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Research Article

Thermal Vacuum Synthesis: Physical Processes in Nanomaterial Production

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Abstract

The thermovacuum process offers an efficient and cost-effective method for producing nanomaterials by ensuring the continuous flow of dispersed material inside a spiral heating element. This is achieved by introducing the material into the heating element's cavity along with air, forming a two-phase gas-solid particle system. The material moves upward through the heated space, where pressure gradually decreases. Experimental studies on materials like carbon, brown coal, and zirconium dioxide indicate specific conditions are necessary for the system's continuous operation. One key requirement is that the mass of solid particles should not exceed 1.0 to 1.2 grams per liter of air entering the heating element. This limit ensures that nanodispersed and finely dispersed particles can move freely, avoiding collisions and allowing faster-moving particles to overtake slower ones. These particles increase in velocity and temperature as they pass through the heating element, with changes in heat capacity and particle motion contributing to wave motion and pulsed heat loads. The velocity at which the material particles travel depends on the thermal radiation from the heater walls and the energy generated by local pulse steam explosions, which create shock waves. Higher explosion energy results in increased particle velocity, greater impact angles against the heater walls, and higher environmental temperatures. These conditions lead to accelerated electron, proton, and other charged particle flows, forming plasma clots and neutrino clouds. The nanoparticles take various forms, including nanotubes, fullerenes, thin films, and crystals, reaching velocities up to a thousand kilometers per second and heating temperatures of up to 17 million degrees during pulses. This process consistently subjects the material to force, heat, deformation, and ionization, expediting the creation of nanodispersed materials with enhanced physicochemical and mechanical properties. The thermovacuum process not only improves the efficiency of thermotechnological equipment but also reduces energy consumption, production time, and costs. The research findings support its use in the continuous and effective production of high-quality nanomaterials.

Keywords

Thermovacuum Process, Nanodispersed Materials, Spiral Heating Element, Gas-solid Particle System, Pulsed Steam Explosion, Shock Wave, Kinetic Energy, Nanotubes and Fullerenes

1. Introduction

Nanomaterials are transforming numerous industries, yet unlocking the full potential of nanotechnology requires a deep understanding of what nanomaterials are and how they can be synthesized efficiently. The development of functional materials with unique structures and properties is a critical driver of technological progress [1]. While several methods

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for obtaining nanodispersed materials exist, such as electron beam evaporation and vacuum deposition, these methods are both energy-intensive and time-consuming [2].

To overcome these challenges, innovation in scientific and technical processes is essential. The focus is on developing advanced, efficient installations and technologies capable of processing raw materials into new, high-performance materials. The ultimate aim is to create scalable processes that can transition seamlessly from laboratory experiments to industrial production. This scalability is crucial for enabling large-scale applications of nanomaterials.

As research progresses, vast amounts of experimental data are accumulated, leading to the refinement of technological processes and apparatus designs [3, 4]. Understanding the dynamic characteristics of nanomaterial production is key to optimizing the relationship between input and output parameters in thermo-technological equipment. This analysis allows for the fine-tuning of production processes, ultimately reducing energy consumption [5].

The objective of this work is to develop a thermal vacuum synthesis method that is both energy-efficient and capable of producing high-quality nanodispersed materials, paving the way for their broader application across industries.

