60 °C and 80 °C leads to further weakening of bonds between molecules of lipid material, so the average diameter of the particles decreases and homogenization effectiveness improves. Nevertheless, the use of high temperatures for DPEI-treatment is not advisable insofar as it is quite difficult in terms of process technology to keep high temperature during the whole process under considerable energy consumption. In addition, the high temperature is undesirable for thermally instable

ISSN 2409-9066. Sci. innov. 2016, 12(4)

substances such as vitamins. Therefore, the most rational option is dispersion at a temperature of 42 ± 2 °C.

The studies have showed that the cyclical pattern of treatment leads to enhanced effect on the processed material due to increasing time of its stay in the zone of active influence, therefore, the particle size decreases after each cycle. The most significant increase in the system fineness is reported for the first three cycles of treatment, when the average particle diameter decreases one and half times and reaches 445 nm. Five or more passes of the material through the working bodies of the device do not lead to a significant increase in the system fineness.

Based on comprehensive studies the efficient process parameters have been selected and efficient energy-saving technology for industrial production of stable lipid nanostructures to be used in the food industry has been designed. The size distribution under the selected efficient parameters of DPEI-treatment regimes are showed in Fig. 2.

The analysis of results has showed that 80% of the particles has a size from 215 to 850 nm and belong to large single-layer vesicles. The inner volume of vesicle capture is 1.75 mg/g lipids; the mean particle diameter is 440 nm.

The complex research of heat and mass transfer processes during DPEI treatment of multicomponent system for the formation of closed stable nanostructures has enabled to offer a new direction in process technology for production of special dietary food, i.e. the production of functional foodstuffs using lipid nanostructures. Their unique biomedical properties enable creating a wide range of advanced efficient functional foodstuffs, including baby food, food for the pregnant women and the elderly, and food for special dietary nutrition under various diseases.

Nutritional therapy is an important factor in the complex treatment of various diseases. Particularly important is the problem of nutrition for patients in critical condition, in pre- and postoperative periods, the patients having burns, disorders of consciousness, maxillofacial and other injuries. The present-day means of nutritional support enable effective correction of energy and plastic needs of the human body under nutritional status disorder of patients in critical condition. Typically, they consist of protein hydrolysates of different hydrolysis degree. The Institute for Engineering Thermophysics, the NAS of Ukraine, has designed a technology for industrial produc-

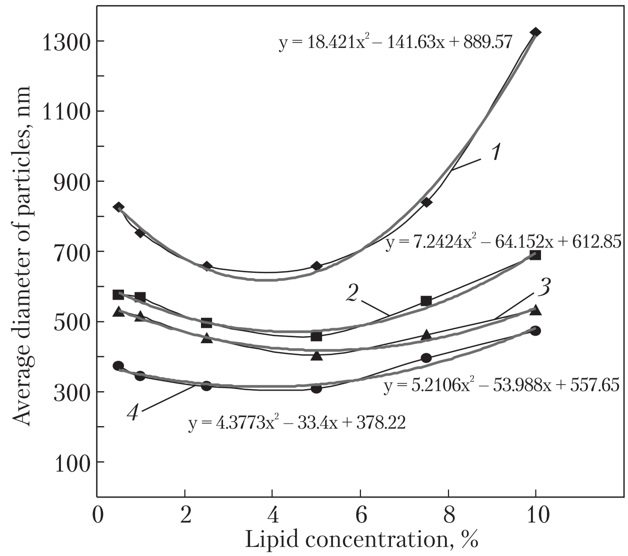

Fig. 1. Concentration dependence of average diameter of the particles obtained as a result of DPEI treatment at an angular velocity 314 rad/s: *1* — 20 °C; *2* — 42 °C; *3* — 60 °C; *4* — 80 °C

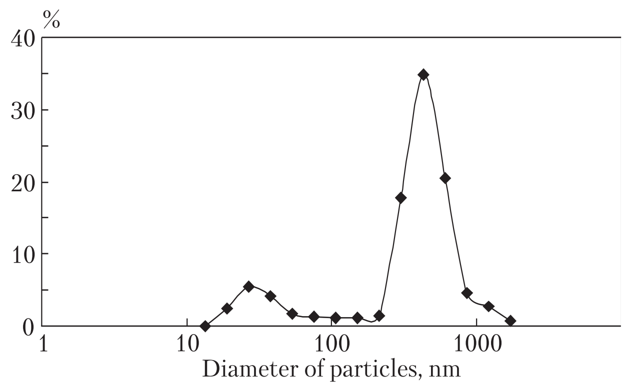

Fig. 2. Size distribution of particles obtained as a result of DPEI treatment using the efficient parameters of process regimes

tion of hydrolyzed proteins — «dried hydrolyzed proteins» with lipid nanostructures according to TU 15.8-05417118-041:2011 for special and nutritional therapy of people with increased protein demand. The protein hydrolysates obtained by enzymatic hydrolysis are mixture of physiologically active peptides and free amino acids having composition similar to that of «the ideal protein» and contain 70% of easily digested physiologically active peptides and free amino acids with a molecular weight of up to 6 kDa.

The production technology involves manufacturing both liquid and dry preparations using the spray method for drying [10]. As compared with the existing technologies, the economic effect is achieved by reducing the electricity consumption per unit of output (using the DPEI-treatment), at least, 5 times. The application of spray method for drying the functional materials with lipid nanostructures reduces the electricity consumption per unit 3—10 times while keeping high quality of dry product as compared with the freeze drying method which is traditionally used for these materials. New functional products with lipid nanostructures manufactured by the factory cost UAH 450, which is 2—5 times lower than the imported counterparts.

