14th European Conference on Mixing
Warszawa, 10-13 September 2012

NEW CONCEPT OF ENERGY-EFFICIENT AND RESOURCE-SAVING APPARATUSES FOR MIXING AND CONJUGATED PROCESSES

Rufat Abiev

St. Petersburg State Institute of Technology (Technical University),
Department of optimization of chemical and biotechnological equipment,
Moskovskii pr.26, 190013, Russia, Saint-Petersburg

rufat.abiev@gmail.com

Abstract. Principles of new generation of apparatuses allowing developing energy-efficient and resource-saving equipment for chemical production are formulated. The total concept based on seven principles. The practical use of all the principles of this concept is illustrated by the examples for apparatuses on liquid-solid, liquid-liquid, liquid-gas systems. The main idea to minimize power consumption was realized by use of essentially transient movement of processed substance in order to shift the system parameters from the steady state, micro scale reactors, vortical flows.

Keywords: Energy-efficient technology, Resource-saving equipment; Transient processes; Micro scale reactors; Vortical flows.

1. INTRODUCTION

Due to the increased problems of energy and resource saving in recent years worldwide interest in creating of sustainable technology and apparatuses is increased [1].

Methods of improving the characteristics of chemical equipment can be divided into two great classes: 1) optimization of existing apparatuses, facilities and entire production on basis of formal mathematical methods (from meso to mega level [1]), 2) quest the most effective physical effects for the process, including the adaptation of the geometric shape of devices and their components (on micro, meso and nano levels).

Among the variety of forms of physical effects on heterogeneous systems are more or less studied and introduced into industrial practice are powerful shear flows (jets, agitators, rotary machines), the centrifugal fields, ultrasonic waves, electromagnetic waves (including microwaves), pulsations of pressure and velocity. The most progressive are apparently pulsating devices [2], ultrasound apparatuses for the metallurgical and chemical processes [3], vibrating devices [4]. The most rational and consistent idea of using the vibration motion of fluid in the processes (in terms of energy conversion efficiency) implemented in papers of A.A. Dolinskii et al. [5, 6].

In our opinion the most promising types of equipment for energy and resource saving are a new generation pulsating devices, microstructured reactors and devices with vortical flows. In this paper we will focus on devices for heterogeneous systems with a liquid continuous medium.

Since mid-1980-s at the Department of optimization of chemical and biotechnological equipment SPbSTI (TU) as a result of theoretical and experimental studies, design and production tests the basic principles of energy-efficient and resource-saving equipment synthesis are developed.

2. GENERAL PRINCIPLES OF ENERGY-EFFICIENT AND RESOURCE-SAVING APPARATUSES SYNTESIS

2.1 First principle

The first principle proposed by Prof. G.M. Ostrovskii from SPbSTI and is excited by vibrations in the apparatus with a frequency close to the eigenfrequency of the system, i.e., a generation of resonance oscillations [7, 8]. This ensures that the energy introduced into the apparatus spent most effectively, which leads to lower power consumption, taken relative to a unit product obtained.

2.2 Second principle

For the rational use of energy appropriate to the temporal and spatial scale effects on the system "device - a heterogeneous mixture" is to be in coincidence with the geometrical, physical and physicochemical properties of elements of the system at meso, micro and sub-micro levels. For example, for pulsating apparatuses used for mixing of solid (optional porous) particles this principle means:

• On meso level (the device and its components or a layer of particles in the unit) - creation of resonant oscillations in the system [9], the organization of the required level of circulation in the whole device (in batch mode), or the alignment of the fields of temperature and concentration of the cross section of the apparatus (in the units positive displacement type).

• On micro level (particles, droplets, bubbles). In the case of processing of deformable particles (drops or bubbles), it is desirable that energy supplied to the interface leads to a sufficient internal mixing, the breakage of large drops and bubbles, including those due to resonant oscillations [10]. When handling solids the timescale has to be agreed with the relaxation time of solid particles in its acceleration/deceleration, and the input energy should be sufficient intensive to supply/drain substance to/from the particles surface.

• On sub-micro level (micro-pores in the particles). The duration and intensity of exposure must be consistent with the length of the microchannels, dimensions of porous material structure and properties of the liquid [11-13].

2.3 Third principle

Transformation of energy introduced into the apparatus from the power source must be very close to the area where it should be used, i.e., where the useful work should be performed.

From the second law of thermodynamics follows that the most efficient way to transform this energy into the apparatus with a heterogeneous system, which leads to the smallest increase in entropy, and hence the temperature, i.e., when the consumed work is minimal for a given useful effect.