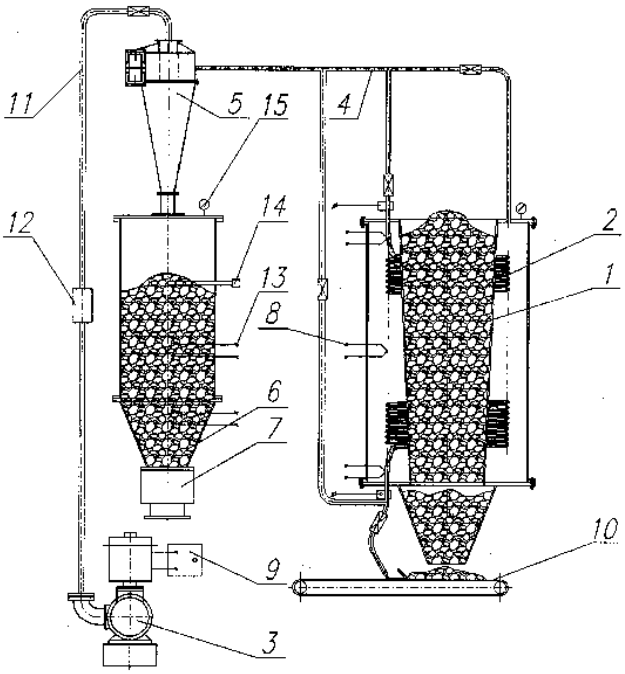


Figure 1. *Scheme of thermal vacuum unit.*

2. Thermal Vacuum Unit Model

On basis of the theoretical and experimental studies carried out, the thermal vacuum unit had been created [6], (Figure 1). It consists of feed hopper (1), hollow heater, which has the shape of helical spiral (2), vacuum pump (3), pipelines (4, 11), cyclone (5), processed raw material receiver (6), sluice gate (7). The unit contains thermocouples (8, 13), control panel (9), conveyor (10), fine filter, which allows better separation of the finely dispersed phase (12), raw material level sensor (14), vacuum gauge (15). This design of the installation provides high-performance dispersion of the material in a thermally insulated space. The maximum heater temperature is 400 ºC. The vacuum pump creates reduced pressure inside the heating element, forms aerodynamic thrust, and ensures continuous movement of two-phase flow. The average pressure is 430 mm Hg in the cavity of the heating element. The movement time of the dispersed material in the spiral heating element is 15 seconds.

This facility (Figure 1) was used to synthesize the nanodispersed materials. The process is continuous.

3. Thermal Vacuum Synthesis of Nanosized Materials

Thermal-vacuum synthesis operates on the principle of combining high-velocity vacuum evacuation with thermal heating of the initial material, occurring in direct contact with the inner surface of a hollow heater. To maximize the contact with the source material, the heater is designed as a helical spiral. The efficiency and economy of this process rely on ensuring a continuous supply of material into the heating element, which can be achieved by introducing the material along with air into the heater's cavity. This creates a two-phase flow of gas-solid particles that moves upwards within a heated, isolated space at reduced pressure.

For optimal performance, the mass of solid particles entering the cavity should not exceed 1.0 to 1.2 grams per liter of air, a value that remains within the standard air density. This requirement arises from the fact that thermal-vacuum synthesis generates a large number of nanodispersed and finely dispersed particles, which increase in velocity and temperature during the process. As a result, the composition and heat capacity of the environment are altered, influencing particle wave motion and leading to impulsive thermal loads.

Maintaining a uniform density of the material inside the heating element is critical to the success of the process. This ensures that nanodispersed particles move freely without colliding with one another, while also enabling faster-moving particles to overtake slower ones. These precise conditions help achieve efficient and high-quality thermal-vacuum synthesis, promoting the production of nanomaterials with enhanced properties.

4. Analysis of Heat-Mass Transfer in Thermal Vacuum Unit

The force F acts on the dispersed material moving in the cavity of the heating element along the spiral channel.

$$F = \frac{m\upsilon^2}{R} \quad (1)$$

where, m is the mass of the particle of the dispersed material, kg; υ is the velocity of movement of the particle of the dispersed material in the cavity of spiral heating element, m/s; R is the radius of the heating element spiral, m.

The centrifugal force presses the particles of the dispersed material against the wall of the heating element. Close contact is formed between the surface plane of the material and the wall of the heater, which makes it possible to maximize the use of the heat of the heating element. There is an instantaneous heating of the surface layer of the dispersed material. Temperature (T_1) inside the surface layer of the material at the moment of contact with the wall of the heater becomes significantly higher than the temperature (T) of evaporation of moisture, which is contained in this material ($T_1 >> T$). A local shock wave front is formed, which is characterized by extremely high values of excess pressure and high temperatures of several thousand degrees. [7]. The duration of the shock wave is $(2…10)10^{-3}$ s. [8]. The surface layer is crushed into small particles of various shapes and masses. The higher temperature is received in a short period of time by the surface layer of the material body, the more powerful is the local impulse steam explosion and the higher is velocity of movement of fine particles. In a pulsed shock wave, irreversible processes occur so rapidly that the rate of polymorphic transformations varies over an extremely wide range. In this moment each detached particle from the main mass acquires kinetic energy. In our case, the kinetic energy of the particle depends on the thermal energy (Q), which it receives from the heating element in a short period of time.

$$Q = dm \cdot c \cdot (T_1 - T) = dm \cdot c \cdot \Delta T \quad (2)$$

where, c - is the heat capacity of the particle, J/(kg deg); T_1 - instantaneous heating temperature of the particle with weight dm, when it touches the heating element, K; T - is the initial temperature of the particle, K; ΔT - is the difference between the initial and final heating temperatures of the particle, K.

