UDC 541.1:541.18

Method of physico-chemical analysis and some aspects of its practical application

Grytsan L.D., Uvarov V.L., Uvarov D.V.
National University of Pharmacy and NSC KIPT, Kharkiv, Ukraine

Key words: physico-chemical analysis, phase diagram, fusion diagram, thermal analysis, boiling diagram, mutual solubility diagram of liquids.

Abstract

The aim of the present work is to give an account of the basic statements of the method of physico-chemical analysis, its merits and drawbacks, and also its most important applications for conducting scientific research. There are considered possibilities of practical application of this method in chemical, chemico-pharmaceutical and fragrance-cosmetic technologies, in material science, metallurgy, halurgy etc.

Introduction

Physico-chemical analysis represents geometric method of study of chemical transformations in solutions, alloys (especially metallic), glasses and other systems that cannot be studied using classical preparative method. The foundations of the method of physico-chemical analysis were laid down in the works by Academician N.S. Kurnakov and his scientific school at the turn of the 19-20 centuries [1]. These works allowed to unify into single research direction the studies of complex heterogeneous systems. The term "physico-chemical analysis" was suggested by N.S. Kurnakov in 1913.

The study and the choice of optimal compositions of alloys, determination of directivity of the processes accompanied by the phase transitions, the selection of the regimes of thermal treatment of various materials are impossible or significantly complicated without application of the method of physico-chemical analysis. In particular, plotting and analysis of the phase diagrams underlie elaboration and optimization of technologies that include processes of separation of phases such as crystallization, rectification, extraction.

Brief historical essay

Till the beginning of the 18-th century there existed only very elementary understanding of the dependence of the properties of substances on their composition. For study of chemical systems there was used *preparative method*, the essence of which consists in extraction of the investigated substance from the system by means of crystallization, distillation and other methods of extraction followed by the study of its composition and properties. Preparative method is used up to now, especially in organic chemistry.

In the second half of the 18-th century and at the beginning of the 19-th century progress of industry required elaboration of new methods to study complex multicomponent systems such as solutions, melts, saline systems and others. Many chemists began to study such systems and their transformations using physico-chemical methods. One can mention such scholars as M.V. Lomonosov, J.T. Lowitz, Ya.D. Zakharov, V.M. Severgin, A.A. Musin-Pushkin and also R.A. de Reaumur, J.B. Richter, C.F. Wenzel, T.O. Bergman, C.W. Scheele, J. Priestley, H. Cavendish, A.L. de Lavoisier and others.

M.V. Lomonosov in his scientific works «Elements of Mathematical Chemistry» (1741), «Discourse on the Usefulness of Chemistry» (1751), «Course in true physical chemistry» (1752) for the first time suggested to apply physical and mechanical methods for study of the chemical transformations of substances and also provided mathematical ground to qualitative results of chemical research.

The first studies of the dependence of the properties of organic systems on their composition were made by M.E. Chevreul in 1823. He examined the dependence of the melting temperature on the composition for the binary system oleic acid – margarine acid. These results attracted great interest and in the sequel found practical application in technology of fatty substances [2]. Studies of organic systems were continued by N.S. Kurnakov in 1908-1909 with the aid of pyrometer constructed by him with collaborators [1]. N.N. Efremov – pupil of N.S. Kurnakov – in his diploma thesis "Application of thermal and microphotographic method to study of substances of the camphoric group" confirmed correctness of one of important theoretical statements proposed by Kurnakov, namely, that among the factors facilitating formation of continuous solid solutions between two components important role is played by plasticity.

In middle of the 19-th century there were laid the foundations of metallurgy in the works by P.P. Anosov, H.C. Sorby, D.K. Chernov and others. In particular, professor D.K. Chernov discovered structural transformations of carbon steel at certain temperatures and elaborated foundations of the steel hardening and tempering technology. Works of D.K. Chernov received international recognition and became the basis of metallography – one of the most important branches of physico-chemical analysis. To that period also belong experimental works by D.I. Mendeleev, V.F. Alekseev, D.P. Konovalov, I.F. Shreder, on the basis of which there were elaborated novel methods of study of solutions, melts and other complex multicomponent systems that, in its turn, facilitated further development of industrial technologies [3, 4, 5, 6, 7, 8].