With regard to the processing of heterogeneous media, where transport processes occur through the interfacial area, the mechanical (and in some cases internal) energy in the ideal case, it must transform itself near the surface of dispersed phases.

In devices, where the interfacial area is formed on the surface of the solid walls (heat exchangers, evaporators, film, packed devices), energy conversion should occur near the surface of the walls. An example of the implementation of such a device is a piezoelectric film camera with the excitation of flowing film vibrations [14].

2.4 Fourth principle

The uniform distribution of external factors on the heterogeneous system results in the uniformity of the output parameters - temperature, concentration of substances.

This refers to the uniform distribution not the entire volume of the apparatus, but means more or less uniform supply of external factors on all particles (or averaged over several periods of oscillation) and equal access of external impact to their surface.

Lack of uniformity of distribution of energy input into the apparatus, and the particle volume unit leads to a significant reduction in the quality of products [15, 16] and the waste of energy, and ultimately results in the unsustainable use of raw materials and energy resources.

2.5 Fifth principle

When handling liquid-liquid or liquid-gas heterogeneous systems dispersed phase should be subjected to continuous or periodic exposure to disperse and keep within the prescribed limits of the dispersed droplets / bubbles sizes and at drops processing a sufficient level of internal mixing in them is necessary.

2.6 Sixth principle

The objective is to reduce the level of turbulence as a side effect, which is accompanied by the appearance of non-productive energy consumption. Indeed, common use the concept of turbulence as a means to enhance homogeneity, heat or mass transfer, the fluid turbulization in the whole volume of the apparatus is carried out intentionally.

Thus, the energy introduced into the device is transformed into the energy of turbulent eddies, which dissipate quickly and the entire volume of the unit, performing useful work only in certain parts of volume (often no more than 3-5%) near the surface of the dispersed medium.

