WAVE TECHNOLOGY IN MECHANICAL ENGINEERING

Industrial Applications of Wave and Oscillation Phenomena

R. F. Ganiev
S. R. Ganiev
V. P. Kasilov
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Preface

The first and second editions of this book created great interest among a broad spectrum of readers. With the entire run of the first editions out of print, the need occurred to reissue. Also, new results obtained after the first editionsubstantially broadened application capabilities of wave and oscillation phenomena for the creation of high technologies in the industries. Therefore, this third edition is significantly reworked and expanded.

Major attention in reworking the book was devoted to issues of the practical implementation of wave technologies in specific industries. It relates to the engineering, chemical industry, materials technology, construction, food, oil and gas production industry, etc. Subjected to reworking were sections related to the wave activation of cements and cement-limestone compositions with respect to facility of understanding and demonstrability of the presented material. The section devoted to the issues of loose component dosage metering and wave metering devices was amended.

The section devoted to wave technologies of developing composite materials including nanocomposite materials was considerably updated. This technology enables, on a conceptually new level, the solving of many currently urgent tasks for producing finely dispersed emulsions and suspensions, including high-viscosity dispersion medium as well as highly-filled composite materials with finely dispersed fillers.

The authors also used results obtained by a number of employees at the Centre of nonlinear wave mechanics and technology RAN to whom the authors are grateful [1–12].

1

Introduction: Capabilities and Perspectives of Wave Technologies in Industries and in Nanotechnologies

Wave technologies are groundbreaking (fundamental) innovations based on fundamental scientific achievements in the domain of nonlinear wave mechanics – a new area of mechanics developed by the Scientific Centre for Nonlinear Wave Mechanics and Technologies of Russian Academy of Sciences (NC NVMT RAN). They enable the solution of earlier inaccessible technologic problems. They also enable a qualitatively new approach to the already known technologic processes, substantially (multiply) increasing their efficiency. In essence, wave technologies is Russia's competitive national advantage on the world market of technologies and the foundation for the implementation of wide-ranging innovations in various industrial disciplines offering high-efficiency solutions of technological problems based on wave phenomena and effects [1–16].

This book does not have the objective of describing wave phenomena and effects discovered in the process of developing nonlinear wave mechanics, which is the scientific base of wave technologies. The objective of this book is to show their conceptual capabilities in the creation of new materials and products or in their multiple improvements for increasing the efficiency of numerous technological processes. The scope of such technologies is huge (not all areas of possible applications are reviewed here) – from materials, in particular building materials, composite materials, nanocomposite materials to petrochemicals, food and medical industries, pharmacology, etc. Reviewed is a wide range of practical issues in these domains. It is possible simply to name new specific results. However, to understand fully their significance, it is no less important also to know how they were obtained. It means understanding on which new phenomena and effects they are based. Nonlinear wave mechanics, wave phenomena and effects are presented in sufficient detail and mathematically stringently, with experimental support and a wide range of applications based on the works of members of the NC NVMT RAN. Most recent achievements are presented in monographs and articles [1–16]. That is why it is inexpedient to again quote their contents. The objective of this book is totally different. It is: to provide a wide range of interested readers with the first idea of basic applied works in the domain of wave technologies. It is to provide them with the information about new results and further perspectives. It is to show the breadth of problems in solving specific type technologic tasks and in developing controlled wave machines and apparatuses, which implement these tasks.

Speaking of groundbreaking technologies in the industries, it is necessary to understand clearly that the time of easy and simple solutions has long gone. Groundbreaking technologies in the 21st century may be created only based on achievements in fundamental, abstract sciences obtained in multiannual research of scientific schools. In the current environment in Russia, the amount of such fundamental, abstract scientific achievement both in industrial and in educational agencies of the country is far from sufficient. The stake of using foreign scientific potential will throw Russia back to secondary positions. The reason is that not a single state and not even a single organization or agency would ever sell the most up-to-date, most perspective developments and technologies. At the same time, in the institutions of the Russian Academy of Sciences there are both scientific schools with century-long history and fundamental scientific developments in physics, mechanics, chemistry, biology, etc., capable of becoming the foundation of new groundbreaking technologies, technologies of the 21 century. In its domain the Scientific Centre for Nonlinear Wave Mechanics and Technologies, RAN has its own fundamental scientific developments in the new area of mechanics. These are nonlinear wave mechanics and wave technologies capable of becoming the foundation of a host of high technologies.

Most of these advances are prepared for rapid implementation of groundbreaking wave technologies based on fundamental abstract science and newly discovered phenomena and effects. Working on the scale of the entire industrial branches and Russia as a whole, they could provide tangible economic effect within the near future.

Mutual understanding is needed here between political leaders, scientists, engineers and businessmen. What is necessary is clear and obvious examples in order not to look for new technologies only abroad. As the "father of Russian aviation" Prof. N.E. Zhukovsky wrote in his time, "Examples in science are no less didactic than the rules" (quoted from memory). We will provide a few examples.

The first example will be relatively simple for understanding technologic problem, fragmentation, fragmentation and activation of solid particles (dry mixes). This problem is quite common in materials technology, in petrochemicals, in food industry, pharmacology, etc., and also in nanotechnologies. Currently, in this area, both scientifically and practically, traditional methods actually reach the limit or in many cases are inefficient and not always economical. At NC NVMT, we managed to identify and practically implement a phenomenon of controlled turbulization in an aggregate of solid particles (in a flow or in closed volume), the phenomenon which efficiently solves this problem. In this case occurs material self-fragmentation. And due to possible nonlinear resonance, it implemented intense turbulization, which creates an environment for the destruction of solid particles reasonably economically and with sufficient purity of the material. (Very little material is carried out of the apparatus walls.) The corresponding wave machine is relatively simple. Here as well are proposed effective metering devices and classifiers, their controlling elements, which enable the creation of automated technological trains for ideal mixing (including with minor additives), pulverization and activation of solid particles.

A second example is the effect of accelerated liquid flow (100–1,000 and more) in thin capillaries and porous media (on the order of 10 μm and less) under wave action. The amplitude of running waves in capillaries is about 1/100 to 1/1,000 of a capillary diameter, i.e., at the level of nanometers. The mechanism of such flow is nonlinear (this is clearly observed when reviewing the flow equations) [4].

Some time ago, this phenomenon was used by the authors for increasing oil yield by reservoirs [10] (as one of mechanisms). The effect has a broad range of applications. It may be used in impregnation of porous media, materials in engineering, 3- to 4-fold increase in efficiency of membrane devices in separation, production of nanosize particles (drops), etc. This trend (as well as a number of others) is directly related to the new trend in hydromechanics, which is currently under intense development in the West, so-called micro-hydromechanics. Wave mechanics created and being intensely developed in Russia, (at NC NVMT RAN) as one of current forward science and practical trends, also creates the base of wave micro-hydromechanics. A number of conceptually new results are arrived at in this area, which have rather high potential in this direction.

We would like to note one more very important issue – a problem of stirring (actuation) of high-viscosity media. The issue arose first of all in mechanics of high-viscosity polymers, in food industry, in the manufacturing of composite materials in the modern technology, nanocomposite materials, etc. In this area, it was possible to develop a method of intense wave stirring (actuation) in high-viscosity media with various modifying additives at their uniform distribution (using shear waves and circulation motion). This is very important for improvement in final product quality in the stated disciplines.

Another perspective arises from the results obtained in wave mechanochemistry. They may lead to the creation of new technologies in oil refining, petrochemicals and in pharmacology.

A description of this kind of effect for the development of wave technologies in industries could be continued.

The above examples are identified only to show that high, i.e. groundbreaking, technologies as a rule are possible when there are great fundamental results, new phenomena and effects. Thus, as the performed fundamental and applied works show, they have already claimed their niche, and in the future, areas of their application can multiply and expand.

Currently, the expected technological breakthrough is closely associated throughout the world with the practical implementation of fundamental scientific developments in the area of nanotechnologies. Therefore, the national priority and practical results obtained in the area of wave technologies may become the Russian contribution, among others, in the world's nanotechnologies. In this area, in the processes of uniform stirring (actuation), wave technologies may have no competitors.

The application of wave technologies enables the solution on a conceptually new level of numerous technologic tasks. They include pulverization, activation, ideal mixing, dosage metering, classification and sectioning of liquid and gaseous nonuniform systems, extraction, drying, filtering, transport, polymerization, etc., in many industrial disciplines. Examples may be engineering, materials technology, food, mining, chemical, oil and gas industries, construction, housing services and utilities, pharmacology and medicine.

The amount of work performed at NC NVMT RAN, the results of theoretical and experimental studies, which underwent experimental and industrial testing, provide us with an opportunity to maintain that the basic part of wave technologies is currently ready for a wide-scale industrial application. This application is associated with the creation of a new perspective engineering trend in Russia, the wave engineering.

Depending on the particulars of specific technologies and manufacturing complexes, different options are available for the incorporation of wave technologies. They may be between completely finished wave technologic complexes and upgrading the existing trains by building wave machines and devices into them, which would radically change manufacturing parameters towards increasing efficiency and quality of the product and lowering energy expenses.

The goal of our book is, based on experimental data, on specific technological examples to show the capabilities and potential for the incorporation of wave technologies in various industries. It relates especially to the creation of new materials with unique properties, nanocomposite materials and highly-filled composite materials. These appear to be most perspective trends, which, in our view, may be most effectively implemented in wave machines and devices.

2

Fragmentation and Activation of Dry Solid Components: Wave Turbulization of the Medium and Increasing Process Efficiency

Pulverization processes are widely used in many domains of industrial production. The dry super-fine fragmentation of solid materials on the industrial scale, i.e., fragmentation of powder materials to nominal size below 40 μm, is a most important practical task of many modern technologies.

The finely dispersed products made in the process of super-fine pulverization are applied as pigments, hydraulic and air binders (Portland-cement, aluminate cement, gypsum hemihydrate, etc.), mineral fertilizers, modifying additives, fillers for making varnish-and-paint materials, sealers, construction plastics, refractories and ceramics, pharmaceutical and cosmetic products.

High demand for products of super-fine pulverization and pulverization and activation technologies in recent times was caused by the creation of new types of ceramics, composite materials, by the evolution of powder metallurgy and ceramic manufacturing, and by industrial application of nanotechnologies.

Super-fine fragmentation, as a rule, is performed using intense mechanical pressure on particles of material. That results in the accumulation of structural flaws in the particles, in the increase of per-unit-volume surface, in phase transformations and also in partial amorphization of crystals. In the process, their chemical energy substantially changes. A process of forming more active substance as a result of mechanical treatment is called mechanoactivation.

Super-fine fragmentation using traditional methods is highly energy-intensive and of low efficiency. For instance, manufacturing nanopowders uses planetary, ball and vibration mills at high energy levels. And the treatment time is measured in hundreds of hours (for instance, Alymov, M.I. Powder metallurgy of nanocrystalline materials. Moscow, Nauka, 2007, 169 pp.).

It is known that low efficiency and elevated energy dissipation in industrial mill machines are substantially a result of damping of the external stress by a layer of crushed material due to friction at mutual displacement of particles in the layer (see, for instance, Selective destruction of materials. Editor corresponding member of the USSR Academy of Sciences, Revnivtseva, V.I. Moscow, Nedra, 1988, 282 pp.). Another pitfall of traditional pulverization processes (ball, rod mills, etc.) at fine and super-fine pulverization is high contamination of the pulverized product along with excessive wear and tear of milling elements. In this context, most efficient traditional mills for dry super-fine pulverization are currently believed to be the mills of centrifugal-shock type. In those, the fragmentation occurs due to impact of particle with balls, reflectors and between themselves.

When particles collide, stress waves form within them. Numerous publications on shock physics deal with study of shock destruction of blocks. As applied to the particles of pulverized material destruction processes, it is easy to show that at uninhibited collisions the stress within these particles can easily exceed breaking strength already at relatively low velocity (tens of meters per second). In number of estimates, that is exactly what determines relatively high efficiency of centrifugal-shock mills. However, due to the effect of centrifugal forces in mills of this type, also forms next to the walls and reflectors a dense layer of pulverized material bombarded by the particles flying from the rotor. A result is that substantial energy is wasted on friction within the layer. This causes strong deterioration in the efficiency of the pulverization process.

Conceptually new opportunities in increasing efficiency of brittle materials pulverization process opens the application of nonlinear wave mechanics methods using radical motion forms in multiphase systems due to nonlinear (including resonance) interaction of oscillations and waves. As applied to technologies of fine and super-fine pulverization, such motion form is wave turbulization of a dual phase medium (composed of the air or, if needed, other gas, and particles of a pulverized material) using wave process for their destruction.

Wave turbulization of air-dust mixes hinders the formation of dense near-wall layer. Wave forces act on particles in the opposite direction compared with centrifugal forces and compel them to move towards particles accelerated by the rotor. The number of collisions between particles drastically increases. A combination of wave turbulization of the medium and the energy supply from the rotor in a combination resonance-oscillation rotation system results in that the interaction between particles occurs not in the form of friction but mostly as force collision of free-flying particles. This provides for their high-frequency shock-impulse stress. The supplied energy is expended more on the creation of the collision-generated stress waves within particles and not on friction among them. As a result, friction loss declines and energy efficiency of the pulverization process increases.

Based on analysis of shock-wave processes in a particle, it is also possible to show that free collision of particles to a much greater extent than a particle impact with a massive block creates conditions for emergence in them of tension stress. And these stresses are more efficient for the destruction of most materials to be pulverized compared with the compression stress. Increased collision frequency and energy facilitates a rapid accumulations of defects in pulverized particles and their destruction. This enables the achievement of required dispersion in the pulverized material at substantially lowered rotor velocity. Actually, the velocity declines 2–3 times compared with the destruction due to impact with a layer of material, due to compressed impact, etc. At equal velocity it results in higher dispersion of the product, which improves energy efficiency of the pulverization process and decreases wear and tear of operating surfaces. Besides, the decrease in wear and tear of mill's operating surfaces facilitates the increase in the extent of product purity, which is especially important for the pharmaceutical, food and a number of other industries.

Optimization of the pulverization process is also facilitated by the application in the mill of internal product classification. What it means is that only particles no larger than assigned dispersion level (and also due to regulation of rotor rotation speed, control of pressure and vacuum in the pneumo-transportation system) may leave the work chamber of the installation. It is possible to set up both running (through-flowing) and batch (fractional) pulverization processes.

A description of a rotor-wave mill is published in [8]. An experimental sample of the rotor-wave mill as part of experimental installation for wave pulverization and activation is provided in Figure 2.1. Following are practical results obtained with the experimental installation. The fragmentation was conducted under regime, at which the velocity of rotor's external surface was about 80–100 meters per second at wave turbulization of the medium. At pulverization in centrifugal mills for achievement of such result is usually used a multi-stage pulverization process, and the rotor surface velocity reaches 200 and even 250 meters per second.

2.1 Calcium Carbonate (limestone) Fragmentation

The source material is limestone sand with particle size of up to 3 mm. Analysis of grinding

Figure 2.1 Automated train of loose material wave treatment. 1. Control panel; 2 Raw material supply line; 3 Separation filter; 4 Finished product discharge line; 5 Loading hopper; 6 Rotor-wave mill aggregate

product showed that after pulverization of calcium carbonate in a rotor-wave mill during five minutes, the amount of particles with dispersion (size) less than 5.47 μm in the work chamber was 85% (Figure 2.2). This is 1.5 times more

Interpolation Values... C:\Program Files\a22 32\fritsch\HIMNT_1.FPS

0.050 – 1.000 µm = 26.86%	1.000 – 2.000 µm = 29.83 %	2.000 – 3.000 µm = 14.70 %
3.000 – 4.000 µm = 7.63%	4.000 – 5.000 µm = 4.46 %	5.000 – 10.000 µm = 9.60 %
10.000 – 20.000 µm = 5.33%	20.000 – 50.000 µm = 1.39 %	50.000 – 100.000 µm = 0.04 %
100.000 –200.000 µm = 0.16%		

Interpolation Values... C:\Program Files\a22 32\fritsch\10_90.FPV

5.0 %	⇐	0.427 µm	10.0 %	⇐	0.561 µm	15.0 %	⇐	0.694 µm
20.0 %	⇐	0.824 µm	25.0 %	⇐	0.952 µm	30.0 %	⇐	1.083 µm
35.0 %	⇐	1.220 µm	40.0 %	⇐	1.368 µm	45.0 %	⇐	1.530 µm
50.0 %	⇐	1.712 µm	55.0 %	⇐	1.922 µm	60.0 %	⇐	2.171 µm
65.0 %	⇐	2.476 µm	70.0 %	⇐	2.861 µm	75.0 %	⇐	3.405 µm
80.0 %	⇐	4.197 µm	85.0 %	⇐	5.472 µm	90.0 %	⇐	7.708 µm
95.0 %	⇐	12.089 µm	99.0 %	⇐	23.337 µm			

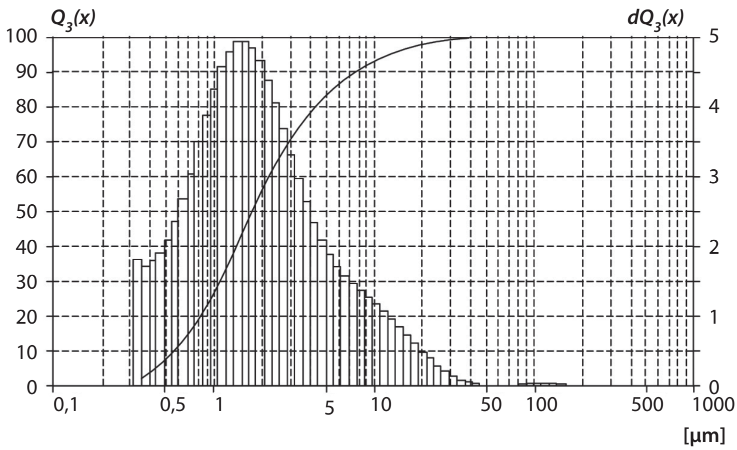

Figure 2.2 Calcium carbonate dispersion analysis results after pulverization on a rotor-wave mill.

than using traditional ball or rod mills utilized in industrial manufacturing of fine-grained carbonates (Figure 2.3).

At the same time, the amount of particles 20 to 50 µm in size for the rotor-wave mill is only 1.39%. This is almost one tenth of the amount for ball and rod mills (12.17%). In other words,

Interpolation Values... C:\Program Files\a22 32\fritsch\HIMNT_1.FPS

0.050 – 1.000 µm	= 14.37%	1.000 – 2.000 µm	= 18.83 %	2.000 – 3.000 µm	= 11.21 %
3.000 – 4.000 µm	= 7.07%	4.000 – 5.000 µm	= 4.98 %	5.000 – 10.000 µm	= 15.06 %
10.000 – 20.000 µm	= 16.25%	20.000 – 50.000 µm	= 12.17 %	50.000 – 100.000 µm	= 0.06 %
100.000 –200.000 µm	= 0.00%				

Interpolation Values... C:\Program Files\a22 32\fritsch\10_90.FPV

5.0 %	⇐	0.564 µm	10.0 %	⇐	0.804 µm	15.0 %	⇐	1.028 µm
20.0 %	⇐	1.258 µm	25.0 %	⇐	1.508 µm	30.0 %	⇐	1.792 µm
35.0 %	⇐	2.129 µm	40.0 %	⇐	2.539 µm	45.0 %	⇐	3.069 µm
50.0 %	⇐	3.762 µm	55.0 %	⇐	4.686 µm	60.0 %	⇐	5.903 µm
65.0 %	⇐	7.452 µm	70.0 %	⇐	9.351 µm	75.0 %	⇐	11.633 µm
80.0 %	⇐	14.373 µm	85.0 %	⇐	17.740 µm	90.0 %	⇐	22.141 µm
95.0 %	⇐	28.791 µm	99.0 %	⇐	40.561 µm			

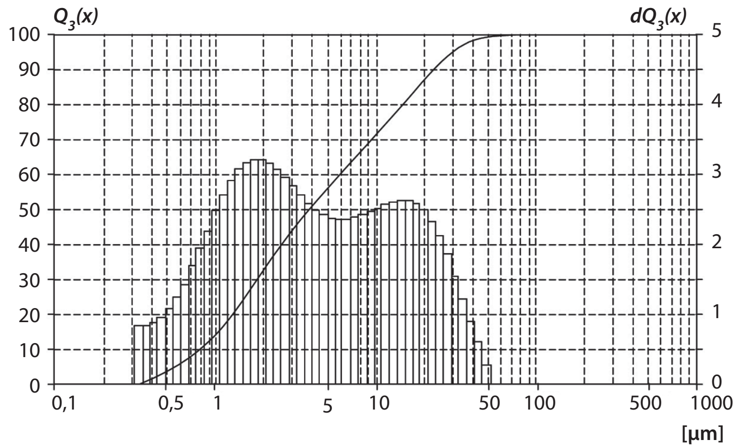

Figure 2.3 Industrial vintage calcium carbonate dispersion analysis results (this product is used in construction).

the results of this technologic experiment show that the fragmentation of calcium carbonate using wave technologies produces super-finely pulverized product of narrow granulometric composition in one pulverization stage without additional classification and with relatively low rotor velocity (80–100 m/s).