That is, the kinetic energy of the particle is equivalent to the thermal energy (Q), which was received by particle of mass dm at the moment of touching the wall of the heating element.

$$dm \cdot c \cdot \Delta T = \frac{dm \cdot v^2}{2} \quad (3)$$

where,

$$\Delta T = \frac{\upsilon^2}{2c} \quad (4)$$

It follows from expression (4) that the temperature received by an individual particle is directly proportional to the square of the body's velocity and inversely proportional to its heat capacity.

At the moment the material touches the hot wall of the heating element, an instantaneous concentration of thermal energy occurs in the surface layer. This leads in a limited space to the formation of the local pulsed steam explosion with the appearance of a shock wave and gives the body a thrust force

$$F_т = m \cdot a \quad (5)$$

where, a is the acceleration, with which the body moves, $\frac{м}{c^2}$.

The body moves to the opposite wall of the heating element. In this case, the traction force of the material body is greater than the centrifugal force ($F_T > F$). The body collides with the wall of the heater at an angle "φ", again loses part of the mass, the new thrust force is formed, which is directed towards the action of the centrifugal force. At this time, the force $\Sigma (F_T + F)$ acts on the material particle. At the moment the body touches the heater wall, the thrust force is equal to the centrifugal force ($F_T = F$). Then,

$$m \cdot a = \frac{m \cdot v^2}{R}; \frac{m \cdot v}{\tau^2} = \frac{m \cdot v^2}{R} \quad (6)$$

where, τ - is the time of exposure of the temperature of the heating element to the material particle when it touches the heater wall, s.

After transforming expression (6), we obtain:

$$\tau = \sqrt{\frac{R}{v}} \quad (7)$$

It follows from the expression (7), that the time of the effect of the temperature of the heating element on the material particle during its contact with the wall of the heater is equal to the square root of the radius of the heating element divided by the velocity of the material particle in the cavity of the heating element.

If we assume that the body moves linearly inside the heating element of the thermal vacuum unit, then its velocity is 6.7 m/s. However, during movement in the cavity of the spiral heating element, the material body moves in a zigzag manner from one wall to another. In this connection, the velocity of movement of the material body in the thermal vacuum unit will depend on the angle of incidence on the opposite wall of the heater and on the length of the path traveled.

At the start of the movement in the cavity of the heating element at temperature of 100^o C, the phase transition occurs: liquid - steam. With further movement in the cavity of the heating element, the temperature of the crushed particles rises, the steam decomposes into oxygen and hydrogen, and the surface layer of the solid body decomposes into (atoms, molecules, crystals, nanodispersed particles). A spectrum of photons appears. All this moves in different directions at different velocities. In this case, the particles are electrified, large and small particles acquire charges of opposite signs [9]. There is static electricity. The voltage of static electrification

can reach a value sufficient to detach electrons from atoms, which leads to ionization. This contributes to the formation of a new crystalline structure of matter and the appearance of neutrino cloud. In this case, the rest of the mass of matter, which is located outside the shock wave, is in a metastable state.

5. Determination of the Material Particle Movement Velocity in the Cavity of the Heating Element

Let us calculate the velocity of movement of a body particle at different angles of movement to the opposite wall of the spiral heater. From the point "C", where the supposed point of contact of the body with the wall of the heater is, we set a perpendicular to the opposite wall of the heater (see Figure 2):

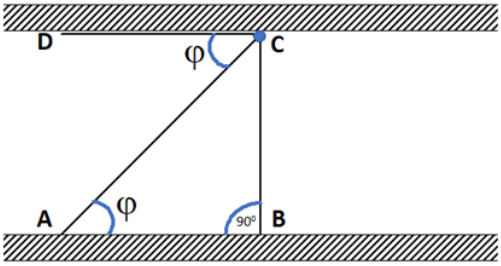


Figure 2. *One of the predicted movements of a particle of dispersion material from one wall to the opposite wall in the cavity of the heating element.*