Based on the results published by G.W. Gibbs in 1873-1878 [9], in particular, on *the phase rule* that he derived from the conditions of thermal, mechanical and chemical equilibria, scholars began to apply *geometrical method* to the study and analysis of complex heterogeneous systems. The essence of the method consists in the visualization of phase equilibria by presenting them graphically as diagrams that are called *state diagrams* or *phase diagrams*. It is necessary to emphasize that peculiar feature of the state diagrams (in distinction from other diagrams representing dependence between some quantities by curves or surfaces) is that each their point irrespective to its location has *physical interpretation*, namely it corresponds to certain state of a system under study. With the aid of this such diagrams one can represent the process of chemical interaction, for instance, appearance of new phases and compounds, creation of liquid and solid solutions and other phase transitions. Branch of thermodynamics that relies of utilization of this method was named *geometric thermodynamics*. The basic characteristic feature of physico-chemical analysis is utilization of geometric method to presentation and processing of experimental data.

Two principles underlying the method of physico-chemical analysis were formulated by N.S. Kurnakov [1]:

1. **The correspondence principle** consists in mapping each complex of phases that exist in equilibrium state in a given system to a definite geometric image on the phase diagram. Plotting and analysis of such diagrams allows to find how many and which phases form given system. It is this principle that allowed N.S. Kurnakov to define physico-chemical analysis as “geometric method of study of chemical transformations in complex multicomponent systems”. N.S. Kurnakov emphasized that “establishing close relationship between chemical transformations in equilibrium system and geometric images of these transformations physico-chemical analysis introduces geometric method of study to chemistry”.

2. **The continuity principle** states that upon continuous change of parameters that determine the state of a system, properties of its separate phases also change continuously. Upon the change of the number of phases of a system its properties also change, as a rule, abruptly.

Later Ya.G. Goroshchenko proposed third principle of the physico-chemical analysis – **the compatibility principle** [10]. It states that an arbitrary set of components regardless of their number and physico-chemical properties may form a system. From this principle it follows that *diagram of arbitrary system contains all elements of subsystems of which it is composed*.

Advantages of the method of physico-chemical analysis are the possibility to judge by the form of the state diagram about the character of interaction between the components of the system under study, about formation of chemical compounds, their quantity and composition, to determine domains of coexistence and composition of equilibrium phases *without actual extraction of components from the system*. Therefore the method of physico-chemical analysis can be applied to objects that cannot be thoroughly studied only using the preparative method [11, 12, 13, 14, 15, 16, 4].

Phase diagrams are plotted down on the basis of experimental data or computer simulations in coordinates “physical property – equilibrium factor” (for instance, pressure, temperature, composition). All chemical processes taking place upon the change of equilibrium factors such as formation and/or decay of chemical compounds, their quantity and composition, formation and disappearance of solid and/or liquid solutions and so on can be expressed as geometric changes of surfaces, lines and points constituting the diagram.

For analytic purposes it is preferentially to choose such property of the system under study that additively depends on its composition and to plot down phase diagram in the coordinates “physical property – composition”. In modern physico-chemical analysis the number of those properties reaches several dozens, for example, melting temperature, heat capacity, electric conduction, refractive index, density, viscosity, surface tension and other. Therefore it is necessary to preliminary choose appropriate physical property for a given system and the way of expressing concentrations of its components. In some cases to increase reliability of the results of analysis it is necessary to consider and confront measurements of several properties.

Limitation of physico-chemical analysis is that it allows to find whether chemical transformations take place in the system but does not allow to find their reasons and mechanisms. Besides diagrams of dimension greater than three that correspond to three equilibrium factors cannot be plotted graphically.

Presently on the basis of modern physical theories using numerical methods it became possible to obtain analytic expressions for functions describing the dependence of the physical properties of the system on its composition without experiment and to plot phase diagrams or their parts.

Some examples of practical application of the method of physico-chemical analysis

For chemical and pharmaceutical sciences, chemico-pharmaceutical, fragrance-cosmetic and biotechnological industry of the primary importance are phase diagrams of the binary systems. For their plotting as the physical property there are commonly taken melting (crystallization) temperature, boiling (condensation) temperature and clarification (turbidity) temperature. Analysis of the phase diagrams of binary model systems that describe processes of melting (crystallization), boiling (condensation) and mutual solubility of two liquids facilitates optimization of processes involving separation of phases that allows to increase output and reduce power inputs.

Phase diagrams are also used in pharmaceutical analysis for identification and determination of purification efficiency of pharmaceutical and auxiliary substances.

Plotting and analysis of **the fusion diagrams** of binary systems of pharmaceutical substances allows to establish their *physical and chemical incompatibility* that is important for elaboration of production techniques of novel dosage forms and medicines.