The classification of super-fine powders is currently an independent and rather complex problem requiring bulky and expensive equipment, additional manufacturing room, energy, service personnel, etc.,

This experiment shows that the application of wave technologies generates an opportunity of creating an industrial technological train enabling the production of super-fine powders (99% smaller than 24 μm) without additional classification. This is the most economically efficient and expedient method, with high product purity and lower energy expenditure due to lower velocity of work organs.

2.2 Wave Activation of Cements and Cement-limestone Compositions

Energy use is definitive in manufacturing Portland-cement. Cement price decline directly depends on the decrease in fuel and electric energy use per ton of manufactured cement. The technological potential for lowing energy intensity in cement production, together with ecological security, is practically exhausted. Since 1992, per unit weight use of energy for the manufacturing of Portland-cement practically has not changed and is about 3,500 kj per a kilo of clinker.

One possible way for lowering energy usage and improving ecology security in cement manufacturing is the production of multicomponent cements using limestone. The limestone is no inert filler and takes part in the process of Portland-cement hydration. The addition of limestone to the cement renders regulating effect on the setting and velocity of hydration reactions of major minerals in Portland-cement. Scientific studies and European experience using limestone Portland-cements showed efficiency of its application in manufacturing of construction and decorative concretes with high physico-mechanical properties, in dry construction mixes and construction slurries. However, for the manufacturing of this kind of multicomponent Portland-cement, it is necessary to provide a super-fine fragmentation of limestone to a particle size less than 5 μm. The application of traditional pulverization technologies utilized in manufacturing limestone Portland-cements does not allow for providing a decline in energy usage for the manufacturing, although it decreases negative ecology impact of the cement manufacturing.

For experimental confirmation of efficiency of the wave activation application at manufacturing of limestone Portland-cements, a series of experiments was conducted of Portland-cement wave activation with the addition of limestone. Pure Portland-cement as well as a mix of cement with limestone (90:10 and 80:20) were treated dry at the rotor-wave mill (Figure 2.1) for five minutes. The produced binders were tested for their compliance with GOST 31108-2003 "General construction cements. Technical stipulations". The testing was conducted in compliance with GOST 30744-2001 "Cements. Testing methods using multifractional sand". The strength of samples with the usage of activated cements was determined at the age of two and 28 days compared with the strength of reference samples prepared using Portland-cement not subjected to wave treatment. Water/cement ratio for all studied samples was assumed 0.5.

It was established as a result of the study:

- compression strength of the samples made with the application of cement-limestone binder treated in the rotor-wave mill exceeds the strength of the samples with the compositionally similar binder without wave treatment by 50% for all time lengths of sample solidification (Figures 2.4, 2.5)

- tensile strength when bending the samples made with the application of cement-limestone binder produced in rotor-wave mill exceeds the strength of samples with compositionally similar binder without wave treatment by 35% (Figure 2.6).

- compression strength of samples made with application of the cement-limestone binder produced in rotor-wave

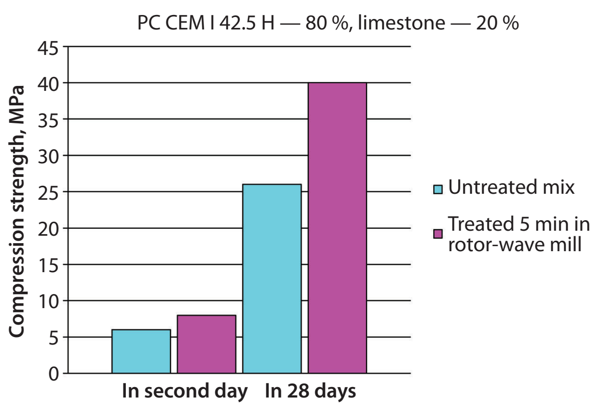

Figure 2.4 Increase in compression strength (MPa) in samples with cement-limestone binders (cement 80%, limestone 20%) after dry mechanoactivation of binders in rotor-wave mill.

mill exceeds by 10% strength of reference samples made with application of 100% Portland-cement not subjected to wave treatment (Figure 2.7).

2.3 Grinding Blast-furnace Sullage

Blast-furnace sullage is the main product for manufacturing no-clinker and low-clinker cements. In order to make binders based on blast-furnace sullage noninferior in their physico-mechanical and construction-technological properties to traditional Portland-cements, it is necessary to provide blast-furnace sullage with high dispersion. If using traditional pulverization methods,

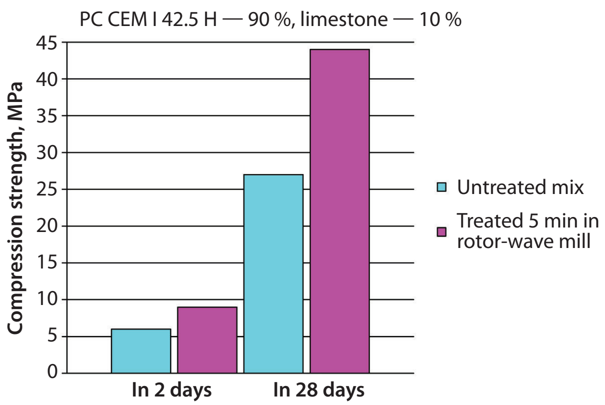

Figure 2.5 Increase in compression strength (MPa) in samples with cement-limestone binders (cement 90%, limestone 10%) after dry mechanoactivation of binders in rotor-wave mill.

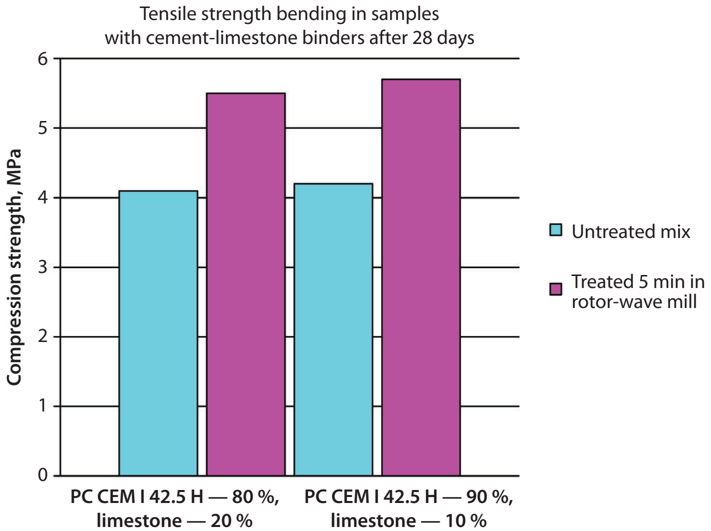

Figure 2.6 Increase in tensile strength at bending (MPa) in samples with cement-limestone binder after dry mechanoactivation of binder in rotor-wave mill.

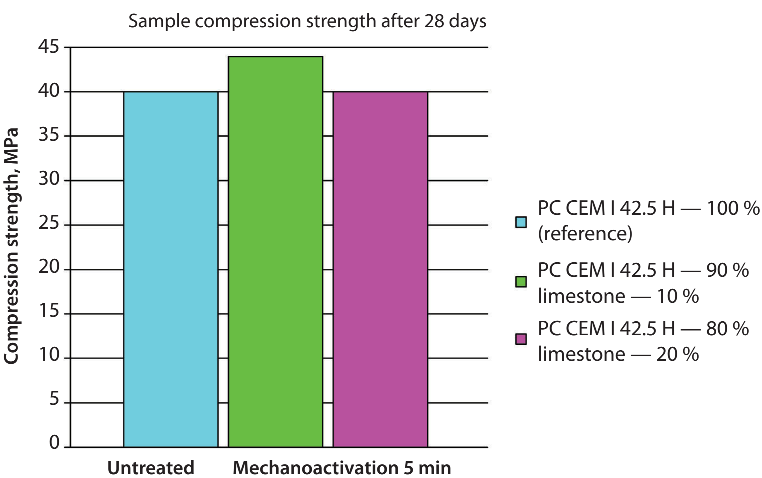

Figure 2.7 Strength comparison for samples prepared with cement-limestone binder after dry mechanoactivation in rotor-wave mill with strength of 100% Portland-cement samples, untreated.

this is associated with high-energy use and makes this type of cement economically unfeasible.

Fragmentation of blast-furnace sullage in the experimental rotor-wave mill showed that the application of the combination wave pulverization process halved maturing time of no-cement binders based on activated blast-furnace sullage and provided solidification dynamics and brand strength comparable with Portland-cement binders. At that, the cost of so derived binder was up to 50% below the cost of Portland-cement. This opens broad potential for the application of rotor-wave mills in manufacturing non-firing binders based on activated blast-furnace sullage and will allow organizing manufacturing of associated product on metallurgical combines. Together with the production of high-quality binders, it will facilitate substantial ecological improvements.

2.4 Production of Coloring Pigment Based on Titanium Dioxide and Dolomitic Marble

Titanium dioxide is a white pigment broadly used in the varnish-and-paint industry, in manufacturing plastics and paper, and in food and pharmaceutical industries. Manufacturing of titanium dioxide is high energy-consumptive and complex. And titanium dioxide demand exceeds the amount of its manufacturing.

In order to replace scarce titanium dioxide, various technologies of manufacturing white pigments alternative to titanium dioxide are proposed. One prospective trend is manufacturing of shell (membranaceous) pigments, which are composition materials composed of particles of optically neutral filler coated with pigment layer. Shell pigments, as a rule, are produced by mechanoactivation of the filler particles together with coloring pigment, chemical modifiers and surfactants. For the manufacturing of a white shell pigment – replacement of titanium dioxide – are applied as fillers natural or artificial minerals, for instance, wollastonite, calcite, dolomite, and as the pigment, titanium dioxide.

Experimental studies of making shell pigment were conducted with the application of wave activation. Dolomite was used as filler and titanium dioxide as pigment. Ratio filler/pigment was assumed 50/50 and 70/30. The treatment of raw material mixes was conducted in a rotor-wave mill for five minutes. The resulting white pigments were tested under GOST 16873-92

“Pigments and fillers inorganic. Methods of color and whiteness determination”.

The results of shell pigments whiteness testing with filler/pigment ratio 50/50 and 70/30 were, respectively, 98.8 % and 98.49% (the pure titanium dioxide whiteness was 98.56; Figures 2.8, 2.9, 2.10).

Cost of shell pigment-titanium dioxide replacement is 50%-70% below the pure titanium dioxide. Thus, the introduction of wave technologies enables lowering the amount of titanium dioxide import by half or more.

2.5 Wave Treatment of Aluminium Oxide

A series of experiments was conducted in pulverization-activation of aluminium oxide GK-1. It was found that as a result of treatment in a rotor-wave mill for only two minutes, the bimodal powder of the source aluminium oxide converts to unimodal, substantially increases the dispersion (per-unit volume surface increase up to two times) (Figures 2.11, 2.12), and improves caking capacity parameters. Analysis of the results was conducted by Scientific-Technical Center “BAKOR”.

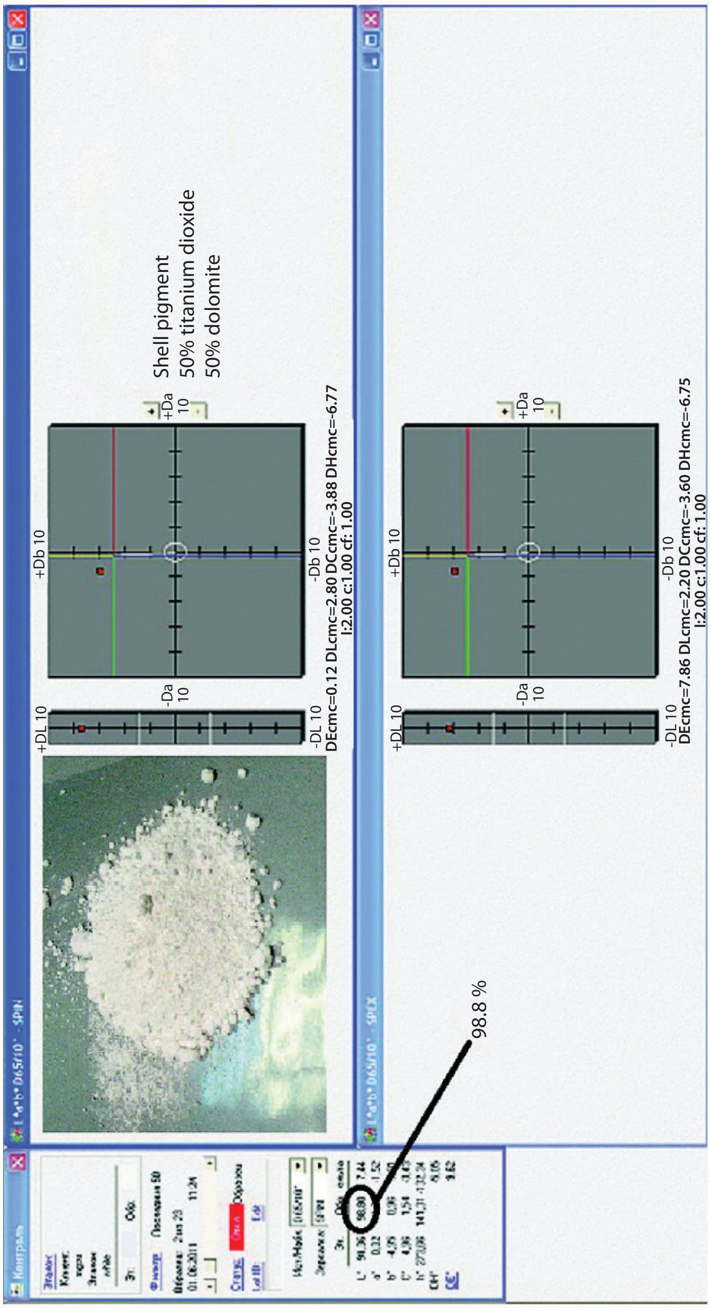

Figure 2.8 Shell pigment whiteness determination results: 50% titanium dioxide, 50% dolomite.

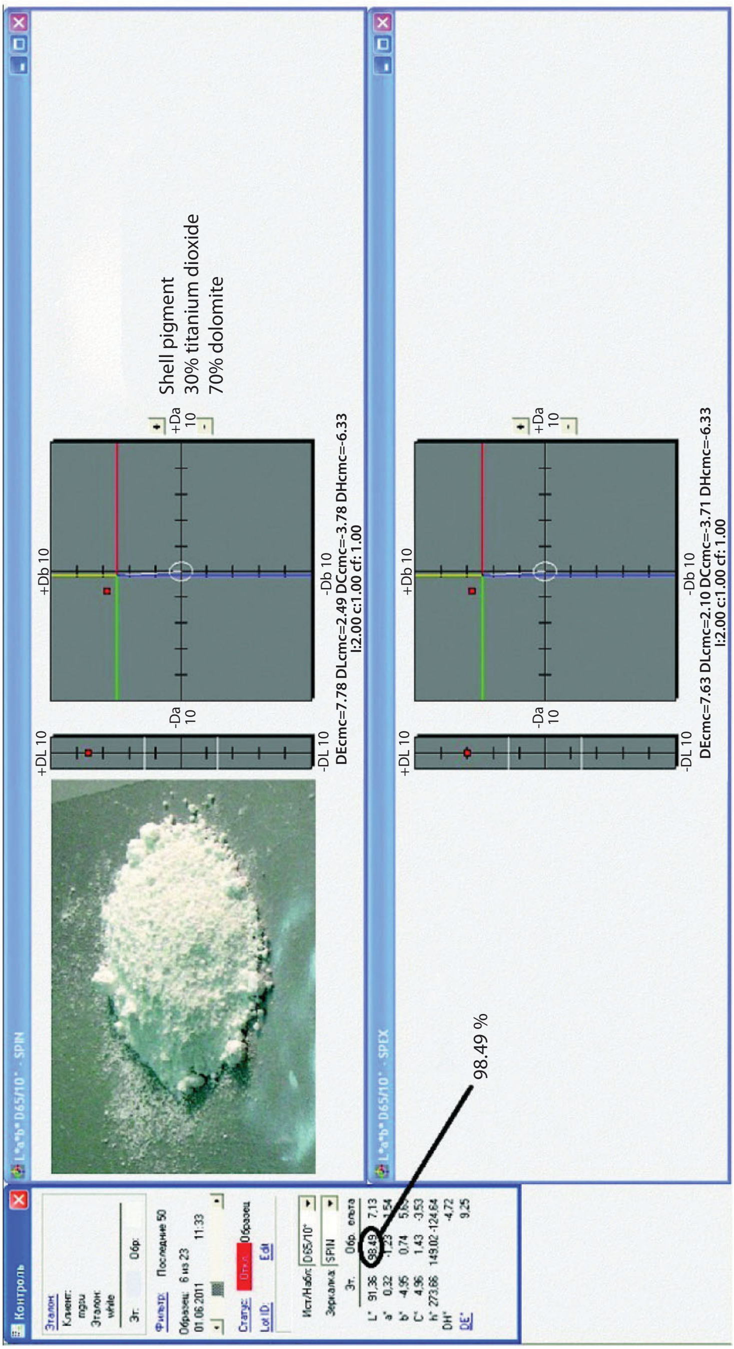

Figure 2.9 Shell pigment whiteness determination results: 30% titanium dioxide, 70% dolomite.

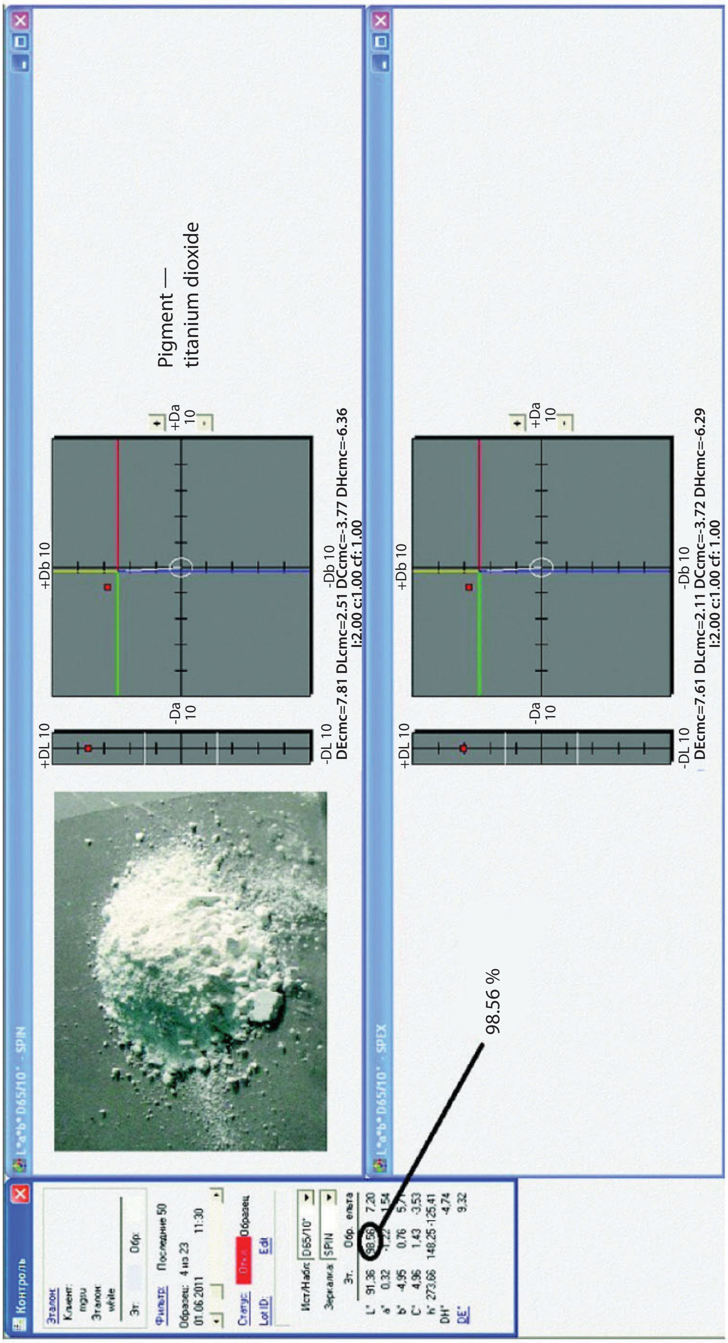

Figure 2.10 Titanium dioxide pigment whiteness determination.