From the point "C" we draw a straight line at an angle (φ °) to the opposite side of the heater wall. We get a right triangle ABC in which the angle CAB is equal to the angle DCA. Side BC of right triangle ABC is equal to the diameter of the inner cavity of the heating element (d), and side AB is the part of the wall of the heating element. It is assumed that at the moment the movement of the body in the cavity of the heating element from one wall to another occurs along the hypotenuse AC at the angle of incidence (φ °) onto the opposite wall of the heater.

In this case, the hypotenuse AC of the right triangle will be equal to:

$$AC = \frac{BC}{Sin\varphi} = \frac{d}{Sin\varphi} \tag{8}$$

Let's calculate the side AB:

$$AB = \sqrt{AC^2 - BC^2} = \sqrt{\left(\frac{d}{Sin\varphi}\right)^2 - d^2} \tag{9}$$

Let us determine how many times the segment AC is greater than the segment AB. So many times the path traveled by the particle is greater than the rectilinear movement, so many times its velocity of movement will be higher.

$$\frac{d}{Sin\varphi} / \sqrt{\left(\frac{d}{Sin\varphi}\right)^2 - b^2} \tag{10}$$

Then the velocity of movement of the material particle of the body is equal to:

$$v = \left[\frac{d}{Sin\varphi} / \sqrt{\left(\frac{d}{Sin\varphi}\right)^2 - b^2}\right] \cdot 6.7 \tag{11}$$

The frequency of contact of the material particle with the wall of the heater, we determine from the expression:

$$f = \frac{v}{\lambda} \tag{12}$$

where, f is the frequency, Hz; λ - wavelength, m.

In our case:

$$\lambda = 2AB = 2\left[\sqrt{\left(\frac{d}{Sin\varphi}\right)^2 - d^2}\right] \tag{13}$$

Let's carry out numerical calculations of the velocity of movement, frequency and wavelength in the heating element of the thermal vacuum unit for different angles of movement of the material particle to the opposite wall.

The calculation results, within the permissible error, are shown in the Table 1.

Table 1. *Velocity of movement frequency, wavelength versus angles of impact *.*

Sin, φ	89 °59′59″	89 °59′58″	89 °59′57″	89 °59′56″	89 °59′55″	89 °59′54″	89 °59′53″	89 °59′52″	89 °59′51″
v, m/s	1 000 000	670 000	450 000	340 000	270 000	230 000	200 000	170 000	150 000
λ, m	$0.3 \cdot 10^{-6}$	$0.48 \cdot 10^{-6}$	$0.72 \cdot 10^{-6}$	$0.94 \cdot 10^{-6}$	$0.12 \cdot 10^{-5}$	$0.14 \cdot 10^{-5}$	$0.16 \cdot 10^{-5}$	$0.19 \cdot 10^{-5}$	$0.21 \cdot 10^{-5}$
f, Hz	$3.5 \cdot 10^{12}$	$1.4 \cdot 10^{12}$	$600 \cdot 10^{9}$	$360 \cdot 10^{9}$	$230 \cdot 10^{9}$	$161 \cdot 10^{9}$	$120 \cdot 10^{9}$	$91 \cdot 10^{9}$	$72 \cdot 10^{9}$
Sin, φ	89 °59′50″	89 °59′49″	89 °59′30″	89 °59′	89 °58′59″	89 °57′	89 °56′	89 °55′	89 °54′
v, m/s	137 000	125 000	46 000	23 000	22 600	7 500	5 700	4 600	3 800
λ, m	$0.23 \cdot 10^{-5}$	$0.26 \cdot 10^{-5}$	$0.8 \cdot 10^{-5}$	$1.4 \cdot 10^{-5}$	$1.42 \cdot 10^{-5}$	$0.42 \cdot 10^{-4}$	$0.56 \cdot 10^{-4}$	$0.7 \cdot 10^{-4}$	$0.8 \cdot 10^{-4}$