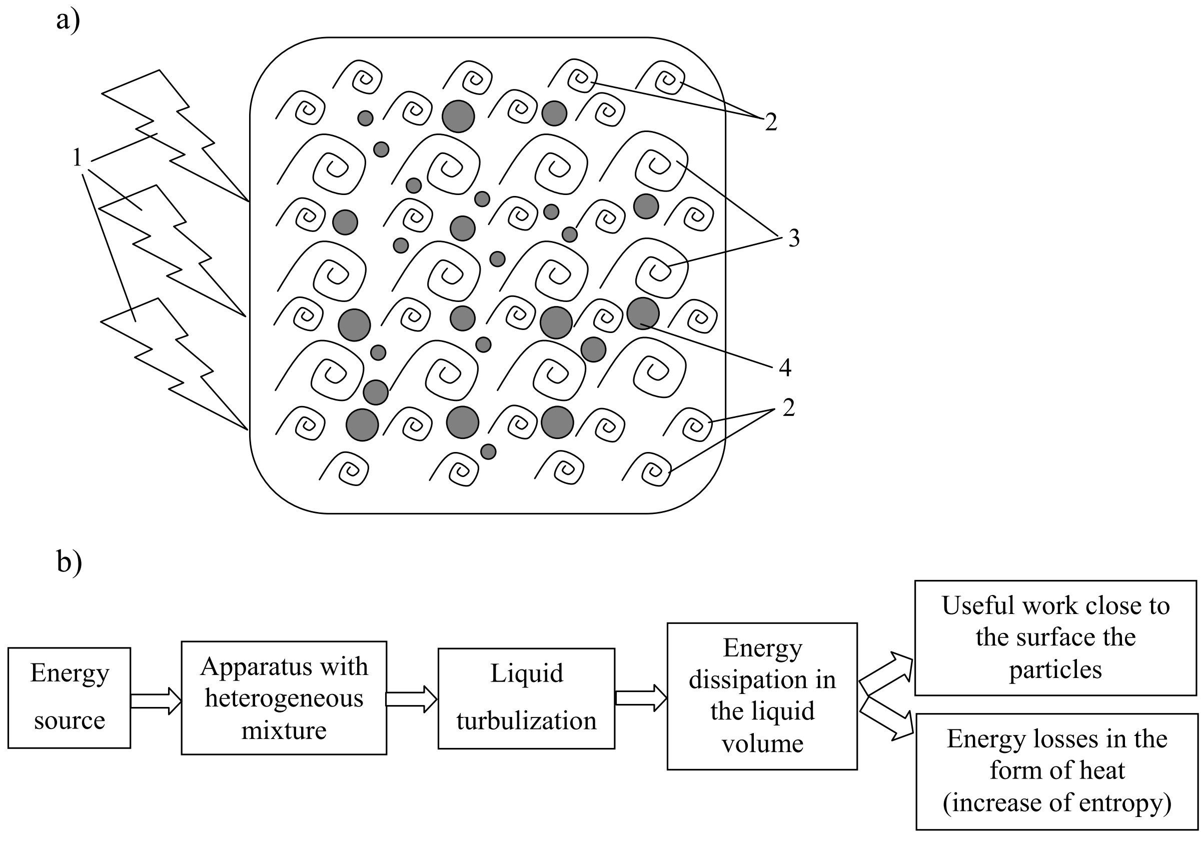

Figure 1. The scheme of energy transformation in the apparatus with deliberate turbulence of the flow: a) – scheme of the flow, b) - the stages of energy transformation. 1 – source of energy, 2 – wall turbulence; 3 – turbulent eddies away from the walls (nearly isotropic turbulence); 4 – particles of dispersed medium.

Obviously, this method of energy conversion is extremely inefficient, because the energy is spent not purposeful (see Fig. 1).

Consider a simple example. It is known that the turbulent motion of fluid in the heat exchanger tubes, the Nusselt number is proportional to the Reynolds number of 0.8 degree:

$$\mathrm{Nu} = \alpha d/\lambda \sim \mathrm{Re}^{0.8}, \quad (1)$$

whereas the energy loss W is proportional to the Reynolds number in grade 3:

$$W = \Delta p \cdot Q = f\,\frac{L}{d}\frac{\rho u^2}{2}\cdot uS \sim \mathbf{Re}^3 . \quad (2)$$

Equations (1)-(2) shows that with increasing velocity of the liquid by 2 times the energy loss increases by 8 times, while increasing the efficiency of heat transfer is just 1.74 times.

Hence we conclude about the necessity of finding a way of organizing processes, in which turbulence is kept to a minimum. This would dramatically reduce energy costs. Instead the turbulent transport of energy and mass one should look for other means of convective transfer.

On the inadvisability of turbulence flows pointed out J. Davis [17], and A.A. Dolinskii [10] compared the efficiency of traditional apparatuses and equipment with discrete-pulsed energy input on the example of the emulsification process.

In this paper, we propose to replace turbrulence by:

• secondary flows arising from the oscillatory motion of bodies in fluids,

• reciprocating movement of the elements of the dispersed phase relative to the solid, accompanied by a renewal of the surface film and mixing inside the droplets / bubbles;

• radial convection due to a periodically varying cross-section of apparatus and their radial velocities generated by the flow (FTPA, Figure 2 [18-19]) or the presence of lateral flow in T-and L-shaped elements (horizontal pulsating apparatus, [20].)

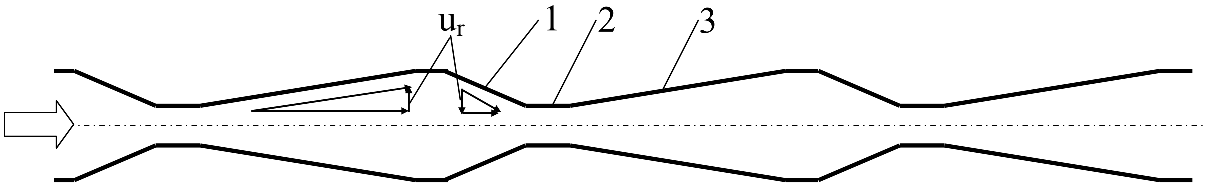

Figure 2. The scheme of flow-through pulsating apparatus (FTPA). 1 - confuser, 2 - neck, 3 - diffuser.

In order to achieve an intense energy and mass transfer due to convection, the role of turbulent eddies may take some other physical objects, like vortices that do not have a fixed volume, and clear boundaries. These may include, for example, standing waves and solitary waves – solitons or vortices, which have an ordered structure.

It is important that the space-time characteristics of these objects were consistent with the parameters of the system at least on one level, and ideally at all three levels.

Thus, it is proposed to use an alternative power conversion scheme shown in Figure 3.

Here we offer not only NOT to generate turbulent eddies whose decay leads to a loss of significant amounts of energy, but rather, to avoid the onset of turbulence, or suppress it.

In the chemical equipment by at least two ways to control the turbulence can be identified

1) Delay of its occurrence by reducing the inertia forces (by creating conditions in which inertial forces do not reach the critical level determined by the viscous forces), at least in local areas of system.