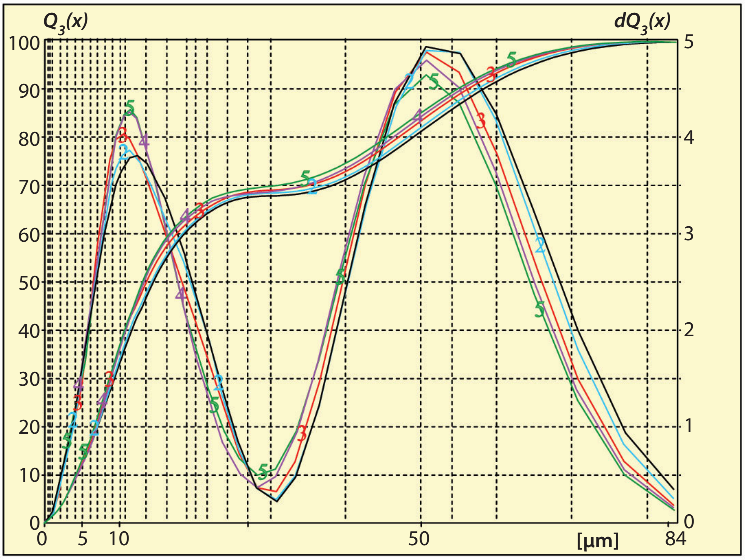

Figure 2.11 Dispersion analysis results of the source alumina GK-1.

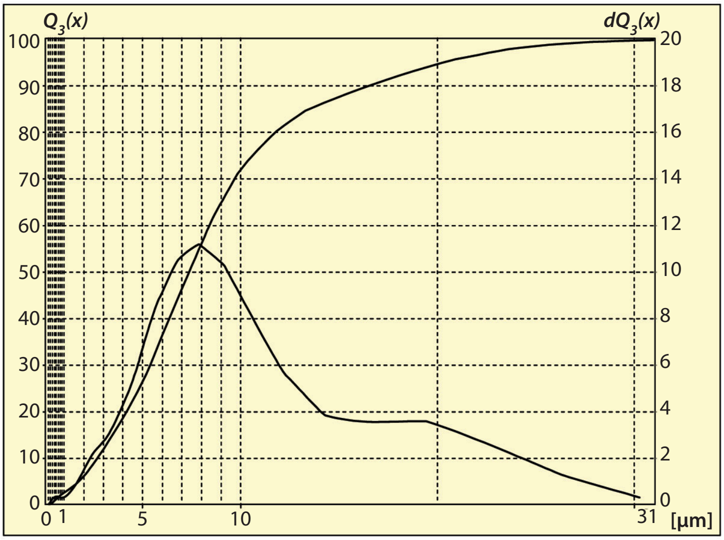

Figure 2.12 Dispersion analysis results of alumina GK-1 after treatment in rotor-wave mill for two minutes.

3

Wave Stirring (actuation) of Multicomponent Materials (dry mixes)

Along with pulverization processes, in present-day manufacturing, are widely applied processes of stirring (actuation) of dry solid components. They find application in construction materials manufacturing technologies, in particular for manufacturing dry construction mixes, as well as in the chemical, food, pharmaceutical and a number of other industries. Growing demands related to the production quality require, in particular, an improved quality of dry component stirring (actuation). A special interest currently causes the stirring (actuation) of super-fine systems (which are, with most difficulty, yielding to fine stirring-agitation) in connection with the development of composite materials manufacturing, powder metallurgy and nanotechnologies.

Major drawbacks of traditionally used industrial mixers are long stirring (actuation) time and insufficient stirring (actuation) uniformity, restricted for industrial mixers by the non-uniformity coefficient $V_c > 1.5\%$. The reason is that in real conditions of stirring (actuation) the trends emerge in mixes, which causes particle segregation, and that results in nonuniformity of the final mixes. Particle segregation at stirring (actuation) of grainy mixes occurs under the action of forces, making particle movement between themselves more difficult (friction, electrostatic, intermolecular forces, etc.). For most traditional stirring (actuation) techniques based on revolution of the work chamber or blades, stirring (actuation) occurs within a dense layer of material where the particle displacement between themselves is hindered, which restricts the opportunity for increasing the uniformity extent of mixes they are producing.

The concepts of mixing and activation through application of resonance motion regimes in dust-air media, implemented in wave dry mix mixers-activators, enable shortening the stirring (actuation) time and obtaining mixes with non-uniformity coefficient $V_c < 1.5\%$.

Within the work chamber of wave installations for dry component stirring (actuation) and activation in the dust-air (dust-gas) medium is generated nonlinear wave resonance flow regime. This results in three-dimensional turbulent motion of this medium. The friction between particles in the process of stirring (actuation) is practically nonexistent. Individual particles of the mixed components, being suspended in the carrier dust-air medium, perform intense complex three-dimensional motion along individual trajectories. This counteracts with particle segregation and in a very short time produces practically ideal mixing.

Fundamental issues of stirring (actuation) in multiphase media are studied and described in detail in publications [1–4]. It is shown, in particular, that under certain conditions a dust-air mix may behave as a liquid filled up with gas impurities. For this reason, wave phenomena and effects observed in liquid media may also show up in dust-air media. This was experimentally confirmed.

Small size of equipment, high extent of stirring (actuation) uniformity of finely dispersed components, high productivity, operation in continuous (flow-through) regime – all of these provide for possible high-efficiency application of wave mixers-activators in automated technological trains of manufacturing multicomponent products, in particular, dry construction mixes (Figure 3.1).

The application of wave technologies in dry construction mix manufacturing improves their physicso-mechanical parameters, adhesion to the base, compression strength and bending strength, as well as water-permeability and frost-resistance (Figure 3.2).

The application of wave technologies for the manufacturing of colored decorative and rubbing-over mixes based on white cement and inorganic pigments substantially inceases coloration intensity (Figure 3.4).

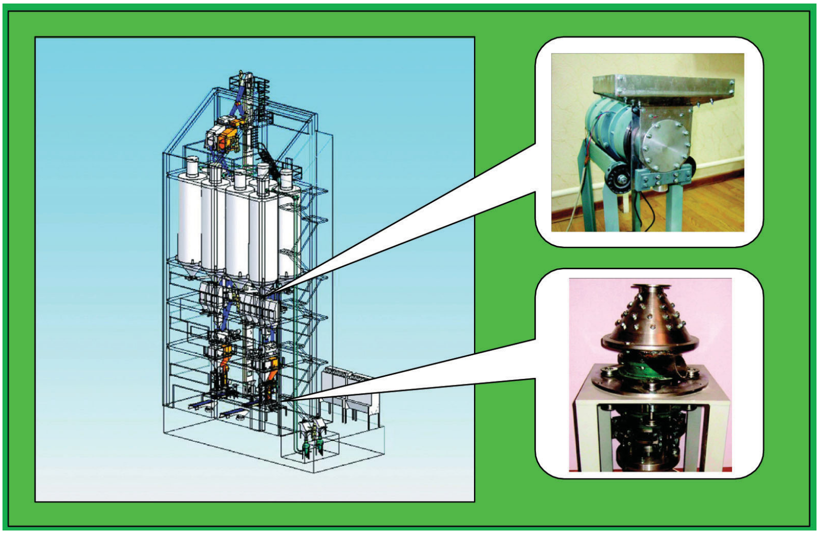

Figure 3.1 Technologic train for manufacturing dry construction mixes with application of wave elements.

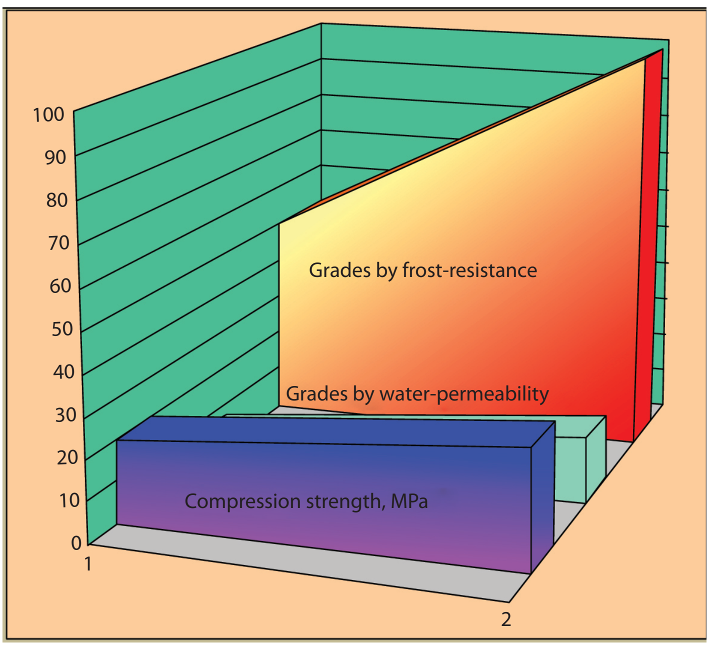

Figure 3.2 Improvement in dry construction mix parameters (experimental results).

Figure 3.3 Dry mix wave mixer-activator.

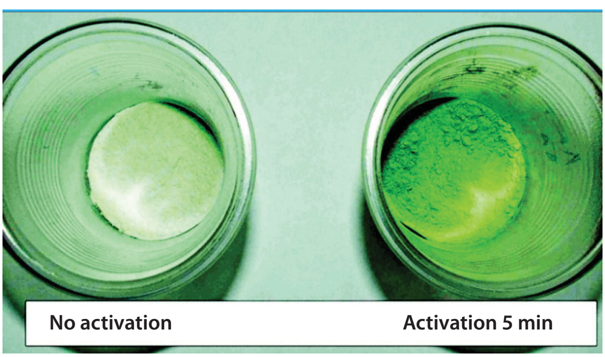

Figure 3.4 Increase in coloration intensity of rubbing-over mixes after wave treatment.

Flow-through wave mixers-activators, as opposed to batch type (intermittent) blade mixers operating in cyclical regime, provide new opportunities in the manufacturing of higher quality construction mixes.

3.1 Technologic Experiments with Installations of Wave Mixing

1. A series of experiments was conducted on wave mixing installation AK-6 (Figure 3.5) concerning wave technology for producing uniform mixes under a running (through-flowing) regime. The model used a mix of the following composition:

    - calcium carbonate (MK-75) -100 parts by weight, with the particle dispersion (size) not exceeding 100 μm;

    - colorant (chromium oxide) –one part by weight, dispersion (size) less than 5μm.

    First, the mix was roughly blended by hand; next, it was processed under the running (through-flowing) regime on the AK-6 installation. Duration of the wave treatment of 1 kg of mix was 50 seconds. After the treatment, the mix color was visually compared with the initial color and color of a reference sample obtained after lengthy hand mixing.

It was found that the sample obtained as a result of wave treatment had much more intense coloration than the reference

Figure 3.5 Installation AK-6 for wave treatment of loose materials.

Figure 3.6 Mixing results: traditional methodology (left-hand) and on wave installation (right-hand). The colorant amount is the same in both samples.

sample, obtained as a result of intense hand stirring (actuation) for 20 minutes.

Analysis of granulometric (grain size) composition of the mix samples (Figures 3.7, 3.8) showed that the content of particle size 100 to 200 μm in mixes after the wave treatment (0.11%) was almost 30 times lower than in compositionally similar mixes after intense hand stirring (actuation) (2.95%).

Results of this experiment show that wave stirring (actuation) gives more uniform distribution of the additive particles in the mass of the basic substance of mixes, substantially decreasing the amount and size of large agglomerates. The outcome is increased total surface of the additive in mixes and more efficient utilization.

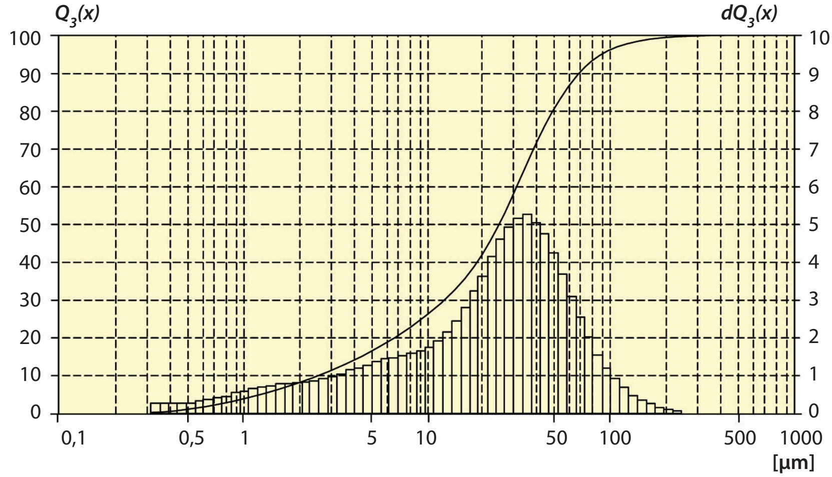

Figure 3.7 Dispersion analysis results of a reference sample: mix of calcium carbonate particles with the colorant (chromium oxide). Hand mixing, 20 minutes.

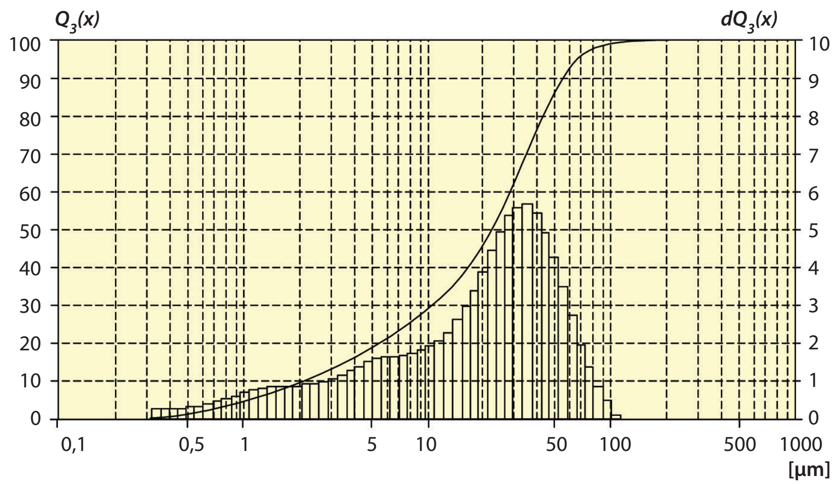

Figure 3.8 Dispersion analysis results of mix of calcium carbonate particles with the colorant (chromium oxide) after wave mixing on the installation AK-6.

2. An experiment was conducted of mixing the active substance (phenazepam) with a ballast (microcrystalline cellulose) under running (through-flowing) regime on the installation AK-6. The amount of active substance was 0.6% of the mass of ballast.

   The traditional-type technologic equipment utilized for this purpose in the pharmaceutical industry cannot provide uniform distribution when the ratio of substances is greater than 1:10. For this reason, the mixing is usually performed by lengthy stirring (actuation) under batch (fractional) regime and sequential dilution in three stages with intermediate unloading.

   Wave mixing was performed in one stage, under running (through-flowing) regime. After the wave treatment, the "Obninsk chemistry-pharmaceutical company" checked the uniformity of the mixes and found that they satisfied the pharmacopoeial norms.

   The above results of technological experiments demonstrate capabilities of upgrading technologies for dry mix preparation by the application of wave stirring devices. It enables the production of high-uniformity mixes of fine powdery components under running (through-flowing) regime with high productivity and low energy usage. Small size of wave mixers for solid components enables creating high-productivity technological trains ín limited manufacturing space, which costs much less money.

4

Wave Metering Devices and Dosage Metering of Loose Components

The quality of produced loose component mixes greatly depends on precision in component dosage metering. Dosage metering of loose materials most often uses various devices operating on the principle of filling up measuring containers or internal volumes of auger devices, which are filled from loading hoppers by way of free flow of the material. However, fluidity mechanisms of the loose phase are different from the liquid flow. Because of air inclusions, the pour density of loose materials is not a constant value. That is why, to assure quality dosage metering, it is necessary to regulate weight of the dose. Besides, a typical property of some granular materials is cleavability, which is the property, under load, of preserving the shape to form strong arches and vertical walls. Therefore, disruption of the uniformity of the material flow drastically complicates the operation of metering devices and often makes them inefficient.

A conceptually new solution — wave metering device of loose components (Figure 4.1) — was designed based on the application of principles and methods of nonlinear wave mechanics and of expertise accumulated at the creation of wave devices. This is a qualitatively new patented solution [9].

The device includes an auger revolving in the body or rotor with dosing cavities. Their fill-up is assured due to the wave action on the dosed loose medium. The wave action is formed by the original electromechanical oscillation generator and a resonance mechanical system. Parameters of the wave actions are controlled by an automatic control system. This assures the fill-up of auger cavities or measuring hollows.

Also, a way was found to control within certain limits the pour density of a dosed loose material by way of changing wave action parameters directly in the process of dosage metering. This, at the introduction of weight control, allows maintaining unchanged weight of the measured doses in the process of work. The system is so designed that the vibration of elements responsible for the wave action on the dosed medium is absolutely not transferred on the support elements.

Various options of the design provide both continuous and discrete supply of the doses of measured material. Also, the design may provide "sparing" action on the dosed material at dosage metering, which is important for dosage metering of fragile products (bulk tea, ground nuts, etc.). A detailed description of wave metering devices may be found in [9]. Figure 4.1 displays one option of the wave metering device.

As a result of such solution, a wave metering device of loose components:

- allows successful counteraction to packing, compacting of the material

Great spare capacity in the level of the wave action on the loose medium assures the formation of a pseudo-liquefied layer and fluidity even for most “difficult” materials;

- assures high precision in dosage metering of loose components in a flow

So high liquidity of the dosed material assures that all measuring pockets of the dosing device totally fill-up, and the capability to control pour density by the regulated wave action allows controlling the weight of each dose;

- enables wide range dosage metering speed control

The combination of assured fill-up of measuring pockets with frequency controlled direct (without gear assembly) operating mechanism and wide range speed control allows controlling the speed of a dosed flow within a wide range;

- is insensitive to overload and foreign bodies in the moving parts of the metering device

Direct (without gear assembly) operating mechanism assures the protection of the metering device parts when the rotor is jammed, for instance, if a foreign object gets into the metering device. Rotating momentum of the gear assembly and the electric current utilized for this purpose remain within acceptable limits. The rotation is resumed immediately after the foreign object is removed. Rotating momentum of the gear assembly is so selected that it is sufficient for dosage metering but far from sufficient for the destruction of metering device parts. As a result, there is no need for complex and unreliable protection and momentum restriction devices.

- has a low noise level:

- produces no vibration of the metering device's structural support

This advantage results from application of wave designing principles. The substance of these principles may be expressed in the organization of resonance motions of the system machine — work medium and attachment fitting of generators and work organs are made at the points where the oscillations are either absent (wave nodes) or not transmitted on the load carrying parts.

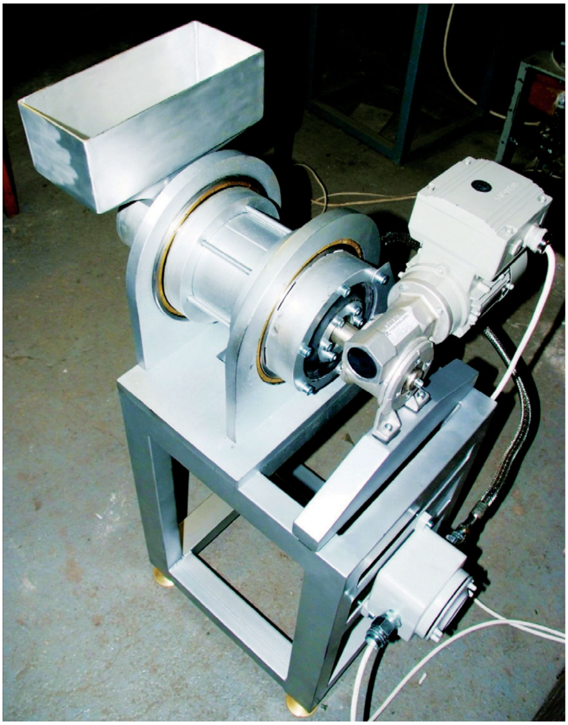

Figure 4.1 Wave portioning device of loose components.

The organization of oscillations are done so that they are at a maximum wherever they are useful and are totally absent where they may be harmful, i.e., they are in principle vibroisolated.

Thus, performing its functions of precise dosage metering for loose materials prone to compacting or packing, the wave metering device assures a non-hazardous and safe work environment for personnel.