f, Hz	$59 \cdot 10^9$	$48 \cdot 10^9$	$5.7 \cdot 10^9$	$1.6 \cdot 10^9$	$1.59 \cdot 10^9$	$1.8 \cdot 10^8$	$1.0 \cdot 10^8$	$6.6 \cdot 10^7$	$4.8 \cdot 10^7$
Sin, φ	89 °53′	89 °52′	89 °50′	89 °47′	89 °45′	89 °30′	89 °25′	89 °21′	88°59′59″
v, m/s	3 200	2 800	2 300	1 800	1 500	770	660	590	380
λ, m	$0.098 \cdot 10^{-3}$	$0.11 \cdot 10^{-3}$	$0.14 \cdot 10^{-3}$	$0.18 \cdot 10^{-3}$	$0.2 \cdot 10^{-3}$	$0.42 \cdot 10^{-3}$	$0.48 \cdot 10^{-3}$	$0.54 \cdot 10^{-3}$	$0.84 \cdot 10^{-3}$
f, Hz	$33 \cdot 10^6$	$25 \cdot 10^6$	$16 \cdot 10^6$	$9.8 \cdot 10^6$	$7.5 \cdot 10^6$	$1.8 \cdot 10^6$	$1.3 \cdot 10^6$	$1.1 \cdot 10^6$	$450 \cdot 10^{3.}$
Sin, φ	88°	87°	86°	85°	84°	83°	82°	81°	80°
v, m/s	190	127	96	77	65	54	48	43	39
λ, m	$1.7 \cdot 10^{-3}$	$2.6\ 10^{-3}$	$3.4\ 10^{-3}$	$4.2\ 10^{-3}$	$5.0\ 10^{-3}$	$6.0\ 10^{-3}$	$6.8\ 10^{-3}$	$7.6\ 10^{-3}$	$8.5 \cdot 10^{-3}$
f, Hz	$114 \cdot 10^3$	$51 \cdot 10^3$	$29 \cdot 10^3$	$18 \cdot 10^{3.}$	$13 \cdot 10^3$	$9 \cdot 10^3$	$7 \cdot 10^3$	$5.6 \cdot 10^3$	$4.5 \cdot 10^3$

* where: φ is the angle of incidence on the opposite wall heating element; v - the velocity of movement of the material particles, m/s; λ – wavelength, m; f - oscillation frequency, Hz.

From the results given in the Table 1, it follows that at the angle $\varphi = 89°59′59″$, the material particle (the size of which does not exceed a wavelength of $0.3 \cdot 10^{-6}$ m and with oscillation frequency of $3.5 \cdot 10^{12}$ Hz) moves towards the opposite wall of the heating element, with the velocity of a thousand kilometers per second. In this range, the kinetic energy of substances increases, and flows of electrons, protons, and other charged particles appear. Plasma bunch is created, neutrino cloud is formed. Optical, x-ray, gamma – irradiations are enhanced. According to expression (4), the instantaneous temperature of the environment heating in a pulse can be 17 million degrees, which corresponds to the temperature of the solar corona (in this case, the specific heat capacity of the environment is the sum of heat capacities of: methane, carbon, hydrogen, oxygen, helium, nitrogen). As is known, the neutrino cloud moves at a speed of 1000 km/s. So, it can be assumed that significant amount of pulsed thermal energy appears in the thermal vacuum unit, sufficient to obtain nanodispersed materials and form a neutrino cloud. According to expression (7), the time of the effect of the temperature of the heating element on the material particle during its contact with the wall is $7 \cdot 10^{-4}$ s.

If the blast wave is directed to the opposite wall of the heating element at the angle $\varphi = 89°59′58″$, then, together with the explosive wave, the finely dispersed material appears, the size of which does not exceed wavelength of $0.48 \cdot 10^{-6}$ m with oscillation frequency of $1.4 \cdot 10^{12}$ Hz and speed of 670 km/s. The time of the influence of the temperature of the heating element on the material particle during its contact with the wall is $8.6 \cdot 10^{-4}$ s.

Changing the angle of motion of a nanodispersed particle by one second (89°59′58″ to 89°59′59″) increases its speed in approximately 1.5 times, the frequency range of oscillation - 2.5 times, and the wave length decreases in 1.6 times.

Changing the angle of movement of a material particle to the opposite wall of the heating element by one minute (89°58′59″ to 89°59′59″) increases its speed in 44 times, the oscillation frequency by $2.2 \cdot 10^3$ Hz, and the wavelength reduces in 47 times.