The efficacy of dry high-protein product based on hydrolyzed proteins with lipid nanostructures has been confirmed by clinical research conducted at the Kyiv Children's Gastroenterology Center under Children Hospital no. 9 in the Podil District of Kyiv and at the Military Hospital m/u A 2923. The studies have showed improved results of overall blood analysis as the number of red blood cells gets normal; the number of white blood cells and monocytes decreases (by 8% and by 15%, respectively); and erythrocyte sedimentation rate (ESR) falls down by 10%. In addition, the dynamics of blood biochemical parameters have been established to improve as the total protein increases by 8—9% due to an increase in albumin level and its normalization; the urea content drops by 11% and transaminase (ALT, AST) slumps by 15—22%.

CONCLUSIONS

1. The use of DPEI method for targeted process control of lipid nanostructure formation has been justified.

2. The DPEI method has been established to reduce electricity consumption and to raise productivity of processes.

3. Efficient regimes of processes for obtaining the lipid vesicles with preset properties to be used in food industry have been selected.

4. A technology for production of functional foodstuffs based on hydrolyzed protein with lipid nanostructures has been designed.

5. A new type of special dietary foodstuffs has been confirmed to have a significant technologic, economic, and social effect.

REFERENCES

1. Branche C. M. *Approaches to Safe Nanotechnology: managing the Health and Safety Concerns Associated with Engineered Nanomaterials. Washington:* National Institute for Occupational Safety and Health (NIOSH) Publication, 2009.
2. Balabanov B. *Nanotechnology. The future of science***.** Kyiv: Eksmo, 2009 [in Russian].
3. Eliseev A.A. *Functional Nanomaterials*. Moskva: FIZMATLIT, 2010 [in Russian].
4. Gennis R. *Biomembranes. Molecular structure and function*: Per. from English. R. Gennis. Moskva: Mir, 1997 [in Russian].
5. Dolinskiy A.A., Ivanitskii G.K. *Heat and mass transfer and hydrodynamics in the vapor-liquid dispresnyh environments*. Kyiv: Nauk. Dumka, 2008 [in Russian].
6. Dolinsky A.A., Basok B.I., Guly I.S., Nakorchevsky A.I., Shurchkova Y.A. *Discrete pulse input of energy in teplotehnologiyah*. Kyiv: Nauk. Dumka, 1996 [in Russian].
7. Promtov M.A. Prospects of cavitation technologies for intensification of chemical-engineering processes. *Herald TSTU*. 2008, 14(4): 861—869 [in Russian].
8. Yegin B., Lamprecht A. Lipid nanocapsule size analysis by hydrodynamic chromatography and photon correlation spectroscopy. *Intern. J. of Pharmaceutics***,** 2006, No 320: 165—170.
9. Henk G. Merkus. *Particle Size Measurements. Fundamentals, Practice, Quality*. Springer, 2009.
10. Sharkova N.A., Zhukotskii E.K., Dekusha A.V., Ivanov S.A. Features of production of hydrolyzed protein products. *Industrial teplotehnika*. 2013, 35(7): 187—190 [in Russian].

Л.Ю. Авдєєва

Інститут технічної теплофізики НАН України,
вул. Желябова, 2а, Київ, 03680, Україна,
тел. +38 (044) 453-28-44

РЕАЛІЗАЦІЯ ПРИНЦИПУ ДИСКРЕТНО-ІМПУЛЬСНОГО ВВЕДЕННЯ ЕНЕРГІЇ ПРИ СТВОРЕННІ НАНОТЕХНОЛОГІЙ ДЛЯ ХАРЧОВОЇ ПРОМИСЛОВОСТІ

Обґрунтовано доцільність використання принципу дискретно-імпульсного введення енергії для спрямованого управління процесом утворення ліпідних наноструктур і промислового виробництва функціональних матеріалів з ними для зниження енерговитрат і підвищення продуктивності процесів. Наведено приклад використання ліпідних наноструктур для підвищення ефективності нового виду харчування спеціального дієтичного призначення

Ключові слова: ліпідні наноструктури, дискретно-імпульсне введення енергії, гетерогенні середовища, продукти спеціального дієтичного призначення.

Л.Ю. Авдеева

Институт технической теплофизики НАН Украины,
ул. Желябова, 2а, г. Киев, 03680, Украина,
тел. +38 (044) 453-28-44

РЕАЛИЗАЦИЯ ПРИНЦИПА ДИСКРЕТНО-ИМПУЛЬСНОГО ВВЕДЕННЯ ЭНЕРГИИ ПРИ СОЗДАНИИ НАНОТЕХНОЛОГИЙ ДЛЯ ПИЩЕВОЙ ПРОМЫШЛЕННОСТИ

Обоснована целесообразность использования принципа дискретно-импульсного введения энергии для направленного управления процессом образования липидных наноструктур и промышленного производства функциональных материалов с ними для снижения энергозатрат и повышения производительности процессов. Приведен пример использования липидных наноструктур для повышения эффективности нового вида питания специального диетического назначения

Ключевые слова: липидные наноструктуры, дискретно-импульсный ввод энергии, дисперсные системы, продукты специального диетического назначения.

Received 04.04.16