2) The imposition on the flow additional force fields (centrifugal, vibration, sound, ultrasonic, electromagnetic, etc.) that can suppress the development of turbulent eddies due to

the organization of other forms of fluid flow (e.g., delay transition to turbulent flow regime in channels with curved axis is due to the occurrence of secondary eddy currents, preserving the scale of the channel), i.e., by organizing an orderly flow.

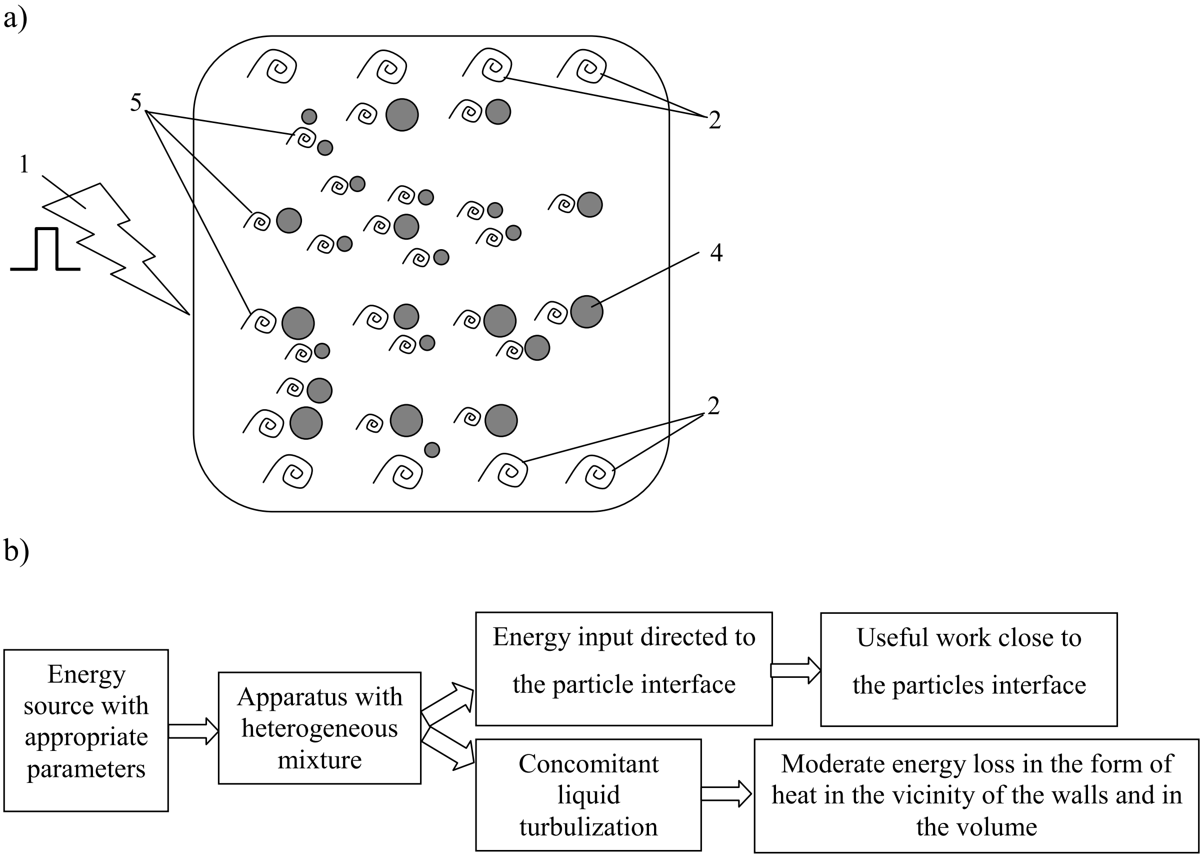

Figure 3. The scheme of energy transformation in the apparatus with energy input directed to the location of useful work: a) - scheme of the flow, and b) - the stages of energy transformation. 5 - the local energy dissipation close to the interface of particles (the other symbols - the same as for Fig. 1).

2.7 Seventh principle

The seventh principle the synthesis of new equipment is to minimize the impact of the apparatus on the environment, in particular, by reducing the vibration and dynamic loads on any foundation.

3. EXAMPLES

There are several practical and theoretical examples supporting the principles described above [21-29].

4. CONCLUSION

As a result of theoretical and experimental investigations of the principles developed by the synthesis of new generation. Laboratory and field tests have confirmed the high efficiency of the studied devices. In some cases, failed to significantly reduce energy costs and a few times to increase yield.