5

Creating Automated Wave Treatment Trains of Dry Solid Components: High Efficiency in a Restricted Manufacturing Room

Wave-technology devices are created on the modular principle. This enables building them into the existing technologies for upgrading or making on their basis integrated independent technological trains. An example of a type wave technologic train for manufacturing of dry mixes is shown in Figure 5.1.

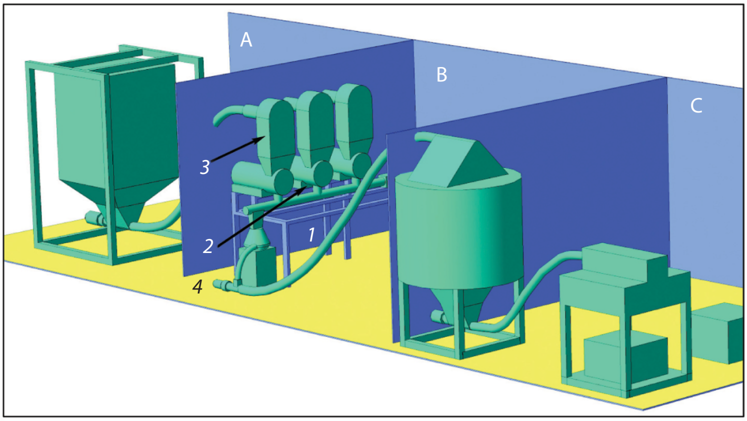

Figure 5.1 Type wave technological train for producing dry mixes.

The Figure shows: A is the section for accepting, storing and preparing the raw material. The system for accepting and storing depends on the raw material delivery method. Shown in this case is an option for raw material supplied in big bags. For unloading, it may be used with commercially produced parts or it can be specially designed for unbagging of components difficult to unload. From the unbagging node, the raw material is transported from the flexible auger into the section of wave treatment. If bolting or classification of raw material is necessary, the appropriate modules are built in additionally. B is the mixing section. There, wave modules of continuous multicomponent dosage metering (1) are installed; they include the summing auger (2) and running (through-flowing) type wave metering device (3) described above. The number of dosage metering blocks depends on the number of components being mixed. The mix components coming from section A are uniformly dosed at the rate assigned by the automatic control system into the gathering auger where their preliminary stirring (actuation) and transport to wave mixing module (4) occurs. There, fine stirring (actuation) of the mix components occurs. The finished mix is transported from the flexible auger into the pre-packing and packing section.

C is the pre-packing and packing section. Finished mixes from section B come into the accumulating holders and from there to the packing machines where they are appropriately dosed and packed in appropriate receptacles. The packed product then goes to storage.

The Figure shows a train for tricomponent wave metering device and wave mixer. Depending on the need, several similar trains may be installed. Automated component supply train switching allows for a rapid change of the product composition.

For manufacturing requiring pulverization or mechanoactivation of components or mixes,

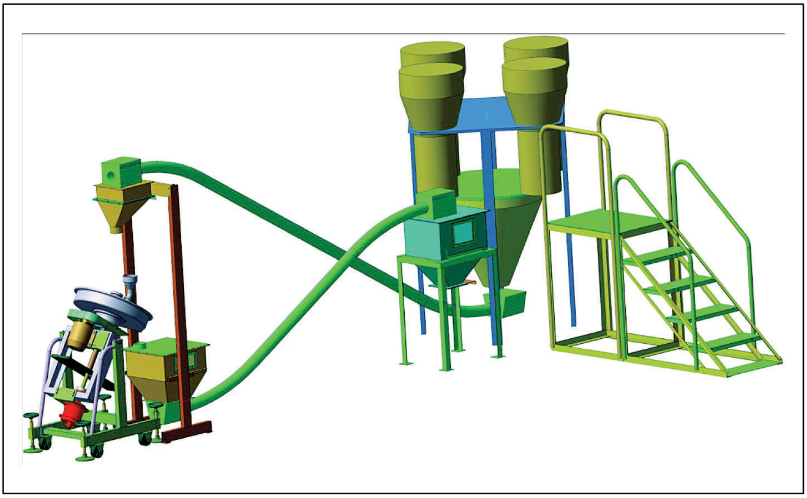

Figure 5.2 Technological train for preparation of dry construction mixes using the node of wave mixing and activation.

instead of wave mixing, node 4 is installed rotor-wave mill of appropriate productivity.

Figure 5.2 shows another option of the mixing and activation of dry components wave train.

Module concept provides for the most complete consideration of particulars of a specific technological process and suggestions of the best solution. The solutions based on wave principles for the running (through-flowing) regimes allow maximum shrinking of manufacturing areas. The equipment by necessity is designed in hermetic (air-tight) option, which eliminates the possibility of dust penetrating the manufacturing room. The advantages of wave machines described above allow for minimizing vibration and noise, thus providing optimum work conditions for personnel. Running (through-flowing) type technologies included in the development of wave technologic machines assure a substantial decrease in the required manufacturing areas compared with technologies of batch (fractional) type stirring (actuation) of similar productivity with simultaneous lowering of labor intensity.

High extent of process automation, low labor intensity and low energy use result in high-efficiency manufacturing.

Advantages from the application of wave mixers and mixers-activators in the manufacturing of mixes based on loose materials, only in manufacturing of dry construction mixes, enable an increase in efficiency of manufacturing technologic trains of up to 50% (due to the decline of stirring/agitation time and improved uniformity of multicomponent products). The total amount of manufacturing dry mixes in Russia as of December 31, 2010 was 6 MMT of finished product. Thus, using wave mixers/activators would increase the manufacturing of dry construction mixes to 9 MMT without allocating additional manufacturing capacities.

The application of wave mixers/activators in the cement industry would result in substantial quality improvement of various types of cement on account of improved uniformity and activation of cements with mineral additives, and it would provide consistency of construction-technological properties in no-additive and oil-well cements. In the manufacturing of cements with mineral additives, on account of a high rate of mixing and productivity, a production increase by 30–40% is possible. For Russia, it would be additionally about 10 MMT of cement per year. This additional amount practically completely covers the demand of the construction discipline in cement and does not require the construction of new cement factories. At that, expenses for the upgrading of existing manufacturing are lower by more than one order of magnitude than for the construction of new manufacturing capacities.

6

Manufacturing and Wave Treatment Technologies of Emulsions, Suspensions and Foam/Skim

Mostly, the action of existing modern devices for generating emulsions, suspensions and foam/skim is based on molecular diffusion and additional transfer of energy to the work medium using mechanical, barbotage, airlift, circulation, jet, pulsating-jet, electromagnetic or magnetic-whirl methods.

Most of these methods are well studied; the efficiency of their application has reached its maximum.

The application of nonlinear wave motion regimes opens new possibilities for making high-quality uniform emulsions, suspensions and foam/skim of high consistency and fine dispersion.

The action of these machines is based on additional energy transfer to the work medium by way of creating nonlinear wave flow regimes using nonlinear wave phenomena and effects (including conditions of nonlinear resonance). This is a conceptually new approach and may be implemented as an independent method or in combination with the known methods. At that, for instance, is excluded a need for high rotation speed of blade actuators. Stirring (actuation) is performed by the forces of wave nature.

Another important advantage of wave technologies is a capability to control the processes of gas phase retention in the liquid medium. This not only increases product consistency but also, depending on technologic requirements, provides for maintaining the content of the gas component at the assigned level. Results of test experimental-industrial exploitation show that the application of wave devices in the technological train of manufacturing paint compositions substantially, by a factor of up to 15, lowered energy usage at consumer product manufacturing without degrading the quality. Also, it substantially simplified the technologic process of manufacturing and broadened the application domain of the technological train — the same train may be used for manufacturing putties, paints and glues.

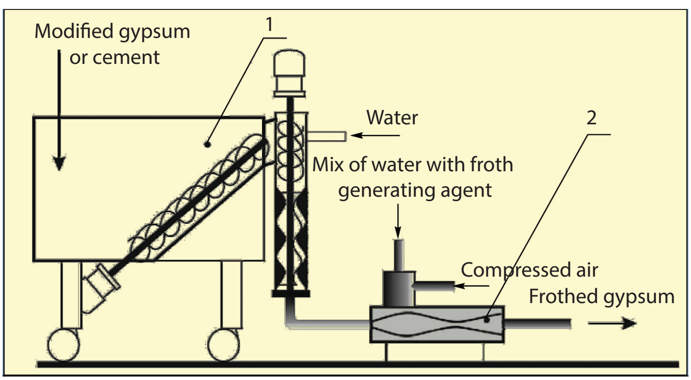

Figure 6.1 Wave technological complex for manufacturing of foam/skim composite materials. 1 plaster station; 2 wave disperser.

6.1 Stirring (actuation) Wave Technologies of Various Liquids, Including High-viscosity Media

Various types of blade mixers are usually used in the manufacturing processes of stirring (actuation) of liquids low or medium in viscosity and not requiring high dispersion and uniformity of mixes. . Higher dispersion and homogeneity in mixes, as a rule, is achieved in two stages. In the first stage, preliminary stirring (actuation) is performed with blade actuators. In the second stage, homogenization of emulsions and suspensions is accomplished by using rotor-pulsating devices, ultrasound action, squeezing emulsions through micro-pores by high-pressure pumps, etc. At that, labour intensity and energy usage increase as do the size, complexity and cost of the equipment.

It is especially difficult to stir high-viscosity liquids with viscosity over 10 Pa*s and non-Newtonian liquids with nonlinear rheologic parameters. For these purposes, most often are used low-rate blade actuators, auger mixers, various combinations of auger mixers and colloidal mills, etc. At lower rate, the stirring (actuation) efficiency declines. To get the acceptable quality, the mix treatment time has to be substantially lengthened. Efficiency of stirring (actuation) is associated with shear deformations occurring when the device is operating. Difficulties of stirring (actuation) in viscous heterogeneous mixes in the devices with a rotating stirring tool are associated not only with high energy usage. To a substantial extent, stirring (actuation) is made difficult by nonuniformity of materials, especially in the first stage of the process, and by nonlinearity of their rheologic parameters. As a result, the shear of material layers occurs on liquid or plastic mass of the lowermost viscosity. The mass under stirring subdivides into more or less large layers and inclusions moving at different rates as intact formations separated by the lubrication of layers with lower viscosity, and in little contact between themselves. The same occurs also in making viscous suspensions from finely dispersed powders. Particle aggregations are coated from outside by a viscous medium and are moving in it as whole inclusions whose destruction by the above methods requires great effort and time.

This scientific-technical problem is urgent, so on the basis of the available theoretical foundation — nonlinear wave mechanics — a complex of theoretical and experimental works was performed. As a result were designed various options of wave technologies of liquid, high-viscosity media treatment, manufacturing and wave of emulsions and suspensions. For this purpose was developed a broad range of hydrodynamic running (through-flowing) wave installations and also a number of technological installations for wave treatment of high-viscosity media. At the foundation of wave-technology, treatment of high-viscosity media is the generation within the medium under treatment of substantial sign-alternative shear stresses created by the combination of shear deformation waves with other wave effects and circulation medium flow.

6.2 Hydrodynamic Running (through-flowing) Wave Installations

The main operating node (driving mechanism) of this wave technology group are hydrodynamic wave generators [1,2,3,4,7]. In liquid media pumped through them, these generators generate whirls, waves and cavitation and complex wave fields. Based on mathematical modeling and large amounts of theoretical and experimental work, numerous oscillation and wave generators were designed for various media and hydrodynamic treatment regimes (Figures 6.2, 6.3).

Depending on the requirements of technologies, the following major operating regimes were implemented with appropriate wave generators:

- mixing and homogenization regime accompanied by whirls, cavitations and waves;
- dispersion and activation regime;
- coagulation and liquid mix separation as well as liquid mix and gas separation regime;
- wave regime of multiple intensifying flow processes.

The experimental installations produced, for instance:

- various finely dispersed (µm to mµ) and high-consistency (months and years) emulsions and suspensions, for instance, lubricating liquids for construction mold boxes; water-oil emulsions for lubricating bread forms in

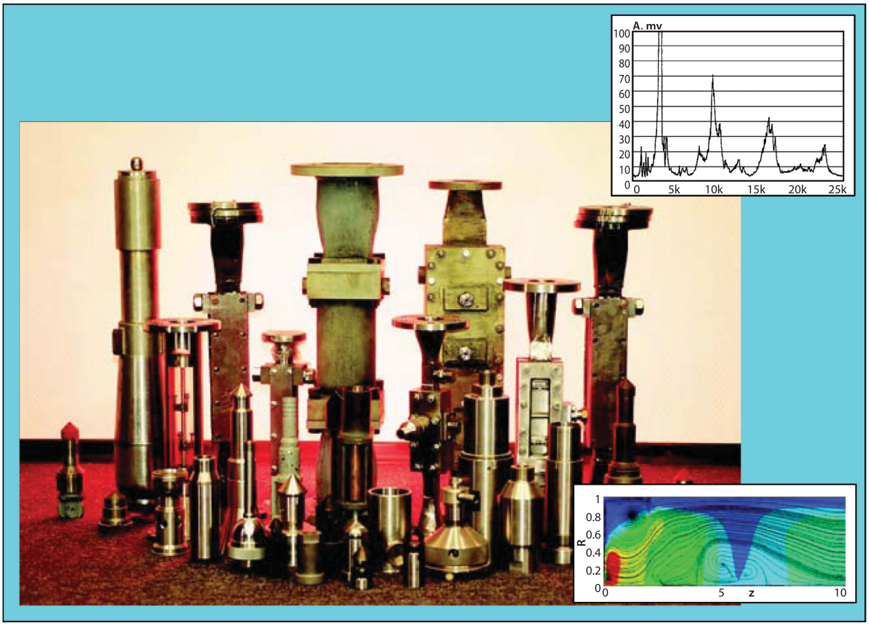

Figure 6.2 Hydrodynamic wave generators.

food industry; lubricating-cooling liquids for machine tools in engineering;

- water heating emulsions (water+diesel fuel, water+residual oil, gas condensate+water), dispersion (size) between μm to 200–300 mμ and other alternative kinds of fuel;
- milk homogenizing to the fat droplet size 1–3 μm at pressure up to 60 atm (which is, substantially, up to 10 times lower than in Alpha-Laval homogenizers), etc.

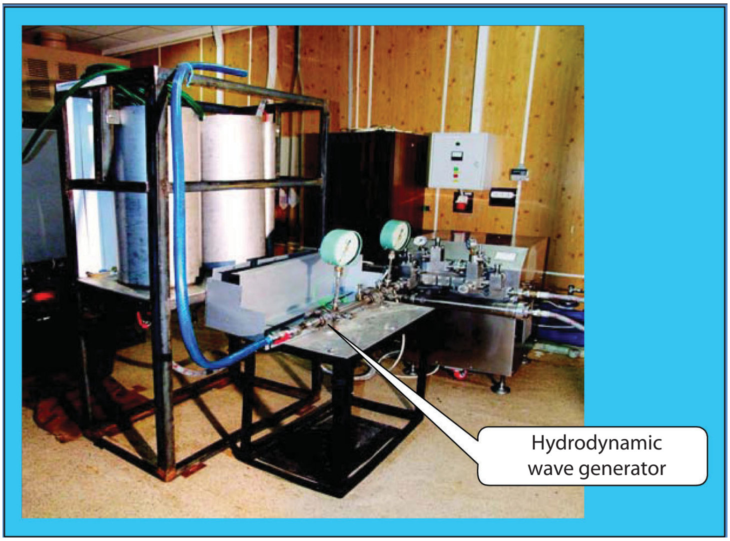

Figure 6.3 Running (through-flowing) hydrodynamic stand for study of processes in wave generators of whirl and cavitation type.

Hydrodynamic installations are distinct in high productivity, relatively simple design and reliability of operation. They may be used in technological trains of high productivity with low energy usage. However, they require serious preliminary mathematical modeling for the determination of stable wave regimes in the appropriate technological processes [3, 4].

6.3 Wave Technology for Stirring (actuation) of High-viscosity Media

Publications [1–4] include theoretical and experimental studies of multiphase liquid flow

Figure 6.4 High-consistency emulsions produced on hydrodynamic wave installations.

under different kinds of wave action. They give examples of technological applications of wave technologies. They also develop major concepts, which must be satisfied by work organs of wave machines for stirring (actuation) of high-viscosity and pseudoplastic liquids, for instance:

- wave action on a high-viscosity liquid flow substantially facilitates and intensifies the mixing processes and improves product quality;
- increase in deformations, in particular shearing, in liquid elements within the entire field of flow results in improved mixing of high-viscosity media;
- creation of instability in one component of velocity or appropriate boundary conditions for the flow of

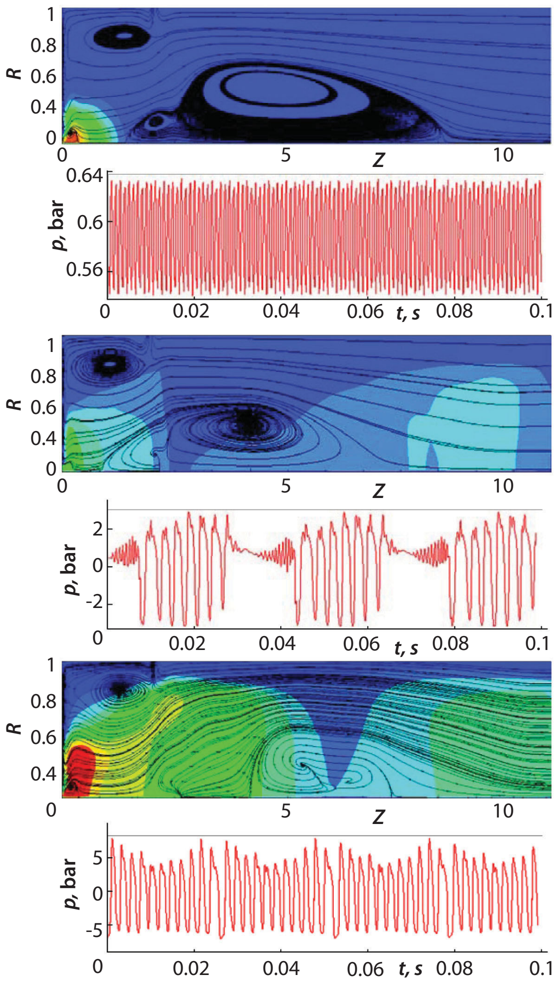

Figure 6.5 Math modeling results of hydrodynamic generator regimes.

pseudoplastic liquids facilitates the transition of "single dimensional" flow to "bidimensional" and "triple-dimensional", and the transition of "bidimensional" and "triple-dimensional" flow.

In view of the stated concepts and results of additional studies, a new option of wave technologies for treatment of high-viscosity media was developed. It is based on a method of creating substantial sign-alternate shear stress through the formation of S-waves of shear deformations in incompressible viscous medium. Oscillations of adjacent layers of liquids in this case display a phase shift, which causes the creation of sign-alternate shear stress in the liquids as well as on the surface of the inclusions, which appeared to be in it. Stresses acting on the surface of these inclusions from viscous liquids are different at different points of the inclusion surface in the oscillation amplitude and phase. It causes varidirectional periodic deformation of the inclusions and their rotation. As a result, it increases the contact area of phase surfaces and their interpenetration, which leads to accelerated separation of parts from inclusions of the dispersion phase and, finally, to substantial intensification of the dispersion process and uniform distribution of additives in viscous media.

For the technological experiments in wave treatment of high-viscosity media, installation VSM-1 (Figure 6.6) was designed and built.

Figure 6.6 Installation for wave mixing VSM-1.

Table 6.1 Emulsion Composition.

No.	Item
Dispersion medium	
1	Purified water
Dispersion phase	
2	Emulsifier EmulgadeSE: glycole stearate, ceteaterh 20, ceteareth 12, cetyi palmitate, cetearyl alcohol.
3	Dicapryl ether
4	ShI oil

6.4 Production of Cosmetic Cream

Cosmetic creams are usually produced by a long stirring (actuation) with anchor-type blade actuators, with additional treatment in dispersers based on a rotor-pulsating device. Wave technology not only accelerates this process (which creates potential for the technology of continuous production) but also adds new quality to emulsions — emulsion of substantially higher dispersion.

The experiment of making direct emulsions (cosmetic face cream) was conducted with the contribution of O.N. Kislogubova. The emulsion composition is a version of cosmetic cream base composition. It is listed in Table 6.1 in descending order of component contents.

The preparation of emulsions was done two ways: either using blade actuator PE-8100 (traditionally) or with installation of wave mixing VMS-1.

The preparation of emulsions using the blade actuator was performed according to traditional technique: the dispersion phase (fat base) was preliminarily melted at a temperature of 80°C and then was, with continuous stirring (actuation), introduced into the water phase heated to 80 °C. The emulsifying was conducted under the following regime: 1,100 rpm for 15 minutes at 80°C, then cooling down at 500 rpm to 40°C for 20 minutes. The total operation took approximately 35 minutes.