Changing the direction of a material particle to the opposite wall of the heating element by one degree (88°59′59″ to 89°59′59″) increases its speed in $2.6 \cdot 10^3$ times, the oscillation frequency by $7.7 \cdot 10^6$ Hz, the wavelength decreases in $2.8 \cdot 10^3$ times.

It should be noted that the velocity of the particle, at the angle of incidence (88°59′59″) on the opposite wall of the heater corresponds to the speed of sound.

It follows from the calculation results that in the angular range (89°59′58″ to 89°59′59″) the highest intensity of thermal vacuum synthesis of nanodispersed materials occurs.

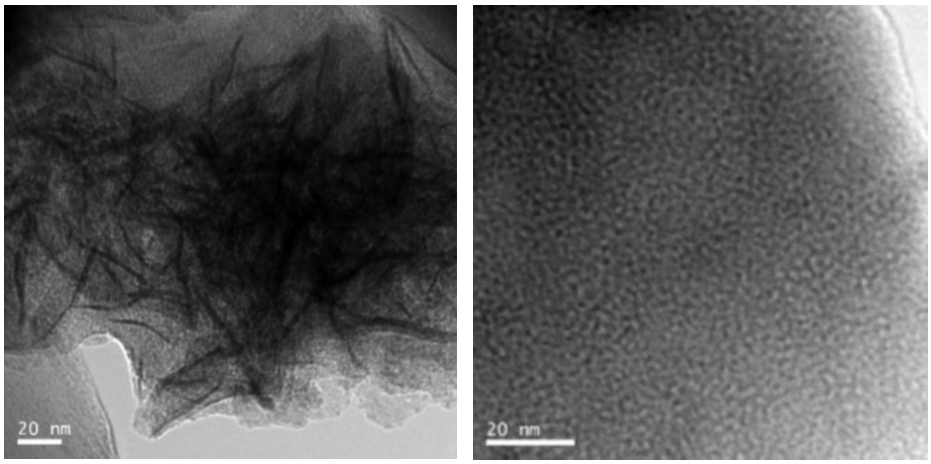
According to expression (4), the two-phase flow will heat up to 100° C at a velocity of 590 m/s and the angle of incidence on the opposite wall of the heater equal to 89°21′ (the specific heat capacity of the two-phase flow is the sum of the heat capacities of carbon and air). At the same time, the influence of the heating element temperature onto the material particle during its contact with the wall is $3.0 \cdot 10^{-2}$ s.

If the material particle moves to the opposite wall of the heater strictly at the angle $\varphi = 90°$, then its path of motion in time will not change, i.e. it is in the potential trap. But it is not occurring due to the fact that the phase shift of the material particles creates an air flow that forms a vacuum pump. As a result of the pump effect, everything within the cavity of the heating element is driven toward the outlet.

6. Thermal Vacuum Synthesis of Heterogeneous Materials

6.1. Carbon

Carbon grade C1 with particle size (9…5) mm, moisture content 6.5% was subjected to thermal vacuum synthesis. Carbon nanotubes and fullerenes have been obtained (see Figures 3 (a, b)).



(a) (b)

Figure 3. *(a). Carbon nanotubes; (b). Carbon fullerene.*

Nanodispersed single-layer graphite with a particle size of (10...40) nm was obtained during thermal vacuum synthesis (Figure 4).

