

Mass-Transfer Equation in Multicomponent Mixtures

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Abstract—A multicomponent mass-transfer equation for the distillation of multicomponent mixtures is derived in terms of the thermodynamics of irreversible processes.

It is well known that the notion of time is absent from classical thermodynamics. It usually considers equilibrium states or infinitesimal transitions from one equilibrium state into another. Meanwhile, real-world processes pass through nonequilibrium states, since they are driven by finite driving forces. The thermodynamics of processes far from equilibrium requires a quite complex mathematical apparatus [1].

In 1916, carrying out an experiment with a system containing hydrogen peroxide, formic acid, and sulfuric acid, M. Morgan observed a periodic generation of carbon monoxide. Somewhat later (1921), Bray detected that the H_2O_2 decomposition in an acidic medium in the presence of the iodate ion has an oscillatory character. In 1930, Frank-Kamenetskii proposed a theory of such oscillatory solutions. The mathematical formalism of these phenomena was borrowed from the Lotka–Volterra model of the periodic coexistence of predator and prey populations. In this model, the numbers of predator and prey individuals are described by nonlinear differential equations, which, as Poincaré (1928) showed, have a totally different solution for oscillatory phenomena. Regardless of their initial state, such systems necessarily come to the same oscillatory motion, which is called the cycle [2].

The nonlinearity of differential equations is a necessary, but not sufficient, condition for oscillatory modes. This is because there are nonlinear processes that cannot occur in oscillatory modes. Among such processes are those whose linear approximation has a symmetric matrix of coefficients. The coefficients can be constants or certain functions of process variables. In the latter case, the symmetric matrix is a functional matrix. If a system is characterized by a nonsymmetric matrix A , it is necessary to determine whether or not this matrix is reduced to a symmetric matrix by the transformation [3]

$$CAC^{-1}, \quad (1)$$

where C and C^{-1} are a matrix and its inverse, respectively. The reduction to a symmetric matrix is possible if the real matrix A has characteristic roots.

Systems for which the first-approximation coefficient matrices are symmetric or can be reduced to symmetric are described in terms of the thermodynamics of linear irreversible processes, which has been sufficiently developed by Onsager and his school of thought. A more general case is the preservation of only the symmetry of the first-approximation coefficient matrices for a number of nonlinear systems. In this case, the first-approximation coefficients are functions of the state variables of the process under consideration [4, 5].

It was previously shown [6] that singular points of the set of paths of continuous distillation can only be generalized nodes or generalized saddles and cannot correspond to eigenvalues among which there are complex, conjugate, or imaginary numbers. Consequently, distillation can be described using the concepts of the thermodynamics of irreversible processes in generalized form.

There can be steady-state and unsteady-state distillation. An example of steady-state distillation is distillation in continuous columns. Examples of unsteady-state distillation are batch distillation and also the startup mode of continuous columns. The latter mode is conveniently represented in a configuration space with $(n-1)(m'+2)$ or $(n-1)(m'+1)$ ordinates, where n is the number of components, m is the number of plates in the rectifying section of a column, and m' is the number of plates in the stripping section of the column. In this case, unlike other representations, the state of the system is described by a point in the $(n-1)(m+2)$ - or $(n-1)(m'+1)$ -dimensional space and, depending on the initial state of the system, all unsteady-state processes are determined by the set of paths. Any of these paths ends at a singular point of the stable-node type. This is the point at which a given steady state takes place.

A system can have several steady states. For example, it can have two stationary points, one of which is an unstable node and the other is a stable node, or three

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Table of Contents Mab Transfer In Multicomponent Mixtures

1. Understanding the eBook Mab Transfer In Multicomponent Mixtures
 - The Rise of Digital Reading Mab Transfer In Multicomponent Mixtures
 - Advantages of eBooks Over Traditional Books
2. Identifying Mab Transfer In Multicomponent Mixtures
 - Exploring Different Genres
 - Considering Fiction vs. Non-Fiction
 - Determining Your Reading Goals
3. Choosing the Right eBook Platform
 - Popular eBook Platforms
 - Features to Look for in an Mab Transfer In Multicomponent Mixtures
 - User-Friendly Interface
4. Exploring eBook Recommendations from Mab Transfer In Multicomponent Mixtures
 - Personalized Recommendations
 - Mab Transfer In Multicomponent Mixtures User Reviews and Ratings
 - Mab Transfer In Multicomponent Mixtures and Bestseller Lists
5. Accessing Mab Transfer In Multicomponent Mixtures Free and Paid eBooks
 - Mab Transfer In Multicomponent Mixtures Public Domain eBooks
 - Mab Transfer In Multicomponent Mixtures eBook Subscription Services
 - Mab Transfer In Multicomponent Mixtures Budget-Friendly Options

6. Navigating Mab Transfer In Multicomponent Mixtures eBook Formats
 - ePub, PDF, MOBI, and More
 - Mab Transfer In Multicomponent Mixtures Compatibility with Devices
 - Mab Transfer In Multicomponent Mixtures Enhanced eBook Features
7. Enhancing Your Reading Experience
 - Adjustable Fonts and Text Sizes of Mab Transfer In Multicomponent Mixtures
 - Highlighting and Note-Taking Mab Transfer In Multicomponent Mixtures
 - Interactive Elements Mab Transfer In Multicomponent Mixtures
8. Staying Engaged with Mab Transfer In Multicomponent Mixtures
 - Joining Online Reading Communities
 - Participating in Virtual Book Clubs
 - Following Authors and Publishers Mab Transfer In Multicomponent Mixtures
9. Balancing eBooks and Physical Books Mab Transfer In Multicomponent Mixtures
 - Benefits of a Digital Library
 - Creating a Diverse Reading Collection Mab Transfer In Multicomponent Mixtures
10. Overcoming Reading Challenges
 - Dealing with Digital Eye Strain
 - Minimizing Distractions
 - Managing Screen Time
11. Cultivating a Reading Routine Mab Transfer In Multicomponent Mixtures
 - Setting Reading Goals Mab Transfer In Multicomponent Mixtures
 - Carving Out Dedicated Reading Time
12. Sourcing Reliable Information of Mab Transfer In Multicomponent Mixtures
 - Fact-Checking eBook Content of Mab Transfer In Multicomponent Mixtures
 - Distinguishing Credible Sources
13. Promoting Lifelong Learning
 - Utilizing eBooks for Skill Development
 - Exploring Educational eBooks
14. Embracing eBook Trends
 - Integration of Multimedia Elements

- Interactive and Gamified eBooks

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