The preparation of emulsions under the wave technologies was performed as follows. The VSM-1 installation was filled with preliminarily heated to 80°C water and fat along with melted emulsifier. Emulsifying on the VSM-1 installation was conducted in one stage without a heating system, at lower temperature than in the first case (around 65–70°C). Total preparation time was about 10 minutes.

All emulsion specimens formed stable cream–like structures. The stability of the produced emulsions was tested by treatment on a centrifuge CLN 2 at 6,000 rpm for five minutes. There was no exfoliation of experimental emulsion samples. Microphotographs of the obtained emulsions and of an industrial cosmetic face cream can be seen in Figures 6.7, 6.8, 6.9.

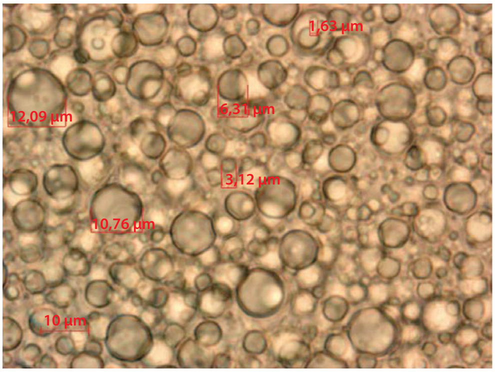

Figure 6.7 Microphotograph of the "night" cosmetic cream by (1,000).

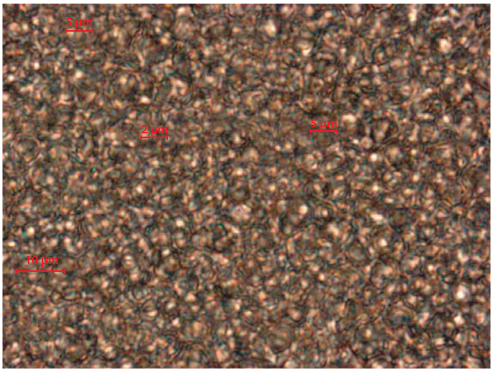

Figure 6.8 Microphotograph of the cosmetic cream made by blade actuator PE-8100 (1,000).

As the Figures show, the emulsion (cream) prepared on installations of wave mixing (Figure 6.9) has by one order of magnitude (10 times and greater) a higher dispersion level than both the traditional mixing method (Figure 6.8) and the industrially produced cosmetic cream (Figure 6.7).

Thus, results of a technologic experiment show that in the preparation of cosmetic cream the application of wave technologies shrank the number of operations, substantially decreased the time of technological process and provided the technologists of cosmetic industry with additional opportunity to get new products with higher (by the order of magnitude and higher) dispersion of the components.

6.6 Production of Finely-dispersed, Chemically Precipitated Barium Sulphate With the Assigned Particle Size

The application of wave technologies in the chemical industry changes the kinetics of chemical reactions, improves catalysts' efficiency and affects the size of synthesized and precipitated particles.

An illustration of one such opportunity is the wave technology of manufacturing finely dispersed chemically precipitated barium sulphate (Ba_2SO_4).

Finely dispersed chemically precipitated barium sulphate is used in chemical, oil production,

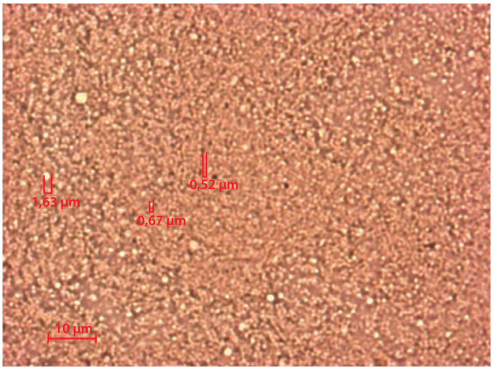

Figure 6.9 Microphotograph of cosmetic cream prepared by wave technology on VSM-1 equipment (1,000).

type-setting industries, medicine, perfumery and cosmetics, and in manufacturing pigments or fillers for paints, glues, drilling muds, paper, caoutchouc products, means of skin treatment, sunscreen creams and also as an X-ray-opaque substance in medicine.

The necessary condition for its application in these products is exceptionally high dispersion. Therefore, special wetting agents and dispersants are used in manufacturing the chemically precipitated barium sulphate. However, even their application doers not result in the required dispersion (size) of barium sulphate. Figure 6.10 shows that when using traditional technologies, only 58.5% of the particles have size less than 2 µm and 11.1% less than 0.5 µm. For this reason,

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0.000 – 0.300 µm =	***	0.300 – 0.500 µm =	11.14%	0.500 – 1.000 µm =	19.63 %
1.000 – 2.000 µm =	27.80%	2.000 – 3.000 µm =	13.47%	3.000 – 4.000 µm =	7.90 %
4.000 – 5.000 µm =	5.12%	5.000 – 10.000 µm =	10.06%	10.000 – 20.000 µm =	3.86 %
20.000 – 30.000 µm =	1.24%	30.000 – 40.000 µm =	0.56%	40.000 – 50.000 µm =	***
50.000 – 60.000 µm =	***	60.000 – 70.000 µm =	***	70.000 – 80.000 µm =	***
80.000 – 90.000 µm =	***	90.000 – 100.000 µm =	***	100.000 – 120.000 µm =	***
120.000 – 150.000 µm =	***	150.000 – 200.000 µm =	***		

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5.0 %	⇐	0.391 µm	10.0 %	⇐	0.497 µm	15.0 %	⇐	0.620 µm
20.0 %	⇐	0.750 µm	25.0 %	⇐	0.878 µm	30.0 %	⇐	1.006 µm
35.0 %	⇐	1.137 µm	40.0 %	⇐	1.282 µm	45.0 %	⇐	1.449 µm
50.0 %	⇐	1.641 µm	55.0 %	⇐	1.864 µm	60.0 %	⇐	2.129 µm
65.0 %	⇐	2.470 µm	70.0 %	⇐	2.895 µm	75.0 %	⇐	3.440 µm
80.0 %	⇐	4.185 µm	85.0 %	⇐	5.230 µm	90.0 %	⇐	6.949 µm
95.0 %	⇐	11.229 µm	99.0 %	⇐	27.179 µm	100.0 %	⇐	44.846 µm

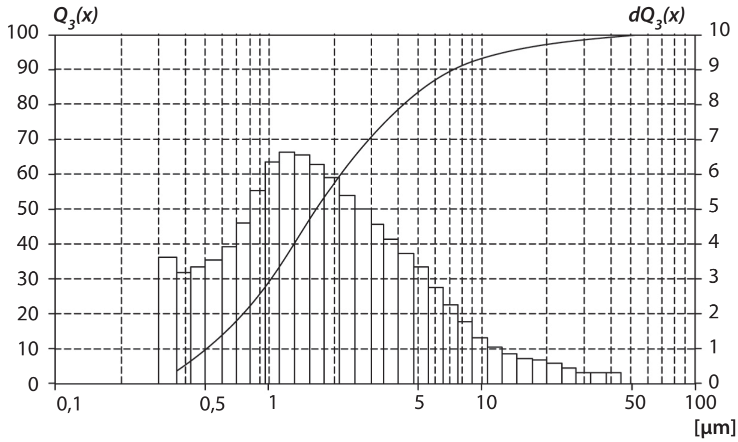

Figure 6.10 Granulometry of chemically precipitated barium sulphate produced by traditional methodology.

the final stage of manufacturing needs an upgrading to achieve the required granulometry.

The objective of the experimental studies was the development of an effective method of manufacturing finely dispersed chemically precipitated sulphate barium, which could be used as additive for cosmetic means or as pigment or filler for paints, glues, drilling muds and caoutchouc objects without using wetting agents, dispersers and additional upgrading.

The stated objective was reached by way of application wave ultrasound to the reaction mix.

Water solutions of $BaCl_2$ and Na_2SO_4 with concentration 0.9 mole/l were mixed in a wave mixer-activator operating under resonance regime. Two regimes were selected to study the effect of different intensity wave treatment, namely Regimes 1 and 2. Treatment duration of the reaction mixes in the mixer-activator was 60 seconds. The suspension produced in the wave mixer-activator was filtered. The separated barium sulphate was washed in water and dried.

Results of granulometry determination in barium sulphate after wave treatment under Regime 1 are shown in Figure 6.11: 97.5% of particles of the finely dispersed chemically precipitated barium sulphate have diameters less than 2 μm. Furthermore, diameters of less than 0.5 μm were found in 24.5 % of particles.

The results of granulometry determination in barium sulphate after wave action under

Regime 2 (Figure 6.12) show that 85% of particles of the finely dispersed chemically precipitated barium sulphate had diameters less than 2 µm, and 12.8% of particles had diameter of less than 0.5 µm.

Experimental studies showed that after wave treatment the amount of particles with a

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0.000 – 0.300 µm =	***	0.300 – 0.500 µm =	24.38 %	0.500 – 1.000 µm =	41.45 %
1.000 – 2.000 µm =	30.60%	2.000 – 3.000 µm =	3.77 %	3.000 – 4.000 µm =	0.58 %
4.000 – 5.000 µm =	0.13%	5.000 – 10.000 µm =	0.07 %	10.000 – 20.000 µm =	0.01 %
20.000 – 30.000 µm =	0.01%	30.000 – 40.000 µm =	0.00 %	40.000 – 50.000 µm =	***
50.000 – 60.000 µm =	***	60.000 – 70.000 µm =	***	70.000 – 80.000 µm =	***
80.000 – 90.000 µm =	***	90.000 – 100.000 µm =	***	100.000 – 120.000 µm =	***
120.000 – 150.000 µm =	***	150.000 – 200.000 µm =	***		

Interpolation Values... C:\Program Files\a22 32\fritsch\10_90.FPV

5.0 %	⇐	*** µm	10.0 %	⇐	0.383 µm	15.0 %	⇐	0.424 µm
20.0 %	⇐	0.469 µm	25.0 %	⇐	0.517 µm	30.0 %	⇐	0.569 µm
35.0 %	⇐	0.625 µm	40.0 %	⇐	0.683 µm	45.0 %	⇐	0.743 µm
50.0 %	⇐	0.803 µm	55.0 %	⇐	0.866 µm	60.0 %	⇐	0.931 µm
65.0 %	⇐	1.003 µm	70.0 %	⇐	1.079 µm	75.0 %	⇐	1.170 µm
80.0 %	⇐	1.275 µm	85.0 %	⇐	1.417 µm	90.0 %	⇐	1.607 µm
95.0 %	⇐	1.995 µm	99.0 %	⇐	2.863 µm	100.0 %	⇐	44.706 µm

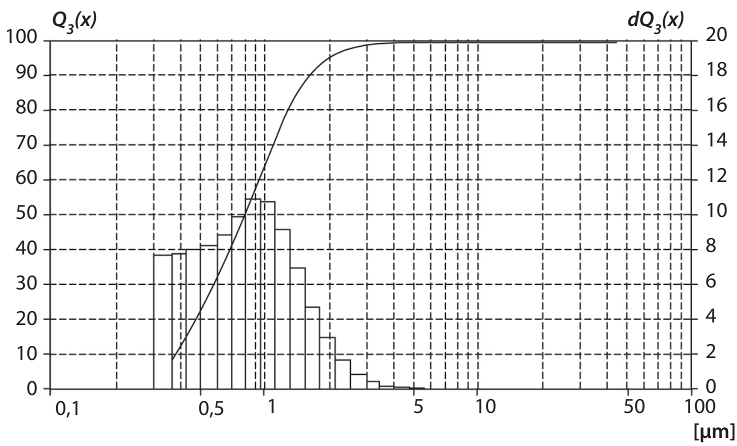


Figure 6.11 Granulometry of chemically precipitated barium sulphate produced by wave technology using Regime 1.

diameter of less than 2 µm in chemically precipitated barium sulphate increased in proportion with the wave action intensity. At that, the greatest increase in the number of particles less than 2 µm is observed in the range 0 – 0.5 µm.

Thus, experiments showed the possibility (in principle) of controlling by wave action

Interpolation Values... C:\Program Files\a22 32\fritsch\HIMNT_1.FPS

0.000 – 0.300 µm =	***	0.300 – 0.500 µm =	12.81 %	0.500 – 1.000 µm =	28.54 %
1.000 – 2.000 µm =	43.50%	2.000 – 3.000 µm =	12.18 %	3.000 – 4.000 µm =	2.84 %
4.000 – 5.000 µm =	0.74%	5.000 – 10.000 µm =	0.38 %	10.000 – 20.000 µm =	0.01 %
20.000 – 30.000 µm =	0.00%	30.000 – 40.000 µm =	0.00 %	40.000 – 50.000 µm =	***
50.000 – 60.000 µm =	***	60.000 – 70.000 µm =	***	70.000 – 80.000 µm =	***
80.000 – 90.000 µm =	***	90.000 – 100.000 µm =	***	100.000 – 120.000 µm =	***
120.000 – 150.000 µm =	***	150.000 – 200.000 µm =	***		

Interpolation Values... C:\Program Files\a22 32\fritsch\10_90.FPV

5.0 %	⇐	0.386 µm	10.0 %	⇐	0.468 µm	15.0 %	⇐	0.561 µm
20.0 %	⇐	0.657 µm	25.0 %	⇐	0.748 µm	30.0 %	⇐	0.834 µm
35.0 %	⇐	0.915 µm	40.0 %	⇐	0.995 µm	45.0 %	⇐	1.073 µm
50.0 %	⇐	1.155 µm	55.0 %	⇐	1.243 µm	60.0 %	⇐	1.333 µm
65.0 %	⇐	1.440 µm	70.0 %	⇐	1.547 µm	75.0 %	⇐	1.690 µm
80.0 %	⇐	1.841 µm	85.0 %	⇐	2.048 µm	90.0 %	⇐	2.339 µm
95.0 %	⇐	2.837 µm	99.0 %	⇐	4.099 µm	100.0 %	⇐	24.429 µm

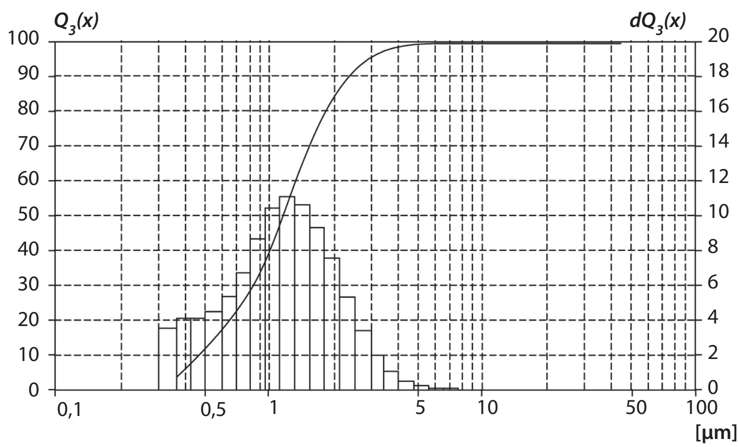


Figure 6.12 Granulometry of chemically precipitated barium sulphate produced by wave technology using Regime 2.

the particle size of substances resulting from chemical reactions. This opens a way to design industrial wave chemical reactors for generating high-dispersion materials with assigned particle size without the application of wetting agents, dispersers and additional classification.

6.7 Accelerating Fermentation of Sponge Wheat Dough After Wave Treatment

A series of experiments was conducted at NC NVMT RAN in wave treatment of sponge wheat dough for improving the fermentation activity and decreasing the timing of its maturation.

Following are the results of two experiments.

Experiment 1.

First, using flour, water and yeast, the pre-dough was mixed according to the following formula:

- Flour – 100 % (dry weight);
- Water – 120% (of the weight of flour);
- Yeast – 1.6% (of the weight of flour).

Mixing was done with a hand mixer for five minutes. Using the same technique and recipe, two portions of the pre-dough (dough sponge) were prepared. One of them (reference) was immediately placed into an oven; the other one was subjected to wave treatment on the installation for 15 minutes. After the wave treatment, the treated pre-dough was also placed into the oven. Temperature in the oven was maintained at 25–28 degrees Celsius. In the process of fermentation, the volume of dough sponge was measured as a function of time. The results are displayed in Figure 6.13.

Experiment 2 (conducted together with experts from the State Research Institute of Chemical Industry GosNN KhP).

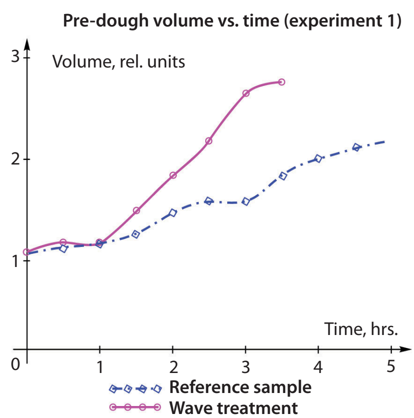


Figure 6.13

From flour, water and yeast, the pre-dough was mixed according to the following formula:

- Flour – 100 % (dry weight);
- Water – 70% (of flour weight);
- Yeast – 1% (of flour weight).

Mixing was done on the laboratory dough-mixing machine for five minutes. Under the same technique and recipe, two portions of dough sponge were made. One of them (reference) was immediately placed in the oven and the other one was subjected to wave treatment on the installation for five minutes. After the wave treatment, the treated pre-dough was also placed into the oven. Temperature in the oven was maintained at 25–28 degrees Celsius. Acidity of the dough sponge versus time was recorded in the process of fermentation.

After maturation of the dough sponge (both subjected to wave treatment and reference), it was used to mix the dough and bake two samples of white bread. Quality of the bread baked from the pre-dough subjected to wave treatment was not inferior even in a single parameter to the quality of the reference sample and totally complied with GOST requirements.

The volume of the dough sponge and acidity versus time in the process of fermentation are displayed in Figures 6.13 and 6.14. They show that the fermentation speed of dough sponge after wave treatment was substantially higher than the reference, and its maturation time was substantially shorter (the doneness of dough sponge is usually evaluated based on acidity; in this case, the pre-dough may be considered done at an acidity of 4.5 degrees).

Quality of the bread baked from the dough mixed from the pre-dough subjected to wave treatment is in no way inferior to the reference samples.

The quoted results demonstrate that the application of wave treatment to the dough, with all other conditions (the dough composition, temperature, humidity, etc.) maintained, accelerates the biochemical reactions in the dough and substantially (approximately two times) reduces time necessary for its maturation. Thus, with the application of a two-stage (pre-dough or dough sponge) technique of making dough, wave

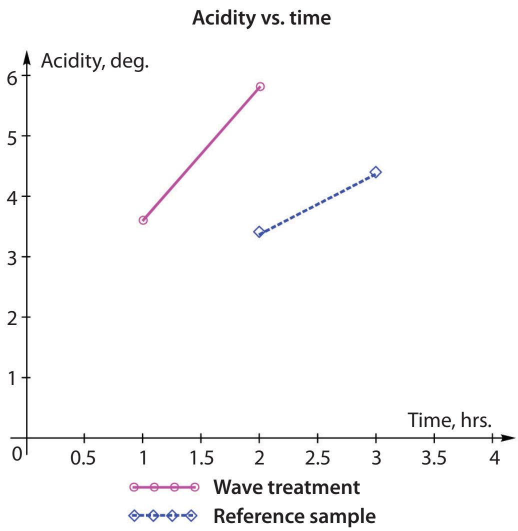


Figure 6.14

treatment of the dough sponge substantially (by 1.5 – 2 hours) shortens the bread-making technological cycle without the application of chemical conditioners.

7

Wave Mixing of Epoxy Resin with Nanocarbon Micro-additives: Production of Composite Materials

Experiments along this trend were conducted jointly with V.V. Vasilyev, a corresponding member of RAN.

One prospective trend in materials' technology is the production of polymer nanocomposite materials combining the best properties of mineral and organic polymers. The capability of nanostructured materials to acquire new properties and unusual parameters is receiving new practical confirmations in recent publications and causing heightened interest in the industry for the creation of new, economically justified techniques in making such materials. Polymer nanocomposite materials are multicomponent materials comprising plastic polymer base (matrix) and filler composed of nanoparticles.

To provide nanocomposite materials with required properties, inorganic nanoparticles (carbon or aluminosilicate tubes, layered silicates, etc.) are introduced in the polymer matrix. The utilization of inorganic nanoparticles in the composition of nanocomposite materials is complicated by their agglomeration and, as a result, poor distribution in the polymer matrix. Thus, the main issue of efficient nanoparticle use in the manufacturing of nanocomposite materials is uniform inorganic particle dispersion in the polymer matrix.