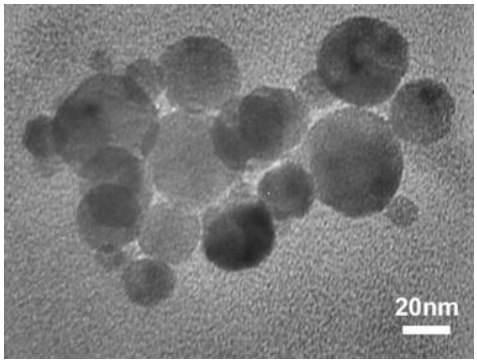


Figure 4. *Nanodispersed single layer graphite.*

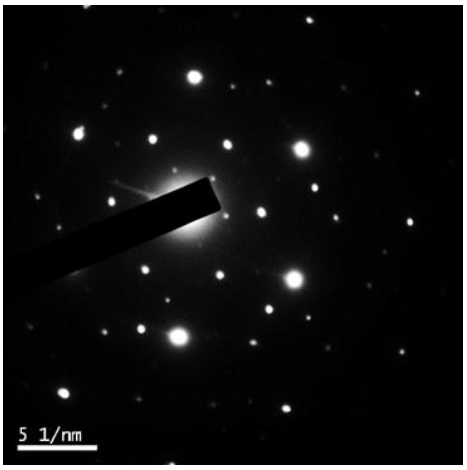


Figure 5. *Hexagonal graphite lattice.*

There is transition of matter from one form to another during thermal vacuum synthesis. Figure 5 shows the reciprocal lattice of a graphite particle, which has conventional hexagonal or rhombohedral lattice with its display in the basis crystallographic plane. According to the figure, this particle includes coherent phase with doubled period, as evidenced by small hexagonal dots in the immediate vicinity to the center of the electron diffraction pattern.

Monoclinic modification of the reciprocal lattice was also found within C1-grade graphite, (see Figure 6).

Figure 6. *Monoclinic modification of the graphite lattice.*

All this confirms the possibility of thermal vacuum synthesis of nanodispersed material. Each newly formed particle in the heating element of the thermal vacuum unit moves along its own trajectory, has its own frequency of movement, speed, mass. A particle that has changed the velocity of movement, mass, size can move from one frequency range to another frequency range, which provides energy-efficient, high-performanc continuous dispersion of the material in vacuum environment.

6.2. Brown Coal

Studies of thermal vacuum synthesis of brown coal were

carried out, also. The minimum size of the obtained brown coal particle was 40 nm. At the same time, the amount of thermal energy spent on obtaining finely dispersed brown coal with moisture content of 1% from raw material with initial moisture content of 40% and initial particle size of 6 mm and heating element temperature T = 250° C is 600 MJ/t. When the heater temperature rises to 300° C, brown coal ignites, despite the reduced pressure inside the heating element (see Figures 7, 8). Although, the ignition temperature of brown coal is (350...450)° C (Reference data).

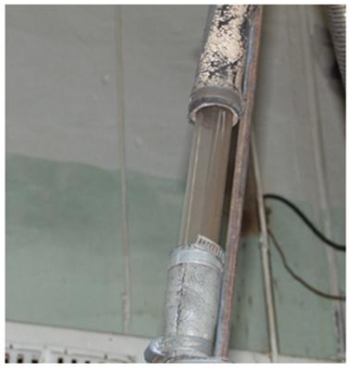


Figure 7. *Fragment of the pipeline.*

Figure 8. *Brown coal combustion in a pipeline.*

The cause of the ignition of brown coal in the heating element is thermal electrization, which under certain external conditions leads to increase in electrostatic voltage and occurrence of electric discharge. Development of electrical discharge is significantly affected by electron avalanche, which creates increased concentration of charge carriers in the temperature range T = (260...300) ℃, sufficient for the direct formation of glow discharge with its transformation into a streamer. After the spread of streamers over the entire interelectrode gap at a heater temperature of T ≥ 300 ℃, powerful electrical discharges occur, plasma formed, which is the cause of spontaneous combustion of crushed brown coal. This indicates that thermal vacuum synthesis occurs in the spiral heater, which generates thermonuclear reactions, sharply increasing the ambient temperature, due to which the process of thermal ionization is enhanced. Molecules will begin to disintegrate into their constituent atoms, which then turn into ions, neutrons, freely moving electrons.

6.3. Zirconium Dioxide

Let's consider the process of thermal vacuum synthesis using the example of obtaining zirconium dioxide from zirconium hydroxide.

As is known, hydrothermal synthesis is one of the most widespread methods for obtaining nanodispersed ZrO_2 powders [10]. However, the described methods make it possible to obtain nanodispersed zirconium dioxide in aqueous, acidic, and alcoholic solutions during long period of time.

Thermal vacuum synthesis forms finely dispersed zirconia directly, from zirconium hydroxide, without water, acid and alcohol additives. The residence time of the source material in the thermal vacuum unit is 15 seconds [11].

Zirconium hydroxide with a particle size ranging from 2 to 10 mm and a moisture content of 12.5% was used to study thermal vacuum synthesis.