5. REFERENCES

[1] Sarkisov P.D., 2000. "The problems of energy and resource saving technologies in the chemical, petrochemical, and biotechnology". Chem. prom. (in Russian), **1**, 20 - 27.

[2] Karpachova S.M., 1990. "Intensification of chemical processes using pulsating apparatus" Russ. J. Applied. chemistry, **63** (8), 1649 - 1658.
[3] Novitskii B.G., 1983. *The use of acoustic vibrations in chemical engineering processes* (in Russian). Moscow: Khimiya.
[4] Gorodetsky I.J., Vasin A.A., Olevsky V.M., Lupanov P.A., 1980. *Vibrating mass transfer devices*, Moscow, Khimiya.
[5] Dolinskii A.A., Nakorchevskii A., 1997. "Principles of optimizing the mass transfer of technologies based on the method of discrete-pulsed energy input", *Thermal engineering*, **19** (6), 5 - 9.
[6] Dolinskii A.A., Ivanitskii G.K., 1997. "Principles for the development of new Energy Saving Technologies and equipment based on the methods of discrete-pulsed energy input", *Thermal engineering*. **19** (4-5), 13 - 25.
[7] Abiev R.Sh., Aksenova E.G., Ostrovskii, G.M., 1994. "New developments of the pulsation resonance equipment for liquid-phase systems", *Chem. prom.* **11**, 764 - 766.
[8] Ostrovskii G.M., Abiev R.Sh., 1998. "The pulsation resonance equipment for liquid-phase processes in the media", *Chem. prom.*, **8**, 468 - 478.
[9] Abiev R.Sh., 2000. "Extractor of oscillatory U-shaped type", *J. Chem. and petrochem. machines,* **8**, 11-14.
[10] Abiev R.Sh., 2003. "The flow of an incompressible homogeneous fluid in a pipe with periodically varying cross-section". *J. Chem. and petrochem. machines*, **1**, 6-10.
[11] Abiev R.Sh., 2000. "Study of the impregnation process of dead-end capillaries under harmonic pressure changes in the fluid". *Russian J. of Appl. Chem.*, **73** (7), 1141 - 1144.
[12] Abiev R.Sh., Ostrovskii, G.M., 2001. "Simulation of the extraction process of the capillary-porous particle with bidisperse structure". *Theor. Found. of Chem. Tekhnol.*, **35** (3), 270-275.
[13] Abiev R.Sh., 2001. "Investigation of the extraction process of the capillary-porous particle with bidisperse structure", *Russian J. of Appl. Chem.*, **74** (5), 754-761.
[14] RF patent № 2060762. Bull. 15, 1996.
[15] Aboukhr M.R., 1996. "Einfluss niederfrequenter Fluidschwingungen auf die Nickelentfernung aus Prozesswasser". Diss. Dr. rer. nat. / Martin-Luther-Universitaet. Halle-Wittenberg.
[16] Ostrovskii G.M., Brisovsky I. 1999. "Effect of dispersion of porosity of the granular layer on the efficiency of interfacial exchange processes", *Theor. Found. of Chem. Tekhnol.* **33** (3), 247 - 251.
[17] Davies J.T., 1987. "A physical interpretation of drop sizes in homogenizers and agitated tanks, including the dispersion of viscous oils", *Chem. Engng. Sci.,* **42** (7), 1671-1676.
[18] RF patent № 2064319. BI 21, 1996.
[19] RF patent № 2186614. BI 22, 2002.
[20] RF patent № 2264847. BI 33, 2005.
[21] RF patent № 2013114. BI 10, 1994.
[22] Hessel V. , Löwe H. , Müller A. , Kolb G., 2005. *Chemical Micro Process Engineering. Processing and Plants*, Wiley-VCH Verlag.
[23] Abiev R.Sh., 2003. "Research and experience in industrial tests of the fluctuation of the resonance apparatus for the treatment of liquid systems - capillary-porous particles", *Chem. prom.*, **80** (7), 21-27.
[24] RF Patent № 2077362, BI 11, 1997.
[25] RF Patent № 2205677, BI 16, 2003.
[26] RF Patent № 2293600, BI 5, 2007.
[27] RF Patent № 2297869, BI 12, 2007.
[28] RF Patent № 2013114, BI 10, 1994.
[29] Abiev R.Sh., 2006. *Theoretical foudations of energy and resources saving in chemical technology.* St. Petersburg. Univ. Publishing house.