7.1 Experimental Studies of Mixing the Epoxy Resin with Fullerenes

To evaluate the efficiency of using wave technologies for stirring (actuation) the epoxy resin with nanoadditives, comparative experiments were conducted, based on mixes of fullerenes, in mixing with traditionally utilized blade actuator and in the installation of wave mixing VSM-1. The same technologic sequence of introducing components was observed. First, stirring (actuation) of ED-20 and DET-1 resins, preliminarily mixed with hardener TEAT-1, was performed. Then a mix of fullerenes (0.1% by mass) was introduced. Stirring (actuation) was done at a temperature of 68°C. After stirring (actuation), the produced composition mix was used to mold samples in the shape of eights, 6mm thick.

Using a blade mixer PE-8100, stirring (actuation) velocity was varied (150, 200, 250 rpm). The stirring (actuation) time was 40 minutes.

Wave stirring (actuation) on the installation of wave mixing VSM-1 was performed under the resonance regime for high-viscosity media for 25 minutes.

The experiment results are shown in Figure 7.1. The hardened samples (backlighted) of the epoxy resin were: without additives (left-hand), epoxy resin with an additive mix of fullerenes in the amount of 0.1% produced by stirring (actuation) with blade actuator (center), and as a result of wave stirring (actuation) with the same amount of black, varying in size fullerenes (right-hand). The samples prepared using blade actuator are transparent, with black various size granules. This indicates nonuniform stirring (actuation) of fullerenes and their agglomeration within the polymer matrix of composite materials. A similar picture was observed in all samples made under different regimes with the blade actuator. The samples made with wave mixer are

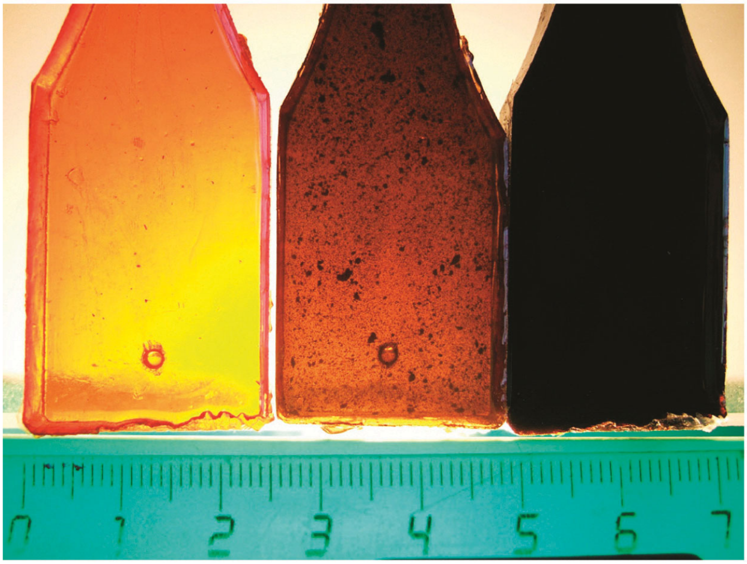


Figure 7.1 Samples of solidified epoxy resin: w/o additive (left-hand), mixed with fullerene mix (0.1 mass%) made with blade mixer (center) and with wave mixing (right-hand).

nontransparent and of a uniform saturated black color without agglomerate inclusions. This indicates uniform fullerene distribution in the entire volume of the polymer matrix.

7.2 Experimental Studies Mixing Epoxy Resin Technical Carbon

This experiment series was the continuation and deepening of wave technology application for producing polymer composition materials and nanocomposite materials. The objective was to evaluate the effect of wave action on the distribution of micro- and nanoadditive particles in the polymer matrix at the micro-level. D.V. Kurmenev contributed to the studies.

For this purpose, a series of experiments was conducted of stirring (actuation) the epoxy resin with micro-additives of the technical carbon. The experiments were conducted on the installation of wave mixing VSM-3, which provides for intense shear stress of both non-periodical and wave action. Comparative experimental studies were conducted both with the wave action and without it when only circulation or drive connection was operational.

Technical carbon is a mix of micro- and nanoparticles of carbon. In this case it is convenient for the observation of stirring (actuation) process dynamics. The properties of a batch of the technical carbon used in the experiment series are listed in Table 7.1.

Treated composition: resin ED-20 and DEG-1 (9:1), technical carbon 1% (mass). Stirring (actuation) of this composition was conducted on installation VSM-3 under two regimes: a regime

Table 7.1 Furnace low-activity technical carbon P803 not granulated (GOST 7885–86)

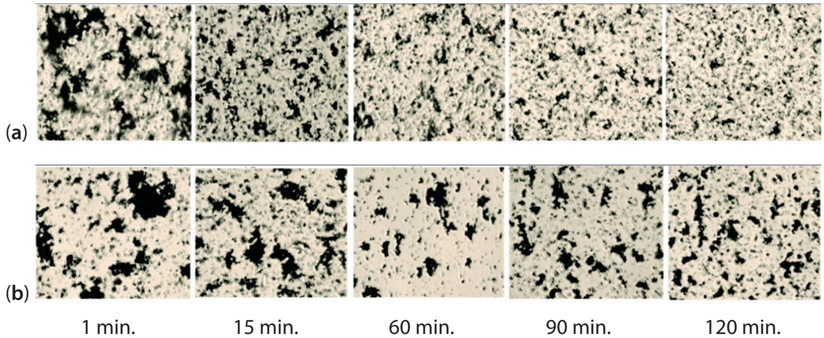
No.	**Parameter**	**Norm under GOST 7885–86 w/changes No.1–4**	**Test result**
1	Per-unit-weight surface, m^2/g	14–18	16.6
2	Dibutilphtalate absorption, $om^3/100$ g.	93±7	86
3	pH of water suspension	7.5–9.5	8.8
4	Mass fraction of loss at 105°C, %	no greater than 0.5	0.15
5	Ash content, %	no greater than 0.20	0.16
6	Mass fraction of residue, %, after sieving through mesh:		
	05K	no greater than 0.001	0.0008
	0045K	no greater than 0.08	0.08

of wave mixing and a reference regime without wave action.

The technique of conducting the experiment was as follows:

A work container was loaded with epoxy composition, mass 100 g, and weighed quantity of the technical carbon (1 g), i.e. 1%. For each regime the treatment was conducted during 120 minutes, and samples for microscopic studies were taken after 1, 15, 30, 60, 90 and 120 minutes. The revolution velocity of the work organ of the circulation drive connection was increased in the process of treatment from 50 to 180 rpm. Wave frequency of the ultrasound was 50 Hz, capacity 80 w. Temperature of the composition in the process of treatment did not exceed 36°C.

The experiments in this series obtained microphotographs (Figures 7.2a and 7.2b) describing change in the distribution of technical carbon particles in the process of stirring (actuation) under wave action and without it. As these photographs show, wave action can (with all other conditions equal) achieve a higher extent of particle deagglomeration and their more uniform distribution in the matrix.



Figures 7.2a and 7.2b Microphotographs of epoxy composition samples with carbon (magnification 1,000x): a) wave mixing; b) mixing w/o wave action.

7.3 Experimental Studies of Mixing Epoxy Resin with Carbon Nanotubes

A series of experiments was conducted of the dispersion in epoxy resin with ultra-low concentrations of carbon nanotubes (UNT) using both ultrasound treatment (UST) and wave technologies (WT). This experimental series was conducted together with IPFH RAN experts under scientific supervision by S.M. Aldoshin and E.R. Badamishina.

The objective of this experimental series was comparison of two dispersion methods of ultra-low UNT concentrations in epoxy resin – UST and BT from the viewpoint of their efficiency and extent of the effect on major physico-mechanical and structural parameters of the solidified resin.

The study used epoxy resin ED-20, hardened ETAL-450 and carboxylated single layer carbon nanotubes (cOSUNT)[1] as a filler. The process compared two dispersion options and UNT introduction into epoxy resin.

Under the first option, the nanotube suspension in dibutylphtalate (DBPH) with the concentration of 1 mg/ml was subjected to UST using the ultrasound generator 10–0.63 at max generator capacity (630 w, middle rod) for 60 minutes. The necessary amount of the dispersion was diluted by DBPH to the needed concentration UNT in the final resin and then added to the epoxy resin. In all experiments the DBPH concentration was 6 mass parts per 100 parts of the resin-hardener mix. The obtained mix was stirred in the velocity micro-mixer with simultaneous vacuuming during one hour at temperature 60^{o}C for the removal of volatile component admixtures and dissolved gases. The calculated amount of hardener (27 g per 100 g of resin) was introduced into

[1] Carboxylated nanotubes were synthesized on a small enterprise "Carbon ChG" http://www.carbonchg.ru).

the degassed mass and stirred for three minutes with simultaneous vacuuming.

Under the second option at dispersion with wave technology, to the epoxy resin was introduced a suspension of carbon nanotubes in DBPH, which had been preliminarily treated with ultrasound for 10 minutes; and then the mix was subjected to the wave action for 60 minutes on the installation of wave mixing VSM-2. To this mix with stirring (actuation) was introduced the calculated amount of hardener and additionally subjected to wave action for 10 minutes.

The experimental technique of wave dispersion UNT in the epoxy resin is similar for each sample. Table 7.2 shows the course of the experiment for a case with nanofiller concentration of 0.002%.

Figure 7.3 is a micro-photograph of the mixes sample after wave treatment for concentration of nanotubes $2{\cdot}10^{-3}\%$ (for other modifier concentrations micro-photographs look similar).

The micro-photograph shows only insubstantial quantity of inclusions, which are agglomerates of carbon nanotubes. Obviously, the remaining

Table 7.2 Wave dispersion experiment

Comments	*t*, min.	Parameters of circulation gear box		Parameters of wave box			T, °C
		n, rpm	W_{circ}, w	*f*, htz	W_w, w	A, mm	
Loading resin in reactor, start	-	56	20	57.2	120	4,5	24
Collecting sample No.1	20	50	18	56.0	98	5	41
Collecting sample No.2	20	50	18	58.2	100	5	42
Collecting sample No.3, stopping treatment	20	50	15	58.2	80	5	42
Loading solidifier, start	10	65	20	54.9	130	5	44
End treatment	-						45

n - circulation drive connection rotor revolution velocity, W_{circ} – active capacity of the circulation drive connection, *f*- frequency of wave action, W_w - active capacity of wave drive connection, A – amplitude of shear waves at the formation boundary.

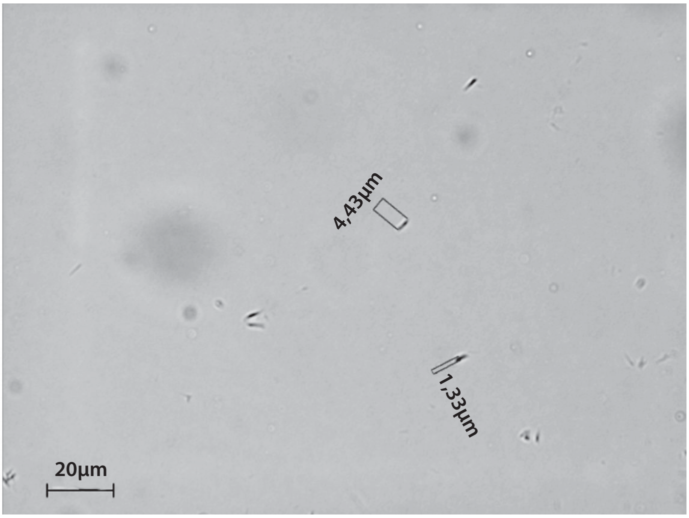


Figure 7.3 Microphotograph of UNT (UNT) suspension sample in epoxy resin after wave treatment.

inclusions are not visible due to their small size (they are beyond the optical range resolution).

In both cases the reaction mass was filled into the forms with separable dumbbells (for mechanical testing) and solidified at 160°C during six hours and annealing at 80°C (10–12 hours). Samples of the solidified epoxy resin not containing UNT were prepared and treated similarly (at the same DBPH concentration).

Mechanical testing of the obtained solidified polyepoxy (OPE) samples modified with carbon nanotubes showed that both dispersion methods within the data scatter give practically identical correlations of rupture strength and deformation and the elasticity module versus the nanotube concentration.

However, as was previously discovered, in the process of storage of both unmodified OPE and OPE modified using ultrasound, their structure parameters substantially change: M_c increases several-fold, and T_g decreases by 20–30°C, especially at high nanotube concentration.

At that, as Figures 7.4 and 7.5 show, in case of carbon nanotube introduction using wave technologies, the change in these parameters in storage is substantially lower, especially at high modifier concentration. In their absence, T_g of a polymer treated under wave technologies at storing even increases by 10°C. That is, samples treated with wave technologies have parameters more stable in time.

Thus, the comparison of two nanoparticle dispersion techniques in the polymer matrix – ultrasound and wave – enables us to assert with high certainty the prospectivity of the latter technique from a viewpoint of obtaining more stable parameters of the solidified polyepoxides.

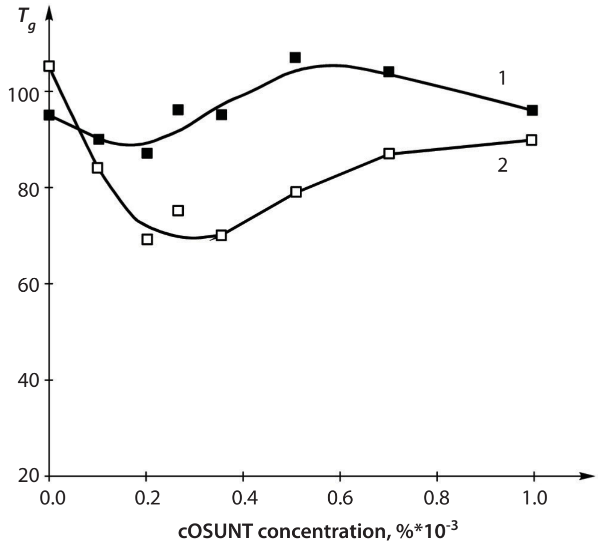


Figure 7.4 Vitrification temperature of modified OPE vs. cOSUNT concentration (cOSUNT is incorporated by wave technology immediately after synthesis (*1*) and after long storage (*2*).

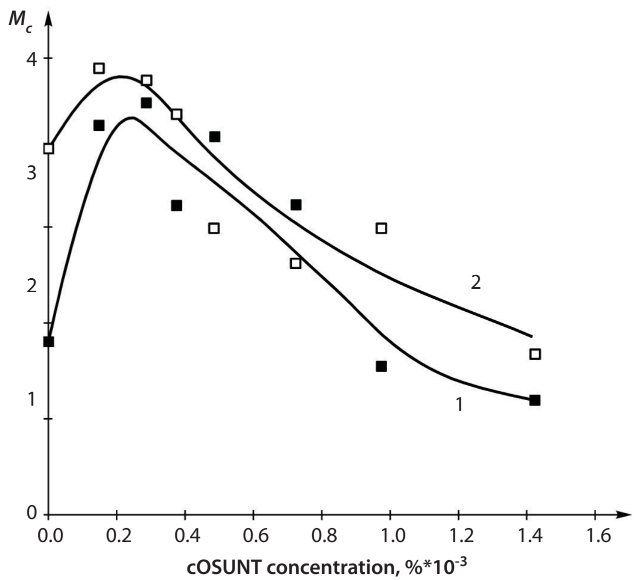


Figure 7.5 M_c OPE vs. cOSUNT concentration introduced under wave technologies, immediately after the synthesis (*1*) and after long storage (*2*).

Besides, wave technology, as opposed to ultrasound treatment, may be applied on a much greater, including industrial, scale and at substantially lower per unit energy usage.

7.4 Production of Highly-filled Composite Materials with Wave Technologies

This series of experiments were conducted to investigate the application of wave technologies in the manufacturing of polymer-inorganic highly-filled composition materials. Such material are quite prospective (for instance, for the creation of refractory constructions) as they have quite high parameters (strength, corrosion resistance and fire-stability). At that, their cost is substantially lower than for metal constructions of similar purpose. However, their manufacturing is difficult due to the complexity of stirring (actuation) of a viscous binder with a great amount of finely dispersed powder filler by traditional methods.

The binder in the study was epoxy composition of resin ED-20 and DEG-1 (9:1). Filler was a mix of Portland-cement (grade M500) and microsilica (83:17). Treatment was performed on the installation of wave mixing VSM-3. Described below is the course of one experiment. Total content of inorganic filler was 84 mass %.

The operating container was loaded with the epoxy composition (mass 200 g) and added hardener TEAT-1 (1:10). Then wave stirring was conducted for 3–5 minutes. In the process of treatment, into the binder was introduced powdered filler in small portions. Frequency of wave ultrasound was 48–52 Hz, capacity 130–200 w, treatment time was 60 minutes. The resulting plastic mass was extracted from the wave reactor, placed in molds of samples for strength testing and subjected to "hot" solidification in a thermocabinet under the following regime: one hour at 100°C, two hours at 120°C, three hours at 140°C and five hours at 150°C.

The resulting samples were studied in the laboratory of the research institute "Construction materials and technologies" at MGSU. Figure 7.6 and Tables 7.3 and 7.4 display the results of strength testing for the samples of highly-filled polymer-inorganic composition materials.

As these data show, the obtained material has high compression strength (120 MPa), whereas

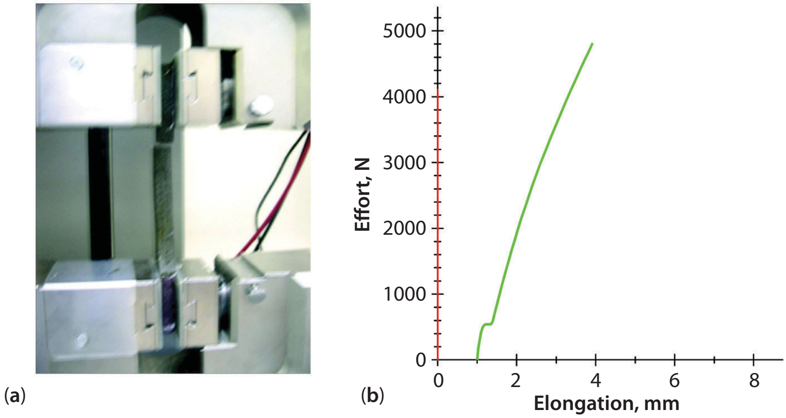


Figure 7.6 Test results of highly-filled composite material samples at extension: a) general appearance of the installation; b) test graph.

Table 7.3 Strength parameters of samples at extention.

Sample	**Sample linear extension**		**Load to failure**	**Strength**
	Width, mm	**Thickness, mm**	**kH**	**H/mm²**
No.1	11.0	13.0	4.16	32.90
No.2	11.0	13.5	4.81	32.46

Table 7.4

Test	Sample linear extension			Load to failure	Strength
	Length	Width	Thickness	kH	MPa
Strength at bending tension	180	11	10	0.573	78.18
Compressive strength	13	11	10	17.2	120.31

the strength of pure epoxy resin is not even possible to measure due to its fluidity under stress.

Thus, wave technologies produced highly-filled composite material based on an epoxy binder with high filling by mineral micro-filler and high compression strength. Besides, due to a high extent of filling with mineral filler, the material has high refractory quality.

Quoted experimental data demonstrate new, mostly unavailable earlier opportunities in the creation of new composition materials and industrial technologies of their manufacturing, which were acquired by materials engineers using wave technologies.

7.5 Using the Installation of Wave Mixing for the Preparation of Polymer-cement and Cement Composite Materials Reinforced by Polymer and Inorganic Fibers

Polymer-cement and cement dispersion-reinforced composition materials have found wide application in industrial and civil construction. Composite materials of this kind include two major components, reinforcing fiber and binder from polymer-cement or cement (Portland-cement, gypsum, magnesia binder). Thin high-strength fiber provides for strength and rigidity of composite materials, whereas the binder takes care of the joint work of fibers, insulates them from external actions and assumes shear and compressing efforts at operating under stress. The per unit volume strength of construction dispersion-reinforced composite materials is 1.5 times higher than some steel, 4 times higher than concrete, and its density is 1.5 times lower than the density of aluminum alloys. The use of dispersion-reinforced composite materials enables lowering the cost of construction elements by a factor of 2–3 and the mass of constructions by a factor of 6–8.

The quality of dispersion-reinforced composite materials is defined by uniformity of fiber distribution in the matrix cross-section. This uniform distribution creates high strength and fracture strength of compositions. However, the application of traditional stirring (actuation) technologies substantially lengthens the manufacturing cycle and often does not provide for uniform fiber and other component distribution in the matrix volume (Figure 7.7).