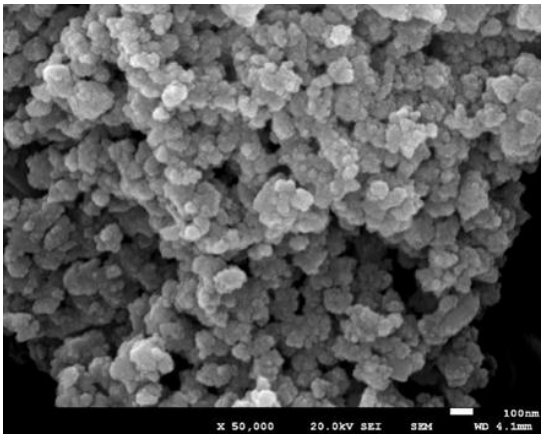


Figure 9. *Amorphous zirconium dioxide.*

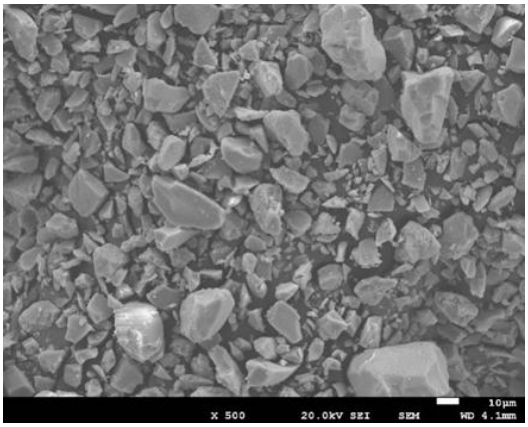


Figure 10. *Crystalline zirconium dioxide.*

As a result of thermal vacuum synthesis from zirconium hydroxide, pure zirconium dioxide was formed in the amorphous state of randomly oriented crystallites with moisture content of 1.8%, with cellular structure (20...200) nm in size, with developed specific surface and large volume of sorption space. Bulk density was 1.64 g/cm^3 (see Figure 9). Simultaneously with amorphous zirconium dioxide, finely dispersed crystalline ZrO_2 was also obtained in the thermal vacuum unit (see Figure 10).

The study of the structural composition of zirconium dioxide processed in a thermal vacuum unit was carried out using X-ray structural analysis and a scanning microscope. X-ray structural analysis of crystalline zirconium dioxide showed that it has a monoclinic structure.

6.4. Helium-4 Synthesis

By analyzing the results of thermal vacuum synthesis of nanodispersed materials, the mechanisms of influence on the studied object can be determined. The high local temperature in the heating element strip initiates the decomposition process of the substance. A large nucleus can disintegrate into several smaller ones, releasing heat in the process. The rate of disintegration depends on both the movement speed and the heat capacity. As the temperature continues to rise, a synthesis reaction occurs, where smaller nuclei combine to form a larger one. For instance, in a local nuclear reaction, hydrogen combustion leads to the conversion of four protons into a helium-4 nucleus.

7. Conclusions

1. Efficient thermal vacuum synthesis method has been developed, that disperses nanomaterials within 15 seconds via thermal fluctuations, shock waves, and ionization.
2. Stable particle flow is achieved by maintaining a solid particle concentration of 1.0–1.2 g/L in the heating element.
3. Particle velocity, driven by steam explosions and heater energy, can reach up to 1000 km/s, forming plasma and neutrino clouds under specific conditions.
4. This method is a powerful, low-energy solution for continuous nanomaterial synthesis, enhancing productivity and quality while reducing costs and energy consumption.

Author Contributions

Volodymyr Kutovyi is the sole author. The author read and approved the final manuscript.

Data Availability Statement

The data is available from the corresponding author upon reasonable request.

Conflicts of Interest

The author declares no conflicts of interest.

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Biography

Volodymyr Kutovyi holds a Doctorate Degree and is a Professor at the Kharkiv Institute of Physics and Technology, National Science Center, part of the National Academy of Sciences of Ukraine. He serves as a Senior Researcher.

Research Field

Volodymyr Kutovyi: Vacuum drying, nano-dispersed materials, energy saving technologies, materials synthesis, electron microscopy