As is known *physical incompatibility* is related to formation of eutectic. For instance, eutectic mixtures are formed by anesthesin and resorcin, antipyrin and phenacetin and others. Dampening can be observed already in the process of preparation of the dosage form. This is explained by fact that melting temperature of eutectic mixture is lower than melting temperatures of pure components.

At the same time formation of eutectic mixtures may result in improvement of the quality of medicines since eutectic mixture consists of finer particles than mixture of the same substances but of different composition. Besides in eutectic mixtures decreasing of particles' size leads to rising of *bioavailability* of poorly soluble pharmaceutical substances. Liquid dosage forms consisting of eutectic mixtures of pharmaceutical substances are used, in particular, in dentistry.

Chemical incompatibility of pharmaceutical substances related to interaction of the components that leads to the synthesis of new compounds can also be studied with the aid of fusion diagrams.

In pharmaceutical technology plotting and analysis of the **fusion diagrams of model binary systems** is also used:

- for determination of the composition of mixtures (**thermal analysis**);
- for determination of aggregate state of mixtures of components of a given composition at the temperature of practical interest;
- for study of existence of several polymorphic modifications of pharmaceutical substances for further investigation and comparison of their therapeutic action;
- for choosing optimal dispersity of the components.

Boiling diagrams of binary liquid mixtures with unbounded mixing constitute theoretical basis of fractional distillation that is used both in pharmaceutical analysis and in technologies of production and purification of organic substances including pharmaceutical substances as well as in creation of novel dosage forms and medicines. Boiling diagrams are also used for choosing optimal conditions of *regeneration* of liquid multicomponent mixtures that are waste products.

Phase diagrams of binary liquid systems with limited solubility, plotted in the coordinates "temperature of clarification (turbidity) – composition" at p=const are used in pharmaceutical practice for determination of the composition of liquid dosage forms that should not separate during the storage.

Literature

1. N.S. Kurnakov. Introduction to physicochemical analysis. – Moscow-Leningrad : Izd-vo AN SSSR, 1940. – 562 p. (In Russian).

2. Yu.I. Soloviev. Essays of history of physicochemical analysis. – Moscow : Izd-vo AN SSSR, 1955. – 223 p. (In Russian).

3. A. Eucken, P. Gmelin, H. Grüss, H. Sauer, J. Krönert, J. Physikalisch-chemische Analyse im Betriebe. – Leipzig : Akademische Verlagsgesellschaft, 1933. -- 348 p.

4. A.V. Novosiolova. Phase diagrams, their plotting and methods of analysis. – Moscow : Izd-vo Moskovskogo universiteta, 1987. – 152 p. (In Russian).

5. L.D. Gritsan, V.I. Kabachny, Thermodynamics of phase equilibiria. – Kharkov : Izd-vo UkrPhA, 1995. – 68 p. (In Russian).
6. P.I. Fedorov. Physico-chemical analysis. In: Chemical encyclopaedia. In 5 volumes. V.5. – Moscow, 1998. – pp.91-92 (In Russian).
7. V.I. Lebid', L.D. Grytsan. Physicochemical analysis. In: Pharmaceutical encyclopedia. Third Edition. – Kyiv : Morion, 2016. – pp.1779-1780. (In Ukrainian).
8. L.D. Grytsan. Some applications of physicochemical analysis in pharmacy. News of Pharmacy. 2016. Issue 4(88), pp.14-16.
9. The Scientific Papers of J. Willard Gibbs, Vol. 1: Thermodynamics, Dover Publications, 1961.
10. Ya.G. Goroshchenko. Physicochemical analysis of homogeneous and heterogeneous systems. – Kiev : Naukova Dumka, 1978. – 490 p. (In Russian).
11. V.Ya. Anosov,M.I. Ozerova, Yu.Ya. Fialkov. Foundations of physicochemical analysis. – Moscow : Nauka, 1976. – 503 p. (In Russian)
12. Yu.Ya. Fialkov. Physicochemical analysis of liquid systems and solutions. – Kiev : Naukova dumka, 1992. – 245 p. (In Russian)
13. Yu.Ya. Fialkov. Binary liquid systems. – Kiev : Tehnika, 1969. – 220 p. (In Russian)
14. V.M. Valyashko. Phase equilibriums and properties of hydrothermal systems. – Moscow: Nauka, 1990. – 270 p. (In Russian).
15. V.B. Kogan. Heterogeneous equilibriums. -- Leningrad : Khimiya, 1968. – 432 p. (In Russian).
16. A.K. Dorosh. Structure of condensed systems. – Lvov : Vyshcha Shkola, 1981. – 176 p. (In Russian).