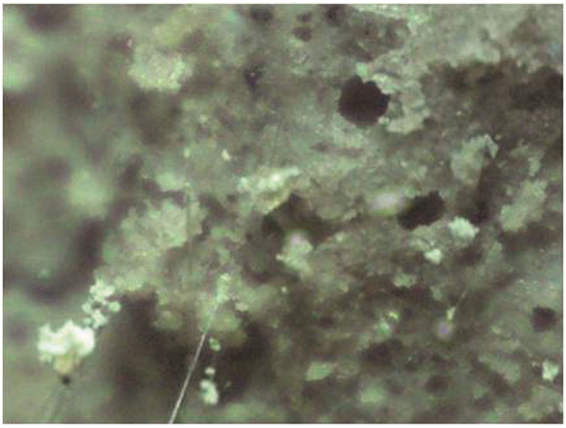


Figure 7.7 Distribution of fibers in polymer-cement solution at traditional mixing method.

The application of wave mixing technologies in this case enables not only lowering the labor intensity and energy intensity of the mixing process, but it also provides for a uniform distribution of fibers in the matrix volume, which in turn provides for high quality of dispersion-reinforced composite materials (Figure 7.8).

Comparative experimental studies were conducted for polymer-cement compositions reinforced polypropylene fiber 5 mm in length and 5 μm thick. Mixing of main samples was conducted in a wave mixer VSM-1 for 3–5 minutes; control samples were prepared using traditional stirring (actuation) technologies in a blade actuator for 20 minutes. The composition of samples

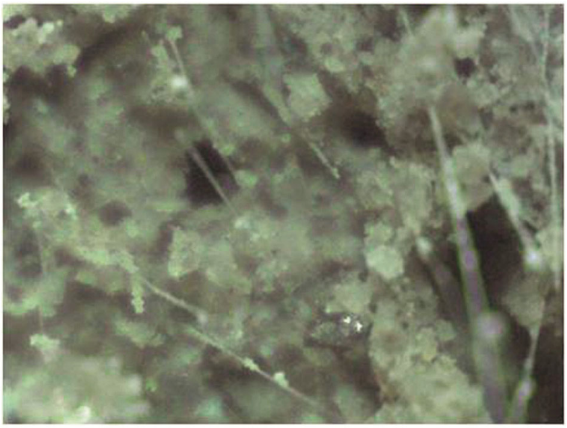


Figure 7.8 Distribution of fibers in polymercement solution at wave mixing method.

and the amount of reinforcing fibers per unit volume were the same in both cases.

Testing results of solidified samples showed that the samples prepared using wave mixer in strength parameters exceed samples prepared under the traditional stirring (actuation) technologies. In particular, it showed an increase in compression strength by 30%, and in tensile strength at bending by 40% (Figure 7.9). Analysis of micro-structure in the main samples (Figure 7.8) indicated uniform distribution of fibers in the volume of polymer-cement matrix in the samples made under the wave technologies. Whereas in comparison, the control samples made with blade actuator recorded nonuniform

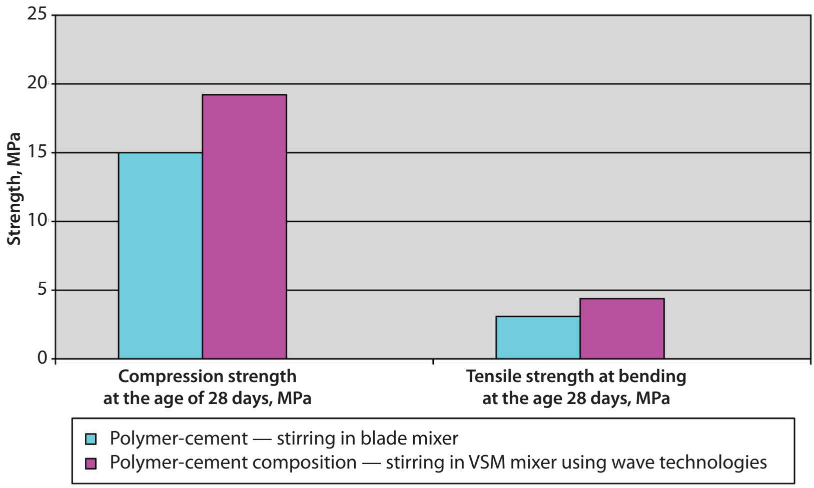


Figure 7.9 Strength increase of cement-polymer composition after wave treatment.

fiber distribution and the presence of voids in the polymer-cement matrix (Figure 7.7).

7.6 Production of Organoclay

The distribution problem of nanoparticles based on montmorillonite may be also solved by modification with organic matter. The modified montmorillonite (organoclay) readily disperses in polymer matrix and forms strong bonds, interacting with the polymer chain.

However, montmorillonite modification with organic polymers is associated with the problem of uniform stirring (actuation) of high-viscosity media and uniform invasion of organic substances into montmorillonite interlayer spaces. As a rule, currently used methods are associated either with high energy expense or are very complex. Whereas industrial manufacturing needs technologically and economically feasible methods that allow for application under conditions of industrial manufacturing.

Conducted experimental studies on the VSM-1 installation in montmorillonite modification through polymer dispersion demonstrated the feasibility of polymer dispersion particles uniform distribution within montmorillonite interlayer space. In the process of wave treatment, in the mixer are created powerful shear forces acting on montmorillonite layers and providing for the polymer invasion into the interlayer space while mixing. As modifying polymers, this experiment used copolymers of vinyl acetate, polyimides, poluurethanes and epoxy resins.

The potential of using the derived nanocomposite materials is associated first of all with various kinds of membrane materials with selective diffusion capability to various gasesand refractory coatings, as well as shatterproof, shrinkage-proof and bulletproof nanocomposite materials.

8

Wave Technologies for Food, Including Bread Baking and Confectionary Industries

Technologies of food, including bread-baking and confectionary manufacturing, require a substantial amount of mixing of various components. The degree of mix uniformity and treatment level define the quality of the resulting production. In particular, baked bread quality depends not only on the quality of flour and other components but also, to a substantial extent, on the dough quality and preparation technique.

An example may be quoted from the manufacturing of flat wafers. Their cost and consumer properties (aeriality, crunchy break, etc.) depend on the dough preparation techniques. The wafer sheet dough is mostly flour and water (other additives are used in small amounts).

To provide high quality wafer sheets, the dough must spread well in the form, i.e., it must be sufficiently fluid, homogenous, without clots. On the other hand, the added water almost totally evaporates in the baking process. Thus, its amount in the dough defines the energy demand for the baking process. During mixing, the dough undergoesprocesses of dissolution and swelling of floury substances. Increasing the length of mixing may result in exceeding flour swelling, which will impair dough spreading, wafer sheet quality, and will require additional water. Thus, achieving high quality in combination with high process efficiency in this case requires the maximum possible stirring (actuation) intensity.

Due to unique capabilities of the described wave technologies, wave mixers-activators in this case enable not only the intensification of the stirring (actuation) process but also make the dough-preparation process continuous (flow-through).

This process eliminates the need for large service containers and shrinks time between dough mixing and baking, which increases quality consistency and decreases manufacturing waste. The function schematics of the wave line for continuous preparation of the wafer dough is shown in Figure 8.1.

Wave technologies also open new prospects in the preparation of dry mixes for manufacturing function nutrition products (products for healthy

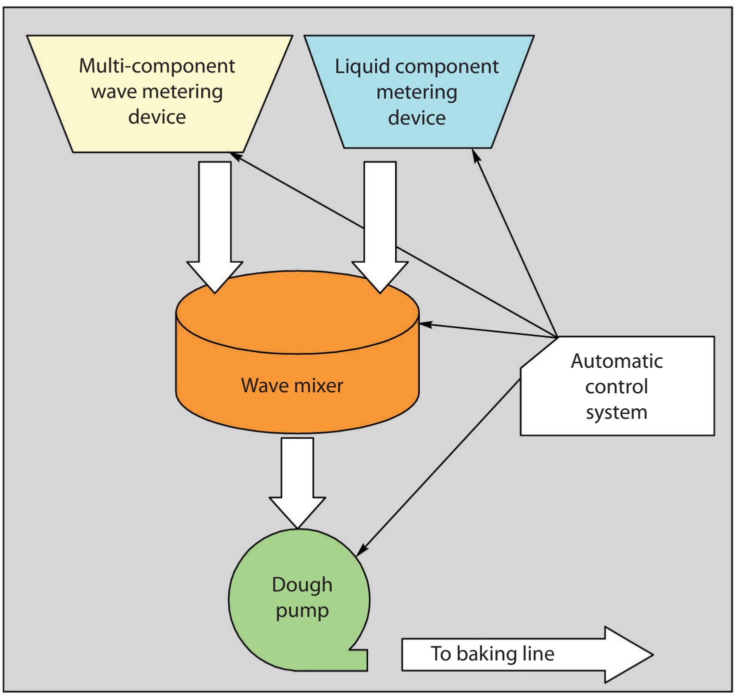


Figure 8.1 Functional schematics of continuous dough preparation automated wave line for baking flat wafers.

life and dietary). The gist of the problem is in that the dough composition must be enriched with useful micro-additives that must be uniformly distributed in volume. Due to the shortage of necessary high-efficiency equipment and technologies, these mixes are currently mostly imported. Wave mixers – activators are capable of solving this problem at a new qualitative level directly in conditions of a bread baking enterprise.

Application of wave technologies under certain conditions enables more efficient control of biochemical reaction velocity, which was illustrated above by experimental data of accelerating the maturation of wheat dough sponge, which is directly associated with economic parameters. In particular, for bread baking industry (where the fermentation and dough maturation time is usually over half of the total technological process time), accelerating the dough maturation process enables substantial saving of manufacturing space by shrinking time of the manufacturing cycle, which eventually results in lower production cost. In many cases, a decrease of the manufacturing cycle duration allows bread factories to convert to a single- or double-shift work schedule, i.e., get rid of the night shift, which improves working conditions.

Application in the process of dough-preparation of thinly-dispersed emulsions and suspensions obtained with wave technologies also broadens the opportunities for manufacturing of function nutrition products. This process enables uniform distribution in the volume of bread sponge of micro-additives (vitamins and other micronutrients increasing bread nutrition value) added to the liquid phase used in the dough preparation process.

The quoted examples do not exhaust opportunities of the wave technologies application in food manufacturing. The reason is that, in this sphere of manufacturing, a large place belongs to the processes of dosage metering, transport, stirring (actuation), dispersion and homogenizing both solid loose components and liquid, paste type emulsions and suspensions. For this reason practically all described options of wave technologies and machines may be utilized in food industries accounting for specific technologies. Creation of modular type aggregates allows for the most complete utilization of possible combinations of different versions of wave technologies between themselves and with other technologies. High productivity, together with low energy and labor expenses, provides the possibility to

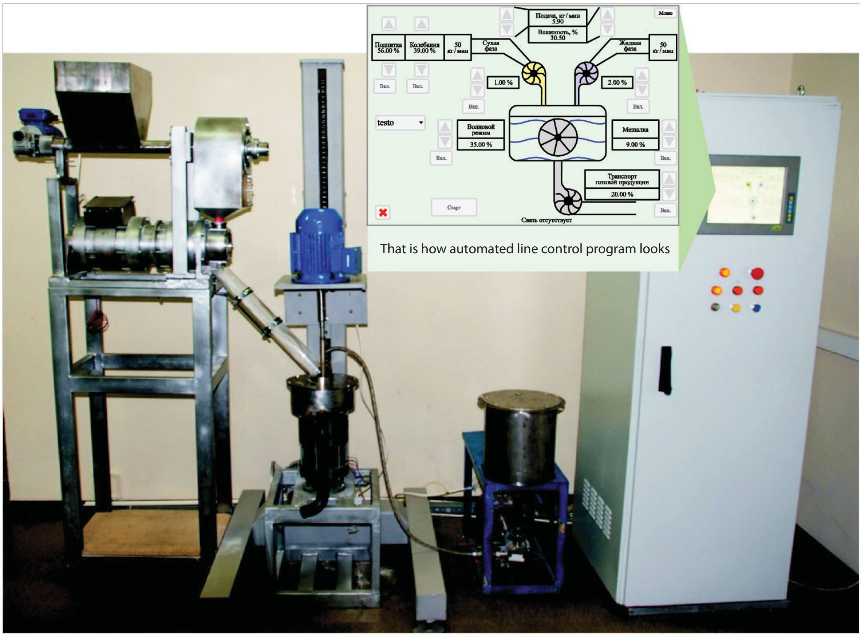


Figure 8.2 Experimental automatic train for making suspensions using wave dosing modules of loose components and wave mixing of liquid and viscous compositions.

create technological lines of continuous (flow-through) type, which facilitate saving of manufacturing space and creation of high-efficiency manufacturing complexes based on wave concepts for a broad class of food manufacturing.

9

Wave Technologies in Oil Production: Improving Oil, Gas and Condensate Yield

The application of the discovered wave phenomena and effects for solving issues of the petroleum industry is the foundation of patented qualitatively new high-efficiency technologies. The substance of these effects is transformation of wave and oscillation motions in oil intervals into unidirectional motion of liquids (oil or water) and of solid inclusions (this is only one type of phenomena used for the stimulation of oil production [4,10].

The oil is a viscous liquid saturating rocks (porous medium). To raise oil to the surface, it is necessary to force it to filter through the rock, i.e., to flow through very thin capillaries. Pore size in rocks is small (sometimes just a few micro-meters). In order to force the oil to move, it is necessary to pump water into the reservoirs at high pressure (improving oil yield by water flooding). There are also other methods [10].

Studies have found that waves, acting on porous media, capillaries, are capable of substantially accelerating liquid flow. For instance, a wave in a capillary with a diameter of about 10 μm with amplitude of 1/100 -1/1000 of the diameter (Figure 9.1) is capable of accelerating the liquid flow up to 1,000 times. This effect shows that waves are one of most efficient mechanisms for stimulating liquid flow in capillaries and porous media. There are also other wave mechanisms for oil displacement from reservoirs, such as displacement mechanisms of capillary-retained oils [4,10].

Another method for improving well productivity by wave technologies is to clean the bottomhole zone from solid inclusions (clay particles, drilling mud particles and other contaminants), which obstruct the flow of oil. This action is performed by wave treatment of the bottomhole zone in resonance conditions. The source of wave action are specially developed hydrodynamic oscillation and wave generators of various design, including controlled autonomous or shock-wave devices.

The creation of required wave action in conditions of so-called multi-frequency resonance developed a whole spectrum of special hydrodynamic generators and wave devices [2, 3, 4, 10].

Practical application of wave technologies for treatment of the bottomhole zone resulted in a productivity increase for injection wells on average by 70–80%, and production wells by

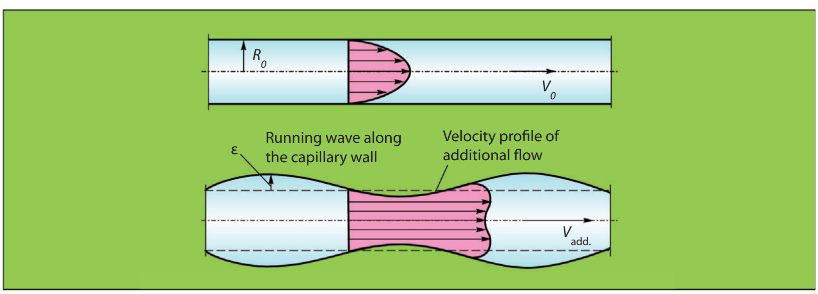


Figure 9.1 Increase in flow velocity in capillary under wave action.

50–60%. In some cases productivity increases 2–5 fold [10,15].

Improvement in reservoir properties of productive intervals in a well bottomhole zone, on account of wave treatment and displacement of the capillary-retained oil in fields under resonance conditions, can stimulate oil production and improve oil yield up to 5–10%.

Mathematic modeling recently enabled the creation of a scientific foundation for nonlinear resonance wave energy pumping into whole oil-saturated intervals (Figure 9.2) for stimulating oil production and improving oil yield [3,4,10,14,15].

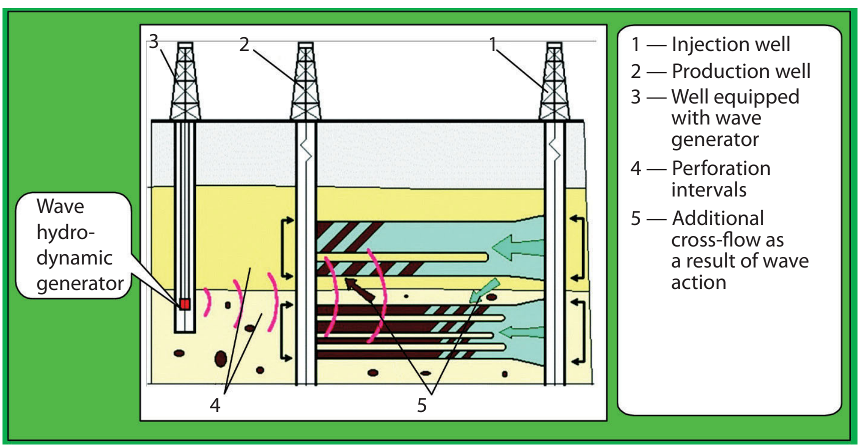


Figure 9.2 Schematics of oil reservoir wave treatment.

It was established that depending on the resonance conditions, the energy absorption by reservoir substantially changes. For each interbed thickness, there is a frequency at which energy absorption is maximized. This frequency depends on the parameters of the porous medium and saturating liquids, and also on various nonuniformities caused by natural properties of fields. The resonance energy pumping in the whole reservoir under conditions of multi-frequency resonance (arrived at in consideration of various nonuniformities of fields), as the theory and practical testing of the method show, facilitates a decrease in its water-saturation and an increase in oil production and oil yield.

This also helps stimulate oil recovery from hard to produce local oil accumulations (like bypassed oil and lenses) inaccessible for traditional technologies [4,14], thereby solving a problem of oil-yield including high-viscosity oil production.

The study of nonlinear wave mechanics led to the development of a conceptual basis of wave technologies for improving gas and condensate yield [4], which is currently being followed up.

Scientific centre (NC NVMT RAN) has the capability of correct well and oil interval selection; its programs are developed for the selection of individual technologies for effective treatment and increased well productivity and oil yield. A host of controlled devices and oscillation generators for treatment of the bottomhole zone and for treatment of entire fields in resonance conditions is currently under development.

Basic trends in application of the wave technologies in oil production are schematically shown in Figure 9.3. The detailed information on this issue is published in [2, 3, 4, 10, 14, 15].

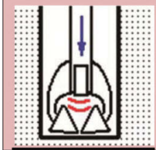
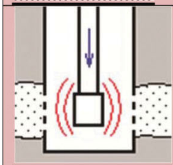
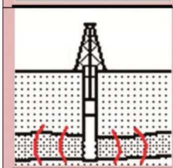
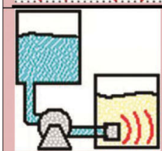
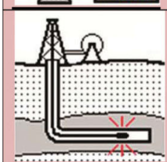
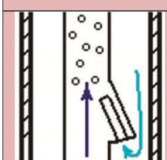
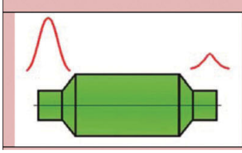
	**Drilling:** - increase in drilling rate; - preventing drilling mud invasion of the reservoir; - colmatage of well walls; - improved well productivity.
	**Wave treatment of wells:** - cleanup of bottom hole zone (including after drilling); - increase inflow rate of production and infectivity of injection wells; - reanimation of depleted wells; - decreasein water content of produced oil.
	**Resonance stimulation of reservoirs (fields):** - improvement of oil yield; - decrease in reservoir water-saturation; - production stimulation in gas-condensate wells.
	**Preparation of drilling mud and cementing slurry:** - improvement in mud quality; - increase in cement plasticity; - increase in strength of set cement.
	**Horizontal well cleanup:** - screen cleanup of the residue of drilling mud; - screen cleanup of various sediment and contamination.
	**Gaslift oil production:** - lower energy use.
	**Improvement in reliability of pipeline system in oil production complex:** - improved vibration resistance; - damping vibration; - damping hydraulic shock.

Figure 9.3 Wave technologies in oil production.

10

Wave Technologies in Ecology and Energetics

Wave technology may be used in the cleanup processes of natural, industrial and household waste water, in chlorinating and ozonation of public water-supply water (wherever the processes of gas dispersion in liquids are applied) and for improving cleanup quality and lowering energy usage for the implementation of these processes. The application of wave technologies in this case substantially increases gas dispersion (size) in liquids (Figure 10.1) with simultaneous lowering of the energy usage for dispersion [2–4]. Compared with barbotage (bubbling), which is traditionally used for the cleanup of waste waters by active ooze for saturating the water with oxygen, the wave technology produces air bubbles 4–10 times smaller in diameter. At that, energy usage for the dispersion of the same gas volume declines by approximately 20%.

Decrease in the size of air bubbles results in a drastic increase of the per unit area contact between water and air. Besides, the velocity of rising small bubbles is substantially lower than large ones, and the contact time of the liquid and gas phases is at its maximum. Thus, the application in barbotage processes of smaller diameter

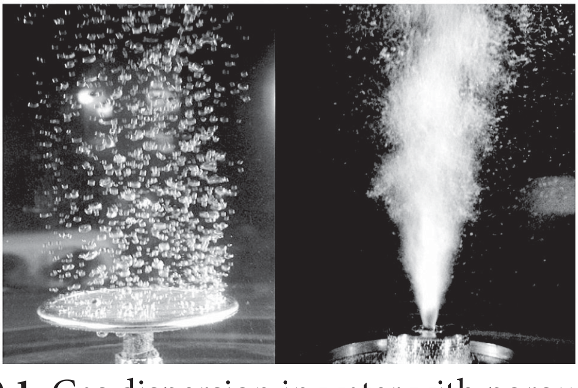


Figure 10.1 Gas dispersion in water with porous disk based on titanium powder (left) and on wave disperser (right) at the same gas usage.

bubbles results in saving gas and, in the final analysis, also substantially lowers energy usage. The gas-in-liquid dispersion systems based on wave technologies may serve as a start for the development of new energy-saving technologies for the cleanup of waste water, chlorinating or ozonation of public water supply. Established effects of gas-in-liquid wave dispersion may also be used for the stimulation of chemical-technological processes based on interaction between liquids and gases, i.e., in dual- and multi-phase media, using wave phenomena of intense stirring (actuation) described above for different devices.

10.1 Production of Mixed Fuels and Improvement in Combustion Efficiency

The application of wave technologies enables the production of high-stability finely dispersed (with water drops of 1–3 μm) water-fuel emulsions: water + residual oil, water + diesel fuel, water + residual oil + coal powder, water + gas-condensate not delaminating during a long time. The application of such emulsions as mixed fuels is of substantial value for boiler rooms, thermal electric stations and other fuel-using enterprises.

The point is that the presence in a fuel emulsion of finely dispersed water phase positively affects the processes of burning liquid fuel. At the water drop size of 1–5 μm, when pulverized fuel drops in boiler burners they boil. This causes disintegration of fuel drops into smaller drops. This in turn facilitates stimulation of stirring (actuation) of the fuel with oxidizer, and that results in a more complete burning of fuel. At that, the usage of residual oil and water steam for its dispersion decreases, and so does atmospheric release of harmful substances. Thus, the application of water-fuel emulsions prepared using wave technologies provides not only for economic effect because of efficiency and complete fuel burning but also for a substantial decrease of harmful substances in the released smoke gas, in particular: nitrogen oxides of up to 40%, sulphur dioxide halved, carcinogenic substances 2–5 times and CO_2 practically to zero [7].

Besides, the application of wave treatment to the boiler fuel eliminates negative consequences of the present crudely dispersed water in various kinds of fuel. These water inclusions are always present, for instance, in furnace residual oil. They get into pipelines and pulverizers, and that in turn disrupts the burning regimes, which

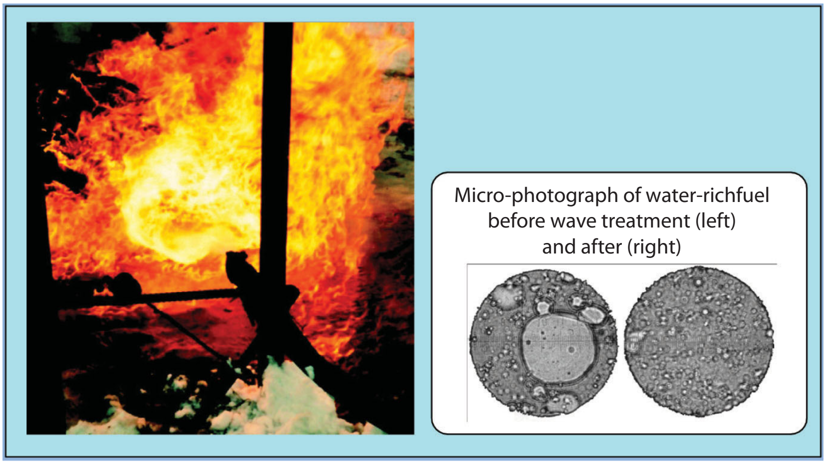


Figure 10.2 Combustion of mixed fuel gas-condensate – water.

deteriorates economic and ecology parameters; in many cases, the breaking off of plumes of flame kill pulverizers.

Drying up residual oil by water evaporation is an energy intensive operation. Besides, it substantially decreases fuel quality on account of the loss of volatile components. Separating residual oil-water phases in settling reservoirs is of low efficiency.

Wave treatment of a residual oil with high water content (Figure 10.2) provides for its stable burning, which decreases the risk of technological emergencies with negative ecological consequences. At that, energy expenses are minimal.

11

Stabilizing Wave Regimes, Damping Noise, Vibration and Hydraulic Shocks Pipeline Systems

Vibration and hydraulic shocks in pipeline systems are the most common causes of breakdowns in pipelines of various functions. Based on results of fundamental studies of wave processes occurring at liquid and gas motion in pipeline systems, concepts of wave stabilization were developed using elastically damping elements providing for high efficiency in damping vibrations and hydraulic shocks, thus assuring

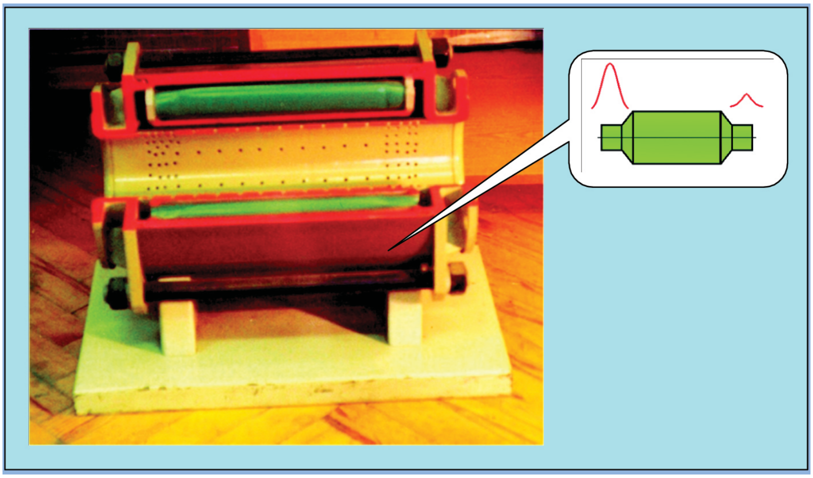


Figure 11.1 Type stabilizer of wave processes in pipelines.

high reliability of exploitation [2–4], [11–12], [14–16].

A new class of devices - wave process stabilizers - was developed (a type of solution is displayed in Figure 11.1) enabling total neutralizing of vibration and hydraulic shock negative action on pipeline structures. Application of the developed wave process stabilizers in pipelines does not cause increased hydrodynamic resistance in the system. As a result, it does not require an increase in capacity of circulation pumps and extends an accident-free term of pipeline exploitation. For instance, the application of wave process stabilizers in the main circulation contour

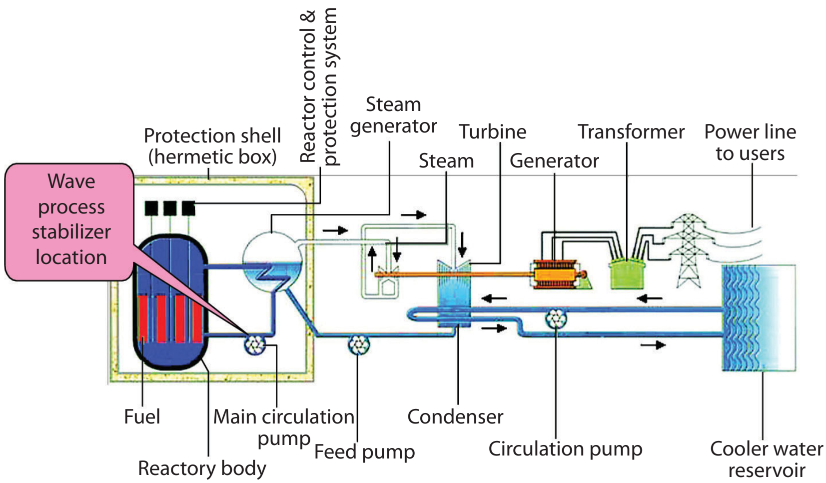


Figure 11.2 Schematics of a nuclear power-generating station.

(Figure 11.2) of the reactor in nuclear power-generating stations can substantially decrease the risk of a major breakdown (disruption of the main circulation circle). This is especially important due to doubling of the normative term at exploitation of operating nuclear power-generating stations.

Testing of a wave process stabilizer in the 500 mm in the trunk oil product pipeline "Kuybyshev – Saratov" on a segment of the Syzran pump station showed a substantial decline in pressure pulsation (by 6.4 Db at frequency 10.75 Hz, and by 28 Db at frequency 9 Hz; Figure 11.3). At that, total pressure pulsation energy in the trunk oil product pipeline decreased by 6.5 Db.

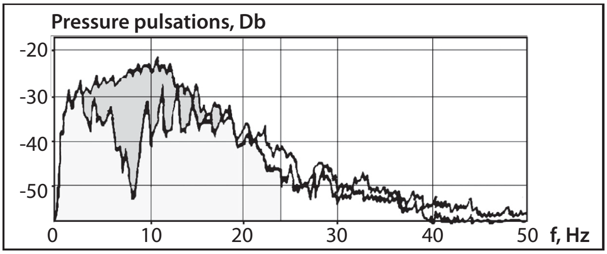


Figure 11.3 Damping pressure pulsation in pipeline in the range of 6–11 Hz.

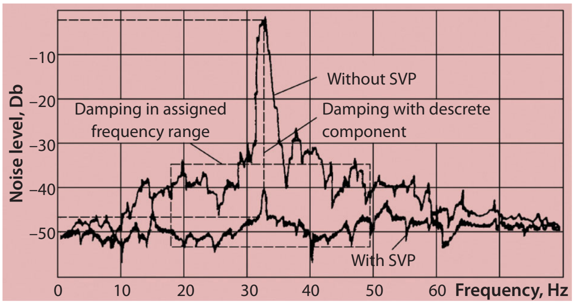


Figure 11.4 Example of wave processes stabilizer efficiency for lowering noise in pipeline.

Experimental studies and estimates indicated that application of wave process stabilizers decreases the noise level in the pipeline systems by 20–40 Db on average (Figure 11.4).

For instance, using the wave process stabilizers for damping exhaust noise in internal combustion engines lowers the noise level in city streets, and using wave process stabilizers in pipelines of industrial enterprises results in the decrease of the noise level at manufacturing.

The opportunity of selective tuning in wave process stabilizers to the wave energy in the assigned frequency range eliminates false response in safety control systems of nuclear and thermal power-generating stations and product pipelines associated with pressure and throughput pulsation in impulse lines of the monitoring sensors. This assures uninterrupted operation of objects.

Compared with foreign equivalents (for instance, "ARKRON-1000" by Growe, USA), the proposed wave process stabilizers, at equal efficiency, have substantially smaller (by a factor of 5 to 10) size and material-capacity. They also do not require additional pump equipment, automation systems and reservoirs. Together with simplifying operation, they improve the efficiency and reliability of domestic stabilizers. Detailed information about wave process stabilizers is found in [2–4], [11, 12, 16]. As publications [14, 16] show, nonlinear resonance mechanics may be prospective for resolution of many current problems in reliability and safety of a number of existing objects, for instance, in helicopters, space technology, hydro-facilities including the destruction causes of Sayan-Shusha hydroelectric power station, etc. See details in [4, 16] with recommendations of the ways to avoid similar breakdown situations.

12

Wave Technologies in Engineering

Three major trends may be identified in the application of wave technologies with regards to the machine-construction discipline.

A first trend includes the following: Studying wave instability and stabilization mechanisms at analysis of dynamics and creation of noiseless and vibro-reliable objects of new technology. Creating new types of drive units. Increasing vibro-reliability and noiselessness of various constructions interacting with liquid and gas (this includes pipeline system of elevated throughput and various purposes). Determining hydraulic facilities destruction mechanisms and developing recommendations for their elimination. Examples of this trend are, in particular, aforementioned wave technologic machines in whose designing and manufacturing were solved the tasks not only of applying wave principles and phenomena in the operating environment but also of eliminating or damping oscillations in bearing structures. The machines have a sufficiently low level of vibration and noise action on the ambient environment.

The experience accumulated in NC NVMT enables the solution of a broader range of tasks in this area. They include designing new machines and equipment. They include analysis and recommendations regarding the operating ones for improving their vibration and noise parameters, their reliability, their technological parameters (including increased vibro-reliability and resource). They include elimination of breakdown situations, for instance, in hydro-facilities such as the Sayan-Shusha hydraulic power generating station. They include the determination of not only nonlinear repetitive resonance mechanisms of their destruction but also the development of practical recommendations for the elimination of such dangerous breakdown situations [14,16].

A second trend is the application of wave and oscillation phenomena for creating and stimulating a number of type processes in machine-construction technologies.

The second trend also includes, for instance:

- manufacturing of high quality lubricating-cooling fluids for metal-cutting machines and, as a consequence, improving efficiency of mechanical treatment, durability of cutting tools;

- efficient regeneration of depleted lubricants;

- efficient cleanup and washing parts of complex shape after mechanical treatment; creation based on them of a new class of washing machines (Figure 12.1);

- cleanup and washing parts of complex shape when conducting repair operations;

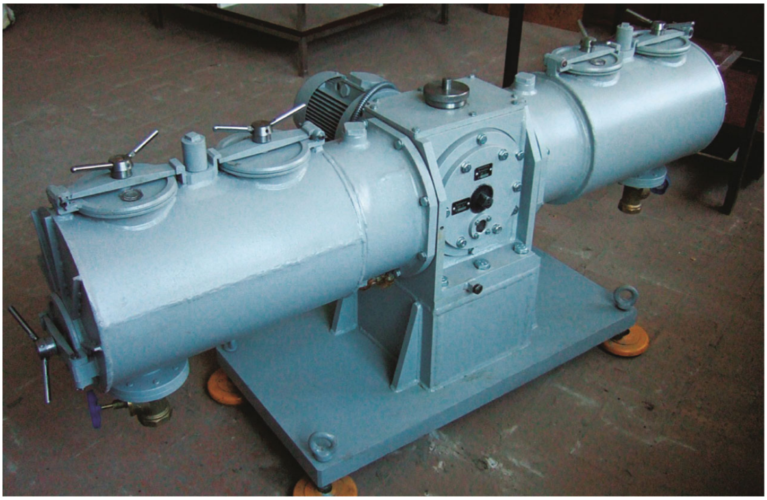


Figure 12.1 Wave device for washing parts of complex shape

- stimulation of the impregnation of porous materials and products based on them;
- stimulation of tempering processes and improving mechanical properties of machine parts;
- solution of ecology problems, waste water cleanup, etc.

These processes do not exhaust the range of wave technologies application in engineering. Potentially, it appears possible to intensify processes of surface cooling at abrasion treatment of parts, to improve quality of metal casting by way of homogenizing the melt prior to crystallization, to intensify processes of manufacturing products made of mineral- and metal-ceramic, etc.

A third trend is the application of wave technologies for creating new construction composition materials and products made of them and also nanocomposite materials and other nano-materials, especially in large technological disciplines. Some results and potential applications of the wave technologies along this trend were described above. More detailed data may be found in [1–4, 15, 16].

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Wave Technologies in Oil Refining, Chemical and Petrochemical Industries

A major distinctive feature of technological processes in petrochemicals and oil refining is using and treating large volumes of liquid media. The objective of most of them is the conduct of heat-mass exchange processes in multiphase and multicomponent systems (catalytic processes, chemical reactions, production of emulsions, suspensions, etc.), mixing and homogenizing, and mixing of high-viscosity media with (micro- and nano-) fillers.

Depending, for instance, on the nature of a technologic process, wave technology enables processing both directly in the stream of multiphase medium and in closed volumes:

Production of high-quality bitumens. The wave technology may be utilized at two stages. The first one is directly in goudron oxidation columns for a purpose of manufacturing bitumen. A counter-flow is created of dropping hot goudron and ascending air flow. Very important is uniform and fine air flow distribution in the entire column volume for a complete contact with goudron. The oxidation process is intensified due to high quality wave dispersion (i.e., a decrease to single mm and micro-meters the size of particles, droplets and bubbles suspended in goudron) in the dual-phase (gas-liquid) medium.

A second stage is the uniform introduction of additives into bitumen (they improve its quality or the preparation of bitumen emulsions). Here as well the wave technology enables high homogeneity of mixes (Figure 13.1) and acceleration of the chemical reaction with lowerenergy

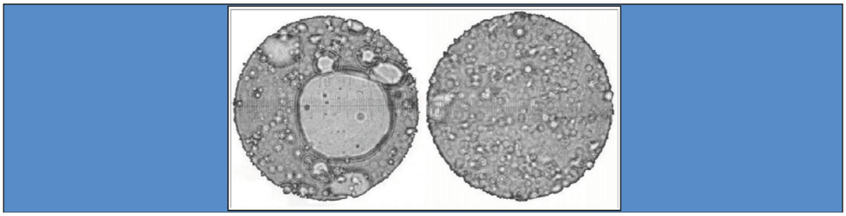

Figure 13.1 Micro-photograph of water-bitumen mix before wave treatment (left) and after (right).

usage, which results in high-quality bitumens. The wave technologies may find application also in many specific processes of oil refining and petrochemical manufacturing, for instance:

- increasing oil refining efficiency, accelerating catalytic processes;
- desalting oil;
- manufacturing high-stability mixed fuels;
- manufacturing market-grade lubricants with uniform and finely dispersed additive distribution;
- manufacturing zeolites and catalyzer carriers;
- manufacturing motor fuels;

- stimulating reactions between liquid and gaseous components;
- manufacturing synthetic detergents and shampoos;
- producing finely dispersed acrylic dispersions, etc.

Details about these and other applications of wave technologies may be found in [1–7, 14,15].

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Conclusions: On Wave Engineering

Initially, wave phenomena and effects, which formed the foundation of wave technologies, were discovered theoretically in the creation of nonlinear wave mechanics. They were further developed in comprehensive theoretical and experimental studies and industrial experiments in a number of industrial disciplines with orientation on specific applications.

Possible technical applications of wave technologies in consideration of disciplinal specifics were tested with specially made facilities and installations and in many cases in industrial conditions.

All of this experience is concentrated in the developed type wave technologies. The implementation of wave technologies needs the development of a complex of automated wave machines, devices, drives and drive connections, and oscillation generators. All of these, together with a control system, form the foundation of the so-called wave engineering covering dozens of industrial disciplines, such as (some are already developed and tested):

- engineering and materials technology (composite materials, nanocomposite materials, etc.);
- energetics and transport;
- petroleum industry (increasing oil and gas production, improving oil, gas and condensate yield, accelerating processes of drilling and making high-quality drilling muds);

- process industries (petrochemicals and oil refining, food industry, etc.);
- construction industry (building materials, dry mixes, activation of cement, highly-filled high-strength composite materials);
- pharmacology and medicine (development of diagnostic equipment, in particular, for diagnostics of the cardiovascular system);
- mining and coal industry (separation of valuable components, production of water-coal fuel, etc.).

For the indicated disciplines, the use of wave technologies assures the solution at a conceptually new level of most common technologic tasks. They include fragmentation and activation, mixing, homogenizing and dosage metering. They include also classification, separation of multiphase media, energy saving drying, polymerisation, filtration and transport, and production of new materials (among them composite materials, nanocomposite materials and highly-filled composite materials).

They also include the production of alternative fuels (in particular, mixed fuels, liquid homogenized water-coal fuels) and many others (some of them are indicated above). It should also be mentioned that nanotechnologies in pulverization and stirring (actuation) in major industries may now be realistically implemented most exactly based on wave technologies. This capability especially concerns processes of uniform stirring (actuation) in high-viscosity media with nano- and micro-fillers. As the quoted results show, machines and devices based on wave concepts are most efficient for the implementation of groundbreaking technologies. Such technologies include, for instance, materials technology for manufacturing nanocomposite materials and highly-filled composite materials based on mixing high-viscosity media with uniform distribution of micro- and nanofillers.

Within this framework, the wave technologies may not have competitors. Currently it is possible to maintain that a complex of controlled automated wave machines and devices such as technological trains provide an opportunity to make a large step in industrial development to reach a new efficiency and energy saving level. The creation and broad implementation of wave engineering will produce tangible economic effects in Russia and will enable the nation's entry into foreign markets. Currently, nonlinear wave mechanics and wave technologies are completely a Russian priority without analogues in the world practice.

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